



Combining SWOT analysis and neutrosophic cognitive maps for multi-criteria decision making: a case study of organic agriculture in India

Jagan Obbineni¹ · Ilanthenral Kandasamy² · W. B. Vasantha² · Florentin Smarandache³

Accepted: 23 March 2023

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Abstract

The conventional agricultural system heavily depends on chemicals and inorganic fertilizers, which cause environmental issues. Organic agriculture impacts 6 of the 17 Sustainable Developmental Goals (SDGs) of the United Nations. Strategies to develop organic agriculture have used SWOT and MCDM techniques for analysis. However, the examination of the influence of one strategy over the other strategies has yet to be investigated. This paper proposes a model that combines the existing SWOT analysis with neutrosophic cognitive maps (NCM) models to analyze interconnections among the various strategies obtained from SWOT. This research deploys the proposed SWOT–NCM model to analyze the case study of developing organic farming in Tamil Nadu, India. It offers insights into the strategy's influence over other strategies so that the best is given maximum importance while implementing organic farming. The framework captures the interconnections and ranks the strategies by order of influence, providing fresh insights by taking the farmers' perspective while working with the strategies from the SWOT analysis to model an NCM. A comparative analysis of this SWOT–NCM model with other MCDM models that use SWOT to analyze the agriculture problem, and a sensitivity analysis of the proposed model, is performed. According to our study, the best possible strategy to encourage organic farming is minimum support price (MSP) and centralized procurement. This proposed model can analyze other MCDM problems that use SWOT analysis.

Keywords Sustainable organic farming · SDGs · SWOT · Neutrosophy · Neutrosophic cognitive maps (NCMs) · Multi-criteria decision making

✉ Ilanthenral Kandasamy
ilanthenral.k@vit.ac.in

Jagan Obbineni
jagan.obbineni@vit.ac.in

W. B. Vasantha
vasantha.wb@vit.ac.in

Florentin Smarandache
smarand@unm.edu

¹ VIT School of Agricultural Innovations and Advanced Learning (VAIAL), VIT, Tiruvalam Rd, Vellore, Tamil Nadu 632014, India

² School of Computer Science and Engineering (SCOPE), VIT, Tiruvalam Rd, Vellore, Tamil Nadu 632014, India

³ Department of Mathematics, University of New Mexico, 705 Gurley Avenue, Gallup, NM 87301, USA

1 Introduction

The existing global agricultural system relies on chemicals and fertilizers that have boosted productivity (Tsvetkov et al. 2018), but over the years, it has created a significant imbalance in nature. There have been detrimental effects on the environment, and society (Udeigwe et al. 2015), ranging from soil degradation (Liu et al. 2018), water pollution (Cai et al. 2018), biodiversity loss (Wintermantel et al. 2019; Shakoor et al. 2018) and harmful effects on human health (Nicolopoulou-Stamati et al. 2016).

The United Nations, in its 2030 Agenda (Palmer 2015) (United Nations General Assembly, 2015), listed 17 Sustainable Development Goals (SDGs) for sustainable development for all without leaving anyone behind. Nearly six goals are connected directly to food production, consumption and environmental issues (SDGs 2, 3, 6, 13, 14 and 15 listed in Fig. 1a). Since organic agriculturalist refrains from using agrochemicals and produce in harmony with nature, it

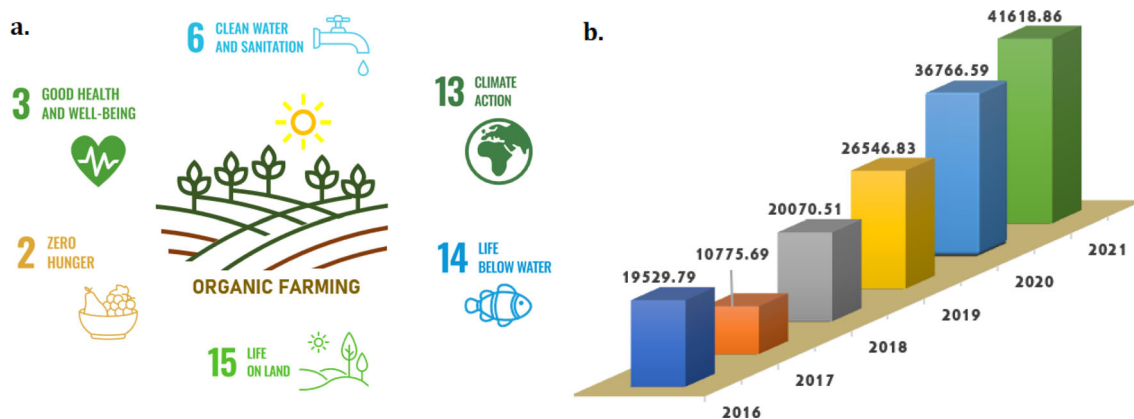


Fig. 1 **a** Sustainable organic farming and its impact: The impact of organic farming on food production and consumption influences SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-Being). Its impact on the environment indirectly influences SDG 6 (Clean Water and San-

itation), SDG 13 (Climate Action), SDG 14 (Life Below Water) and SDG 15 (Life on Land). **b** The area of organic farming in hectares (ha) in Tamil Nadu during the past 6 years (2016–2021)

is natural that organic farming is a feasible solution (Smith and Lampkin 2018). As a global community that is seriously involved in achieving the SDGs by 2030, we must shift to organic farming, which is more sustainable.

According to the surveys conducted by the Research Institute of Organic Agriculture, nearly only 1.4% of the world's farmland is under organic farming. Organic farmlands have increased in China and Argentina, and it has decreased in Ukraine and Iran. Although there is no significant expansion in organic farmland, the tendency to prefer organic products has increased due to consumers making an informed choice in purchasing organic products (Bryła 2016; Jarczok-Guzy 2018). Thus, organic farming development contributes to the goals of sustainable agricultural development and aids in meeting consumers' demand for organic products in local and global markets.

The annual report 2020–21 issued by the Indian Government¹ states that nearly 54.6% of the Indian workforce is involved in the agricultural sector, and it accounts for nearly 18% of Gross Value Added (GVA). Also, 60% of the land area is agricultural farmland. Hence, it is well established that agriculture plays a vital role in India's economy. Currently, in India, only 4.34 million hectares are under organic farming, which is lower than the 2015–16 total area of 5.71 million hectares and only 3.1% of the 140 million hectares of the net cultivable land area. In Tamil Nadu, it is estimated that an area of 41,619 hectares is under organic cultivation, which is about 0.8% of the net sown area in the state.² Figure 1b shows the trend in Tamil Nadu for the past five years.

Despite efforts to promote organic agriculture, the progress in this direction is plodding, and the state has shown a meager increase in area under organic cultivation year on year. Hence, it is crucial to determine and select the most promising techniques or strategies for developing organic farming based on a comprehensive list of various factors. Several researchers have studied the various strategies for organic farming development. Implementation of innovative technologies (Ferreira et al. 2020), support for scientific research methods (Tsvetkov et al. 2018), governmental support and subsidies to farmers (Adams Inkoom 2017), creating awareness among customers and farmers (Aghasafari et al. 2020) and management of organic farming constraints and various modifications to the regulatory standards (Brzezina et al. 2017), were some of the strategies that researchers suggested. Other investigations suggested green marketing (Acelandu 2016), the establishment of organic certification institutions (Adebisi 2014) and trade policies (KhezriNejhad Gharaei and Bakhshoudeh 2014).

These studies use qualitative and quantitative techniques such as statistical analysis, mathematical modeling for regression, equations and summary information. They do not consider all the other factors influencing organic agribusiness in a region, like the regional historic influences related to organic agriculture, indigenous technical knowledge, suitable soil, water resources, local pests and plant diseases. Furthermore, these factors will play an essential role in a country like India, which has a rich culture, tradition and unique geological ecology. Determining strategies explicitly for individual geographic locations dependent on diverse climates is essential, and at the same time, it is also an MCDM problem.

Some studies on organic farming have used the SWOT-Analytic Network Process (ANP) or the SWOT-Analytic

¹ Published by Department of Agriculture, Cooperation & Farmers' Welfare, India

² APEDA Consolidated Report, 2020–21

Hierarchy Process (AHP) methods. In KhezriNejhad Gharaei and Bakhshoudeh (2014), using a case study of Iran, the factors influencing the transition from conventional to organic farming were identified. Studies have also involved fuzzy or neutrosophic theory and SWOT analysis to handle MCDM problems. These MCDM decision-making models do not analyze the interconnections; they compare the SWOT strategies based on specific criteria.

For example, a SWOT strategy may positively impact another strategy and aid in improving/implementing the other strategies. Similarly, a strategy can negatively impact or stall the implementation of another strategy. If both these strategies are implemented together, it may have a negative impact. Hence, it is crucial to analyze the influence of one strategy on other strategies to get the best results. We have proposed a technique that helps one understand the strategies' interactions and their positive and negative influences on others.

This paper proposes an MCDM model based on SWOT and NCMs to analyze the interconnections between the given strategies/alternatives and select the most effective and influential strategies.

1.1 Contributions of the paper

- This work proposes a new framework that analyses the interconnections between the strategies proposed by the SWOT model using a neutrosophic cognitive maps (NCM) model. To the best of our knowledge, this work is the first in this category to merge SWOT analysis with cognitive maps to understand the interaction between the strategies to provide better decision-making methods and the determination of the most impactful nodes.
- The proposed model uses NCMs instead of FCMs since neutrosophy can handle uncertainties related to experts' opinions regarding vagueness, ambiguity and inconsistency. The proposed model is exceptionally equipped to deal with human opinion, which can sometimes be contradictory, inconsistent and vague.
- Most MCDM models do not analyze the interconnections, and they compare the SWOT strategies based on specific criteria. We have proposed a new technique that helps one to understand the strategies' interactions.
- The model is used to analyze the case study of developing organic farming in Tamil Nadu, India.

The rest of this research paper is organized as follows: Sect. 2 deals with the fundamental concepts to make this paper remain self-contained. Section 3 proposes the new framework, provides the SWOT analysis for organic farming and deploys the NCMs model to find hidden patterns. Section 4 discusses the results from SWOT-NCMs models in detail, along with the sensitivity analysis and comparison of

the model with other MCDM models. Section 5 summarizes the conclusions and provides further feasible research works.

2 Literature survey

Various fuzzy and neutrosophic sets have been applied to improve MCDM approaches. An MCDM approach based on the probabilistic linguistic term set (LTS) was proposed and used to evaluate IoT platforms in Lin et al. (2020). An MCDM method with hesitant fuzzy LTS was proposed in Lin et al. (2020) and used to rank satellite launching centers and also used in Xiong et al. (2023) for group decision making. Huang et al. (2020) presents a novel Pythagorean fuzzy set (PFS)-based MULTIMOORA method. Lin et al. (2019) proposed a TOPSIS method based on linguistic PFS for multiple attribute decision making and used it for fire-wall production selection. Directional correlation coefficient measures for PFS were used in medical diagnosis (Lin et al. 2021). Lin et al. (2022) proposed a novel MADM method with picture fuzzy sets.

Only some studies on organic farming have used the SWOT-Analytic Network Process (ANP) or the SWOT-Analytic Hierarchy Process (AHP) methods. Identification of factors influencing the transition from conventional farming to organic was made. They offered four strategies: trade and financial policies, developing investment motives, responsive research foundation and awareness programs in Iran (KhezriNejhad Gharaei and Bakhshoudeh 2014).

Similarly, a SWOT-fuzzy-ANP approach (Aghasafari et al. 2020) was used to select the most suitable strategies for developing organic farming in Iran's Khorasan Razavi province, and the best strategy suggested was creating awareness among customers and farmers. Firdaus et al. (2021) used MCDM and the fuzzy-AHP technique for developing a method to improve organic farming in Indonesia; they ranked developing an export-oriented competitive organic product as the best strategy. Recently, multi-expert Fermatean fuzzy AHP was used to prioritize strategies for the digital transformation of supply chains (Alkan and Kahraman 2022).

The SWOT-fuzzy-ANP approach (Aghasafari et al. 2020) and SWOT-fuzzy AHP (Firdaus et al. 2021) do not handle conflicting information or indeterminacy present, and they have only evaluated in terms of specific criteria and the inter-connection among the considered strategies.

Neutrosophy has been applied in many fields to solve problems related to indeterminacy since they are better equipped than fuzzy sets. Florentin Smarandache founded it in 1998 (Smarandache 2002) to further generalize fuzzy sets, intuitionistic fuzzy sets, PFS, spherical fuzzy sets and picture fuzzy sets. Neutrosophic logic and set are gaining significant attention in solving many real-life problems that

involve uncertainty, impreciseness, vagueness, incompleteness, inconsistency and indeterminacy (Wang et al. 2021).

Neutrosophic refined sets were introduced in Smarandache (2013). Abdel-Basset et al. (2019) introduced the concept of Type-2 Neutrosophic Number (T2NN) and its operational rules. It can efficiently estimate information in the decision-making process and accurately describe real cognitive information. The paper also proposed a strategy combining T2NN and TOPSIS under group decision making as an application of T2NN. The study (Cali et al. 2022) proposes a T2NN based on distance from the average solution to evaluate and prioritize a set of existing use cases of an energy blockchain system. Simic et al. (2022) uses T2NN and proposes a new MEREC-MARCOS model that could be used as decision support while mitigating climate change effects of urban transportation and other human activities. Deveci et al. (2022) proposed an analytics approach using T2NN to prioritize the decision alternative for zero-emission zone logistics. The approach integrates a combined compromise solution (CoCoSo) with the context of T2NN to identify the optimal alternative. Gokasar et al. (2022) proposed using T2NN-based decision-making approach to aid in ranking bridge maintenance projects based on CO₂ emission.

A T2NN-based MCDM model (Torkayesh et al. 2021) was proposed to identify factors contributing to failure in adopting IoT and blockchain in smart medical waste management systems in Turkey. In Deveci and Torkayesh (2021), a decision support model for charging type selection using interval-valued neutrosophic sets was proposed.

Neutrosophic AHP was introduced, and an MCDM technique was applied to select a learning management system (Radwan et al. 2016). Interval-valued neutrosophic AHP using cosine similarity measure was used in energy alternative selection (Bolturk and Kahraman 2018). Using the Starbucks company as a real-world case study, an extension of neutrosophic AHP-SWOT analysis was proposed (Abdel-Basset et al. 2018). Evaluation of international search engines was done using the neutrosophic AHP-Delphi-based group decision-making model, which used trapezoidal neutrosophic numbers (Abdel-Basset et al. 2018). A neutrosophic AHP-SWOT method was used for strategic planning methodology selection (Basset et al. 2018). Supply chain risk in the automotive industry of Pakistan was assessed using the neutrosophic AHP-TOPSIS framework (Junaid et al. 2019). Bipolar neutrosophic MCDM framework was used to select professional (Abdel-Basset et al. 2020). Supplier selection problems were analyzed using an integrated neutrosophic ANP (Zaied et al. 2019) and a hybrid neutrosophic group ANP-TOPSIS framework (Abdel-Basset et al. 2018). Eryarsoy et al. (2022) used interval-valued neutrosophic AHP to assess the impact of COVID-19 on IoT challenges in the supply chain.

Neutrosophic ANP-SWOT Abdel-Basset et al. (2018) and Neutrosophic AHP-SWOT (Abdel-Basset et al. 2018; Basset et al. 2018; Radwan et al. 2016) take into consideration the indeterminacy involved and evaluate the proposed strategies based on specific criteria, but do not analyze the interconnection between the strategies proposed by SWOT.

However, these fuzzy-AHP and fuzzy-ANP-SWOT approaches do not analyze the interconnections or influences between the various strategies and rank them based on their influence on others.

Neutrosophic cognitive maps (NCMs) are a generalization of fuzzy cognitive maps (FCMs) that can handle indeterminacy in relations between two concepts, bringing greater sensitivity to the results. They were introduced by Kandasamy and Smarandache (2003) and used to study various social problems (Kandasamy and Smarandache 2004). NCMs have been modeled extensively on the AI principle of thinking-humanly approach when the data is unsupervised and have a finite set of attributes/features. Over the years, many researchers have used NCMs to analyze various problems like: pest analysis (Alava et al. 2018), situation analysis (Zafar and Wajid 2019), transgressions against the homeless (Peñafiel Palacios et al. 2021) and imaginative play in children (Vasantha et al. 2019).

The significant benefit of NCMs over other techniques is their ability to represent data realistically and maintain consistency in denoting expert opinions. This makes them a valuable tool for decision-making processes where there is an increased degree of uncertainty or indeterminacy. Hence, we have used NCMs to analyze the interconnections between the given SWOT strategies/alternatives and select the most effective and influential strategies.

3 Basic concepts

3.1 SWOT analysis

The most prevalent method for analyzing strategic cases as a decision-making mechanism is the SWOT, which stands for strengths, weaknesses, opportunities and threats. Internal factors contribute to strengths and weaknesses, while external factors contribute to opportunities and threats. A strategic project to develop any establishment must focus on its strengths, utilize the existing possibilities, improve its weaknesses and mitigate threats. The four strategic plans chosen by employing SWOT analysis are as follows:

- *SO* The reasonable usage of opportunities/possibilities via existing strengths.
- *ST* The excellent usage of strength to annihilate/diminish the threats' effect.

- *WO* Considering weaknesses to figure out the advantages of opportunities.
- *WT* Striving to decrease the consequence of threats by assessing weaknesses.

Let C_a and C_b be concepts/vertices of the NCM, the relationship between them is denoted by e_{ab} , (the edge from C_a to C_b) denotes the influence of C_a on C_b . Every edge e_{ab} is weighted, with a value from the set $\{-1, 0, 1, I\}$; that is $e_{ab} \in \{-1, 0, 1, I\}$.

Similarly,

$$e_{ab} = \begin{cases} 0 & \text{if } C_a \text{ does not have any impact on } C_b \\ 1 & \text{if decrease (or increase) in } C_a \text{ results in decrease (or increase) in } C_b \\ -1 & \text{if decrease (or increase) in } C_a \text{ results in increase (or decrease) in } C_b \\ I & \text{if the effect of } C_a \text{ on } C_b \text{ is indeterminate} \end{cases} \quad (2)$$

SWOT analysis is used in both personal and professional spheres to select suitable strategies but fails to furnish measures and evaluations. SWOT-AHP and SWOT-ANP approaches are used to overcome this and provide a reasonable means to evaluate various strategies and rank them.

3.2 Neutrosophic cognitive maps (NCMs)

Fuzzy cognitive maps (FCMs) (Kosko 1986) are fuzzy-directed graphs that are signed which have feedback. The link denoted by edge e_{ab} from node/concept c_a to node/concept c_b is directed, it measures how much c_a affects or influences c_b . The concept function $c_a(t)$ at time t is time-varying, and it measures the occurrence of a fuzzy event. Maybe the opinion about topics like LGBT rights or feminism or the effect of a political event or legislation. FCMs represent the real-world problem as a compilation of classes and their causal relations. FCMs that have edge values from $\{-1, 0, 1\}$ are known as simple FCMs.

To handle the unsupervised data when the relationship between some two nodes is indeterminate, Kandasamy and Smarandache (2003) introduced the indeterminacy in FCMs, known as NCMs. To make this paper self-contained, we will recall NCMs and some of their basic properties.

An NCM is a directed neutrosophic graph representing the causal relationship with concepts like events, policies or strategies as graph nodes and relationships as edges. Assuming C_1, C_2, \dots, C_n denote the n nodes/concepts of the NCM, where every concept is a neutrosophic vector from V , a neutrosophic vector space. Hence, a node C_a will be denoted by (x_1, \dots, x_n) .

Here

$$x_k = \begin{cases} 0 & \text{OFF state} \\ 1 & \text{ON state} \\ I & \text{Indeterminate} \end{cases} \quad (1)$$

for $k \in 1, \dots, n$.

A simple NCMs has edge weights from $\{-1, 0, 1, I\}$. The neutrosophic adjacency matrix of the NCM is given by $N(E) = (e_{ab})$ where $e_{ab} \in \{0, 1, -1, I\}$. Let $B = (b_1, b_2, \dots, b_n)$ where $b_i \in \{0, 1, I\}$, for $i = 1, 2, \dots, n$; is the neutrosophic instantaneous state vector space, and it denotes the ON(or OFF or indeterminate) state of the node at a given instant. The explanation is as follows:

$$b_i = \begin{cases} 0 & \text{if } b_i \text{ is OFF (no effect)} \\ 1 & \text{if } b_i \text{ is ON (has effect)} \\ I & \text{if } b_i \text{ is indeterminate} \\ & \text{(effect cannot be determined)} \end{cases} \quad (3)$$

Let $\overrightarrow{C_1C_2}, \overrightarrow{C_2C_3}, \overrightarrow{C_3C_4}, \dots, \overrightarrow{C_nC_1}$ be the directed edges of the NCM. If the edges do not form a cycle, then the NCM is acyclic, else it is cyclic. Consider $\overrightarrow{C_1C_2}, \overrightarrow{C_2C_3}, \dots, \overrightarrow{C_{n-1}C_n}$ to be a cyclic NCM, when node C_a is switched ON the influence will flow through the existing cycle and causes C_a , again. This equilibrium state of the dynamical system is known as a hidden pattern.

It is known as a fixed point if it results in a unique state vector. Consider the same NCM with C_1 in ON state. Assuming the NCM resolves to C_1 and C_n ON, with state vector as $(1, 0, \dots, 1)$, it is known as the fixed point.

Consider the same NCM with feedback. Let the associated adjacency matrix be the neutrosophic matrix $N(E)$. The input is given as the vector $B_1 = (1, 0, 0, \dots, 0)$ when C_1 is in ON state, the data should be transformed by $N(E)$, so we multiply B_1 by $N(E)$.

Let $B_1N(E) = (b_1, b_2, \dots, b_n)$ is thresholded by replacing b_i accordingly to the equation.

$$b_i = \begin{cases} 1 & \text{if } b_i > k \\ 0 & \text{if } b_i < k \text{ (} k \text{ is a suitable positive integer)} \\ I & \text{if } b_i \text{ not a an integer} \end{cases} \quad (4)$$

The resultant is updated; to make the concept c_1 as 1 in the resulting vector.

Suppose, $B_1N(E) \leftrightarrow B_2$ (where \leftrightarrow denotes the resultant $B_1N(E)$ which is both thresholded and updated) and for $B_2N(E)$ we replicate the exact procedure until we obtain a fixed point or a limit cycle. If the NCM resolves to a neutrosophic state vector replicating in the form

$$B_1 \leftrightarrow B_2 \leftrightarrow \dots \leftrightarrow B_i \leftrightarrow B_1,$$

then this equilibrium is known as NCM's limit cycle.

Only in NCMs, can we tell that the influence of a node on some other nodes can also be indeterminate, and this concept is nonexistent in the case of FCMs.

4 Methodology

4.1 Overview of the proposed model

An innovative method that combines SWOT analysis and NCM is proposed as the case study of organic farming, which is taken for analysis.

SWOT-NCM framework: Fig. 2 gives the proposed framework that outlines various phases, from the data collection to conclusions.

Phase one: Data collection and SWOT analysis:

The data collection using interviews was accomplished between January 2019 and April 2021; it involved collecting opinions from over 30 farmers who practiced organic farming in Tamil Nadu, two personnel who worked in the organic certification process and three persons involved in producing organic inputs. Selected organic farms and farmers were visited in certain villages in Tamil Nadu, and over 20 face-to-face interviews were conducted between January 2019 and March 2020. Post the COVID lockdown; field visits were not possible. Hence, interviews were conducted over WhatsApp video calls or regular voice calls since most people did not have access to the Zoom app. Before the start of the interview, personal content was obtained. Most in-person interviews also lasted a few hours since we visited the farms. The interviews were semi-structured in Tamil; questions were asked based on the interviewee's answers. It mainly focused on the strengths, opportunities, weaknesses, threats of organic farming and personal experience. The interviews/questionnaire was formulated in the regional language Tamil and then translated to proceed with the SWOT analysis.

Phase two: Creation of SWOT matrix: The study's SWOT factors and subfactors resulted in nine strengths, sixteen weaknesses, seven opportunities and nine threats. This SWOT analysis helped to create 16 strategies (3 SO strate-

gies, 3 ST strategies, 7 WO strategies and 3 WT strategies,) as given in detail in the upcoming session.

Phase three: Neutrosophic cognitive maps (NCMs): The expert's opinions used the directed neutrosophic graph that maps the interconnections between the various 16 strategies (or a subgroup). Some experts wanted to work with only some of the 16 nodes; some felt comfortable with fewer nodes that they thought were well-related. Both approaches are considered for analysis, and two models were created. The first model used only six strategies, and the second used all 16.

Phase four: Dynamical systems of the NCMs: The dynamical systems of the NCM were created for both approaches using the neutrosophic graphs given by the experts. Then every node was individually put in the ON state and worked with to arrive at the hidden pattern.

Phase five: Finding hidden patterns for each strategy: For both the NCM models, the hidden pattern was found for each strategy, tabulated, and the strategies were ranked.

Phase six: Ranking of strategy and arriving at conclusions: We arrived at the conclusions on the most effective strategies based on the experts' opinions and tabulated the results of the hidden patterns.

4.2 SWOT analysis

Since SWOT-AHP and SWOT-ANP do not handle human decision-making problems and the probability/uncertainty present, fuzzy theory-based SWOT-ANP and SWOT-fuzzy AHP approaches were introduced. Since the neutrosophic theory is more equipped to handle uncertainty, the neutrosophic approach for SWOT-ANP and SWOT-AHP was introduced. However, these approaches do not analyze the interconnections or influences between the various strategies; they merely rank them. To analyze the interconnection between the strategies that the SWOT model proposes, we have proposed to construct neutrosophic cognitive maps (NCMs) using the various strategies.

SWOT Analysis: The SWOT analysis of organic farming in Tamil Nadu, India, resulted in 16 strategies; three under SO (Strength-Opportunity) strategies, three under ST (Strength-Threat) strategies, seven under WO (Weakness-opportunity) strategies and three under WT (Weakness-Threat) strategies.

The SWOT table is given in Table 1: *Introduction to the problem:* The strengths, opportunities, weaknesses and threats that the experts have identified are:

Strengths (S): S_1 —Suitable soil, S_2 —Favorable climate, S_3 —Indigenous Technical Knowledge (ITK) Systems, S_4 —Profitability, S_5 —Organic Farming Communities, S_6 —Reliable Certification System, S_7 —High quality and safe food, S_8 —Benefit to human health and S_9 —Mechanized tools for small and marginal farmers

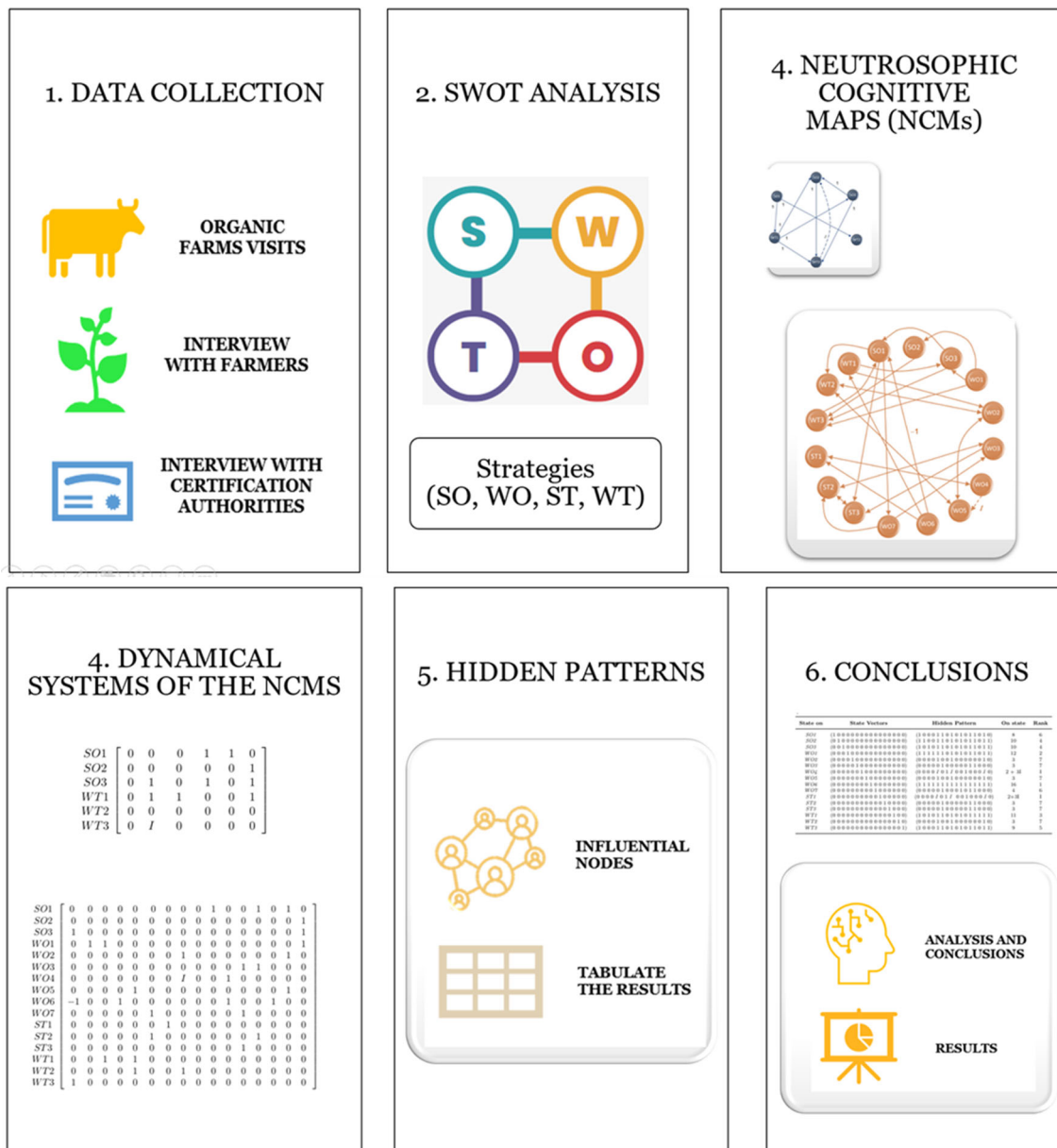


Fig. 2 The proposed framework contains 6 phases: phase 1 deals with data collection, phase 2 involves SWOT analysis and determination of various strategies, and phases 3 and 4 deal with expert opinion

using NCM and working of the dynamical system. Phase 5 deals with obtaining the hidden patterns, and phase 6 works on the analysis and conclusions

Weakness (W): W_1 —Lack of technical knowledge, W_2 —Low yield per unit area, W_3 —Marketability and branding, W_4 —Lack of supply chain, W_5 —Loss of profits to middlemen, W_6 —Losses during the transition period, W_7 —Soils with very low or no organic matter content, W_8 —Irrigation water with high TDS levels, W_9 —No subsidies or schemes to support organic farming, W_{10} —Poor farmer literacy, W_{11} —Product quality loss due to the high incidence of storage pests, W_{12} —No MSP guarantee, W_{13} —No centralized product procurement, W_{14} —No financial assistance, W_{15} —Lack

of proper feedback system between farmer and promoter and W_{16} — High cost of certification.

Opportunities (O): O_1 —Incentivized farming, O_2 —Huge demand for organic products, O_3 —Sustainable agriculture, O_4 —Reduced environmental pollution, O_5 - Reduced lifestyle diseases, O_6 —Scientific validation of ITK systems and O_7 —Donations from the private sector.

Table 1 SWOT analysis of the status of organic farming in Tamil Nadu, India

Internal factors/external factors		Strengths (S)	Weaknesses (W)
		S1—Suitable soil S2—Favorable climate S3—Indigenous technical knowledge (ITK) Systems S4—Profitability S5—Organic Farming Communities S6—Reliable Certification System S7—High quality and safe food S8—Benefit to human health S9—Mechanized tools for small and marginal farmers	W1—Lack of technical knowledge W2—Low yield per unit area W3—Marketability and branding W4—Lack of supply chain W5—Loss of profits to middlemen W6—Losses during the transition period W7—Soils with very low or no organic matter content W8—Irrigation water with high TDS levels W9—No subsidies or schemes to support organic farming W10—Poor farmer literacy W11—Product quality loss due to the high incidence of storage pests W12—No MSP guarantee W13—No centralized product procurement W14—No financial assistance W15—Lack of proper feedback system between farmer and promoter W16—High cost of certification
		SO strategies	WO Strategies
Opportunities (O)		SO1 —Allocation of CSR funds for organic farming SO2 —Value addition of organic products SO3 —Use of media to promote and advertise organic products and farming	WO1 —Establishment of supply chains WO2—Improve farmers' technical knowledge WO3—Input subsidies WO4—No cost of certification for genuine organic farmers WO5—Developing natural products for storage pest control WO6—MSP and centralized procurement from certified farmers WO7—Financial assistance during the transition period (yield based)
		ST strategies	WT Strategies
Threats (T)		ST1—Promoting, encouraging and facilitating organic certification ST2—Facilitating access to organic inputs ST3—Promoting & handholding startups which manufacture organic inputs	WT1—Dissemination of validated technical & marketing info WT2—Promoting research on pest and disease control WT3—Consumer awareness programs
Threats (T)		T1—Fake organic products T2—Accessibility to organic and microbial inputs T3—Diminishing farm labor T4—Spread of wrong technical info using apps T5—No proven control of pests and diseases T6—Lack of consumer awareness T7—No standard pricing mechanism for organic products T8—Consumer demotivation due to exorbitant prices T9—Excessive information from different sources	

Threats (T): T_1 —Fake organic products, T_2 —Accessibility to organic and microbial inputs, T_3 —Diminishing farm labor, T_4 —Spread of wrong technical information using social media applications, T_5 —No proven control of pests and diseases, T_6 —Lack of consumer awareness, T_7 —No standard pricing mechanism for organic products, T_8 —Consumer demotivation due to exorbitant prices and T_9 —Excessive information from different sources.

The following 16 strategies were obtained from the SWOT analysis:

SO strategies

SO1: allocation of CSR funds for organic farming

Corporate Social Responsibility (CSR) is a funding and grant process for addressing any social issue that can improve people's livelihood. Every high-net-worth company (≥ 500 crore INR) must contribute 2 percent of their profits to this fund. It is suggested that this fund can be utilized to develop organic farming.

SO2: value addition of organic products

Any agricultural product has a short shelf life. In the case of organic farming, this could result in more significant losses due to delays in marketing or the sale of produce. Hence, a better approach would be to utilize organic produce to manufacture value-added products that have a longer shelf life and can improve the farmers' profits.

WO strategies

WO1: establishment of supply chains

When more and more farms turn to organic cultivation, it is crucial that whatever the produce reaches the market. This would only be possible with proper supply chain establishment. The process would involve the construction of necessary infrastructure, cold storage and logistics for transporting the produce to reach the organic stores.

WO2: improve farmers' technical knowledge

In order to carry out organic cultivation, the farmers need to adopt methods and standards prescribed by the certification bodies. Understanding these methods requires the farmer to be trained, thereby improving his/her technical knowledge in the organic production of a crop.

WO3: input subsidies

The union government provides subsidies for the synthetic fertilizers used to grow crops. This makes the fertilizer affordable for the farmer to buy and use in his/her field. This

strategy proposes subsidies for organic fertilizers, making them affordable and accessible.

WO4: no cost of certification for genuine organic farmers

One of the most important aspects of organic farming is to go through the certification process. This increases the financial burden on the farmer as he/she has to pay a considerable sum of money for the certification process. This process can be done free of cost for genuine organic farmers.

WO5: development of natural products for storage pest control

No synthetic chemicals can be used in organic farming, so the post-harvest management of farm produce becomes challenging. In order to store the products, natural product-based methods need to be developed, which will reduce the damage caused by warehouse pests.

WO6: MSP and centralized procurement from certified farmers

Suppose the union government, through the state governments, can procure the organic produce from the farmers, process it and market it through state-run or cooperative organizations. In that case, the farmer will be motivated to do organic farming. This will enable a minimum support price (MSP), i.e., the price that the union government fixes to buy crop produce from the farmer in a given season is guaranteed, and the farmer will not get into a financial burden.

WO7: financial assistance during the transition period (yield based)

When the farmer switches from synthetic inputs to organic agriculture during the initial transition period, there is a yield drop. This is mainly because the soil's organic matter and microbial load need to be built up to get better yields. This yield loss can be very high and discourage farmers from taking up organic cultivation. Hence, necessary financial assistance may be provided to the farmer to overcome this financial burden.

ST strategies

ST1: promoting, encouraging and facilitating organic certification

Although a farmer may be cultivating their crop organically, organic certification is essential to sell effectively, market or export the produce. The certificate enables the organic farmer to get the right price for the crop and hence can reap some profits.

ST2: facilitating access to organic inputs and small mechanized tools

In order to take up organic cultivation, organic inputs must be available and accessible. This would include biofertilizers'

availability, which is a crucial component/input for an organic system. Moreover, the problem of diminishing labor can be overcome by using small, mechanized farm equipment.

ST3: promoting and handholding startups which manufacture organic inputs

Organic inputs' availability for the farmer can be ensured by promoting startup companies which manufacture the inputs. Such companies can be provided with interest-free loans, and their product can be made directly available to the farmer through nearby retail outlets.

WT strategies

WT1: dissemination of validated technical information through proper official channel/means

To improve the technical knowledge of the farmer so that he/she can undertake organic cultivation of the crop, scientifically validated information should be made available through a reliable communication channel/ platform. This enables the farmer to overcome any issues during organic cultivation and not get overwhelmed by information on social media platforms.

WT2: promoting research on pest and disease control in organic farming

As no synthetic inputs can be used in organic farming; a key aspect is the control of pests and diseases naturally. Hence, scientific research in discovering new validated approaches should be promoted.

WT3: consumer awareness programs

The domestic consumer is reluctant to buy organic products for several reasons. They are not convinced to buy organic products at a relatively higher price when compared to the products grown using synthetic inputs. Moreover, the consumer is doubtful if the sold product was really produced organically. The average consumer now understands that to maintain good health and achieve sustainability, he/she needs to switch to organic products. Through these awareness programs, the consumer can be made aware of where to buy genuine organic products and be convinced about the price he/she pays.

4.3 NCMs in SWOT analysis

A study of SWOT factors and subfactors resulted in nine strengths, sixteen weaknesses, seven opportunities and nine threats. This was established using interviews and interaction with farmers and other people from Tamil Nadu, India. Then founded on these aspects, 16 probable strategies were established for organic farming in Tamil Nadu state in India.

We have four groups of strategies given under the heads *SO*, *ST*, *WO* and *WT*. However, working with all 16 strategies together by constructing a single neutrosophic connection matrix related to the NCM graph is difficult. We have obtained the related neutrosophic connection matrices using these directed neutrosophic graphs. These connection matrices are used as the dynamical systems of the NCMs model. In these dynamical systems, we analyze the relevant state vector's effect; it may give the hidden pattern as a limit cycle or a fixed point.

In this paper, we have taken two experts; the first expert has worked with $X = \{SO, WT\}$, and the other expert has worked with all 16 strategies as a single model, which is innovative.

The SWOT-NCM analysis used two NCM models based on the strategies:

The first NCM model works on *SO* and *WT* strategies alone, i.e., only six strategies are considered. The NCM model is given in Fig. 3a. The results of the first NCM model are presented in Table 2.

The second model gives an overall/consolidated view of the influences of each strategy on other strategies; hence, the same results are presented here in Table 3. The NCM model is given in Fig. 3b.

4.3.1 Working of the NCM model using six strategies

The NCM given by the neutrosophic directed graph *G* with six strategies is given in Fig. 1. The dotted line or edge from *WT3* to *SO2* shows an indeterminate relationship. The state vectors and resultant hidden patterns for the NCM using six nodes are tabulated in Table 2.

Table 2 shows that the strategy *SO1* is the most influential one as it makes ON all the nodes/ strategies as seen from the hidden pattern. The two strategies, *SO3* and *WT1*, enjoy equal status, and both are in the second level of the influential node. The node/strategy *WT2* does not influence any other strategy. The node *SO2* influence only the node *WT3*, but *WT3*'s influence on *SO2* is indeterminate. However, this study has limitations since it does not consider all the strategies.

Let $X = \{SO, WT\} = \{SO1, SO2, SO3, WT1, WT2, WT3\}$ be the six attributes/ concepts associated with the strategies given in the SWOT analysis. The related adjacency matrix M_3 of the graph *G* given in Fig. 1a is as follows, where the columns follow the same order as the rows.

$$M_3 = \begin{matrix} SO1 \\ SO2 \\ SO3 \\ WT1 \\ WT2 \\ WT3 \end{matrix} \begin{bmatrix} 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & I & 0 & 0 & 0 & 0 \end{bmatrix}$$

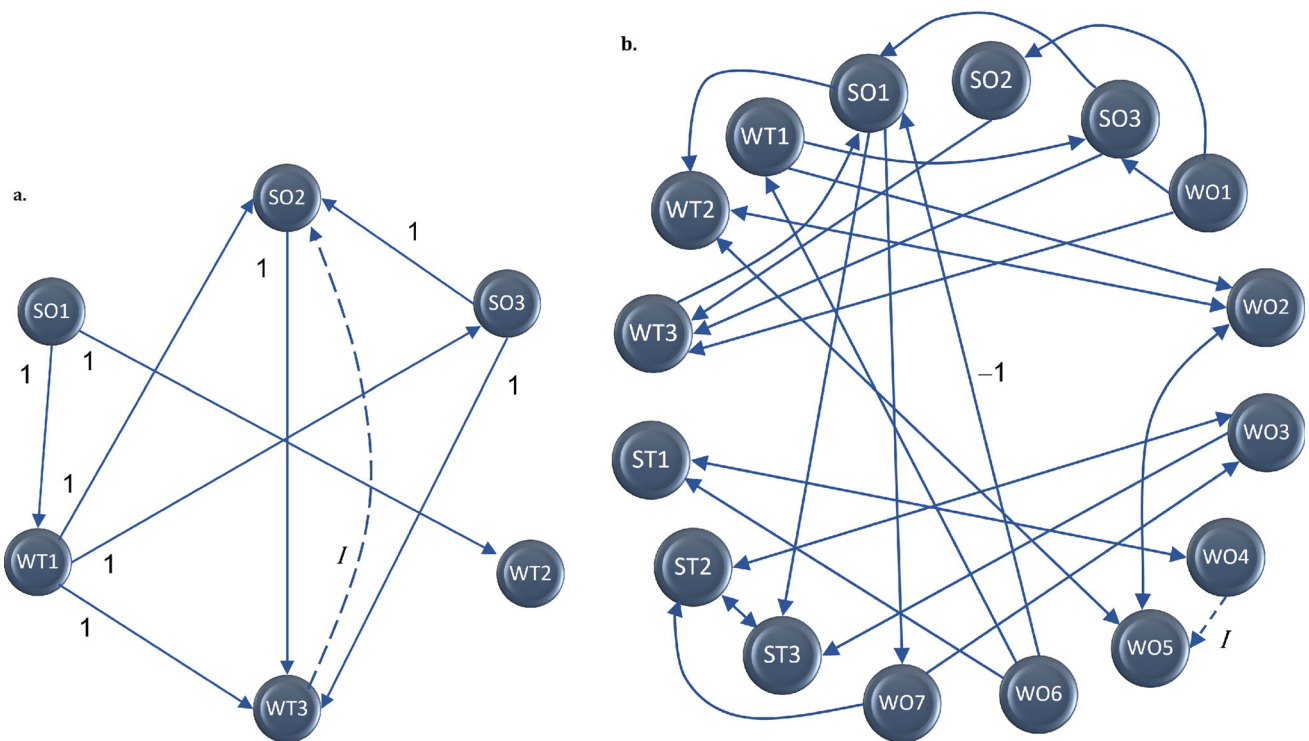


Fig. 3 **a** The neutrosophic directed graph with six strategies given by the expert where the edge from *WT3* to *SO2* is *I*, indeterminate. **b** The neutrosophic directed graph, as given by the second expert, where all

unmarked edges have an edge weight of 1, the edge from *WO6* to *SO1* is -1 , and the edge from *WO4* to *WO5* is *I*, indeterminate

Table 2 Hidden patterns from the analysis using six strategies, which was carried out using the dynamical system M_3

State ON	State vectors	Hidden pattern	No of ON states
<i>SO1</i>	(1 0 0 0 0)	(1 1 1 1 1)	6
<i>SO2</i>	(0 1 0 0 0)	(0 1 0 0 1)	2
<i>SO3</i>	(0 0 1 0 0)	(0 1 1 1 0)	4
<i>WT1</i>	(0 0 0 1 0)	(0 1 1 1 0)	4
<i>WT2</i>	(0 0 0 0 1)	(0 0 0 0 1)	1
<i>WT3</i>	(0 0 0 0 0 1)	(0 1 0 0 0 1)	$I+I$

M_3 is the dynamical system of G (directed graph). Considering the state vector

$$x = (1\ 0\ 0\ 0\ 0)$$

that is solely the strategy; *SO1* is ON, and all others strategies are OFF. The state vector x 's effect on M_3 gives

$$xM_3 = (0\ 0\ 0\ 1\ 1\ 0) \leftrightarrow (1\ 0\ 0\ 1\ 1\ 0) = x_1 \text{ (say)}$$

(\leftrightarrow) symbol denotes the updating and thresholding of the state vector).

The operation where the strategy is in the ON state in the initial vector x should remain in the ON state till the end. This method of replacing in the ON state if it is zero or OFF is called the updating operation. The threshold operation in these models is done using Eq. (4), here with $k = 1$.

The resultant state vector x_1 's effect on M_3 gives

$$x_1M_3 = (0\ 1\ 1\ 1\ 1\ 1)$$

(after updating we get x_2)

$$x_2 = (1\ 1\ 1\ 1\ 1\ 1).$$

The resultant state vector x_2 's effect on M_3 .

$$x_2M_3 = (0\ 2+I\ 1\ 2\ 1\ 3) \leftrightarrow (1\ 1\ 1\ 1\ 1\ 1) = x_3 \text{ (say);}$$

($2 + I$ is replaced by one as the real part is greater than the indeterminate part).

We see $x_3 = x_2$, so the state vector x 's hidden pattern is a fixed point. Further, when the strategy *SO1* is ON, it makes every strategy become ON, thereby proving that CSR funds to organic farming make a total change.

Assume $y = (0\ 1\ 0\ 0\ 0\ 0)$ that is only the strategy *SO2*, that is, value addition of organic products is ON. y 's effect on M_3 is given by

$$yM_3 = (0\ 1\ 0\ 0\ 0\ 1) = y_1 \text{ (say)} \\ y_1M_3 \leftrightarrow (0\ 1\ 0\ 0\ 0\ 1).$$

Hence, this leads to a hidden pattern as a fixed point.

Thus, if *SO2* is ON does not affect other strategies except *WT3*, which becomes ON complying both are related or go hand in hand.

Table 3 Hidden patterns obtained for the sensitivity analysis

State on	State vectors	Hidden pattern	ON-states	Rank
<i>SO1</i>	(1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0)	(1 0 0 0 1 1 0 1 0 1 0 1 1 0 1 0)	8	6
<i>SO2</i>	(0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0)	(1 1 0 0 1 1 0 1 0 1 0 1 1 0 1 1)	10	4
<i>SO3</i>	(0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0)	(1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 1)	10	4
<i>WO1</i>	(0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0)	(1 1 1 1 1 1 0 1 0 1 0 1 1 0 1 1)	12	2
<i>WO2</i>	(0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0)	(0 0 0 0 1 0 0 1 0 0 0 0 0 0 1 0)	3	7
<i>WO3</i>	(0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0)	(0 0 0 0 0 1 0 0 0 0 0 1 1 0 0 0)	3	7
<i>WO4</i>	(0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0)	(0 0 0 0 1 0 1 1 0 0 1 0 0 0 1 0)	2 + 3I	I
<i>WO5</i>	(0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0)	(0 0 0 0 1 0 0 1 0 0 0 0 0 0 1 0)	3	7
<i>WO6</i>	(0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0)	(1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1)	16	1
<i>WO7</i>	(0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0)	(0 0 0 0 0 1 0 0 0 1 0 1 1 0 0 0)	4	6
<i>ST1</i>	(0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0)	(0 0 0 0 1 0 1 1 0 0 1 0 0 0 1 0)	2+3I	I
<i>ST2</i>	(0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0)	(0 0 0 0 0 1 0 0 0 0 0 1 1 0 0 0)	3	7
<i>ST3</i>	(0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0)	(0 0 0 0 0 1 0 0 0 0 0 1 1 0 0 0)	3	7
<i>WT1</i>	(0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0)	(1 0 1 0 1 1 0 1 0 1 0 1 1 1 1 1)	11	3
<i>WT2</i>	(0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1)	(0 0 0 0 1 0 0 1 0 0 0 0 0 0 1 0)	3	7
<i>WT3</i>	(0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1)	(1 0 0 0 1 1 0 1 0 1 0 1 1 0 1 1)	9	5

Next consider $z = (0\ 0\ 1\ 0\ 0\ 0)$

$$z M_3 \leftrightarrow (011101) = z_1(\text{say})$$

$$z_1 M_3 = (02 + I1103) \leftrightarrow (011101) = z_2$$

$$z_2 M_3 = (02 + I1103) \leftrightarrow (011101) = z_3 (= z_2).$$

The hidden pattern of z also results in a fixed point implying ON-state of *SO3* makes the other attributes *SO2*, *WT1* and *WT3* to ON-state; however, media (*SO3*) does not affect the allocation of CSR funds (*SO1*) and promoting research (*WT2*).

The influence of $t = (0\ 0\ 0\ 1\ 0\ 0)$ (where only *WT1* is ON and every other node is OFF) on M_3 .

$$t M_3 = (011101) = t_1(\text{say}) t_1 M_3 = (02 + I1103) \leftrightarrow (011101)$$

which makes it a fixed point.

The expert’s observations after his study with these six strategies are as follows:

- Strategies *SO1* and *SO2* are the most important ones,
- Followed by *SO3*, *WT1* and *SO4*.
- However, *WT2* and *WT3* are not that important strategies in the collection of six strategies.

Authors feel that only an integrated study of all 16 strategies alone can lead to a consolidated result. Moreover, other studies taking two out of the four strategies may yield a poor or incomplete analysis. However, one can say that out of those which happen to be the best or most powerful strategy, i.e., study as small groups, the view or influence of the other

strategies present in the problem but not in this collection leads to an incomplete analysis and is a drawback.

The expert opinion obtained in phase three is represented by a graph which captures the influence (positive, negative or indeterminate) of each strategy on the other strategies. The connection matrix of the graph serves as the dynamical system of the NCM. To study the influence of any node on the other nodes, we consider the state vector, where only one strategy is in the ON state, and all other strategies are in the OFF state. Using the dynamic system, we obtain the hidden pattern. The hidden pattern gives the number of strategies that have come to the ON state. These strategies are influenced by the one strategy that is on in the initial state vector.

A strategy that influences the maximum number of strategies is said to be the most influential one. The hidden pattern table finds even the least effective and indeterminate strategies. Further, the hidden pattern explicitly gives us the most effective strategy and strategies influenced by that strategy using the 16 strategies which resulted from the SWOT analysis.

4.3.2 Working of the second NCM model using all the strategies

The second expert’s opinion using all 16 strategies (*ST*, *SO*, *WT* and *WO*) aided in finding the integrated effect of the strategies on each other and selecting the most influential strategy. This expert’s graph (directed) is given in Fig. 3b. Utilizing the neutrosophic directed graph, the related neutrosophic adjacency matrix S serves as the dynamical system of the NCM. It is vital to mention that in the matrix S , the columns follow the same order as the rows.

$$S = \begin{matrix} SO1 \\ SO2 \\ SO3 \\ WO1 \\ WO2 \\ WO3 \\ WO4 \\ WO5 \\ WO6 \\ WO7 \\ ST1 \\ ST2 \\ ST3 \\ WT1 \\ WT2 \\ WT3 \end{matrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & I & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Now the state vectors, in this case, are 1×16 -row matrices S whose entries are from the set $B = \{0, 1, I\}$. Expert worked with the ON-state of all 16 strategies, which is in Table 3, the hidden pattern analysis table. The complete results of the ON-state of some of the strategies are given in the following:

S serves as the dynamical system of the NCM. Consider x as the state vector where

$$x = (1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0).$$

$SO1$ alone is ON and other strategies are OFF. We find x 's effect on S .

$$\begin{aligned} xS &= (0000000001001010) \\ \Leftrightarrow (1000000001001010) &= x_1(\text{say}) \\ x_1S &= (0000110101011010) \\ \Leftrightarrow (1000110101011010) &= x_2(\text{say}) \\ x_2S &= (0000220201033030) \\ \Leftrightarrow (1000110101011010) &= x_3(\text{say}) \\ x_3S &= (0000220201033030) \\ \Leftrightarrow (1000110101011010) &= x_4(= x_3) \end{aligned}$$

Thus, x 's hidden pattern results in a fixed point. We see the $SO1$ strategy made ON seven strategies. It is interpreted as if the allocation of CSR funds for organic farming ($SO1$) is made ON-state, it will make ON-state seven of the strategies nodes, meaning that it will improve farmers' technical knowledge ($WO2$). It will also influence input subsidies ($WO3$), development of storage pest control methods using natural products ($WO5$), financial assistance during the transition period ($WO7$), access to organic inputs ($ST2$) and will promote the handholding of startups which manufacture organic

inputs ($ST3$). Finally, these CSR funds will promote pest and disease control research in organic farming ($WT2$).

Thus, the hidden pattern given by $SO1$ establishes that $SO1$ (allocation of funds to organic farms by CSR) will influence other valid and contributing strategic nodes, which is clear from the results that several vital nodes have become ON. It is important to note that $SO1$ did not ON all the other strategies like it happened in the first model. Suppose,

$$y = (0\ 1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$$

is the vector with node $SO2$ (value addition of organic products) to ON and all others in OFF. To find y 's effect on S

$$\begin{aligned} yS &= (0000000000000001) \\ \Leftrightarrow (0100000000000001) &= y_1(\text{say}) \end{aligned}$$

The effect of y_1 on S is given by

$$\begin{aligned} y_1S &= (1000000000000001) \\ \Leftrightarrow (1100000000000001) &= y_2(\text{say}) \\ y_2S &= (1000000001001011) \\ \Leftrightarrow (1100000001001011) &= y_3(\text{say}) \\ y_3S &= (1000110101011011) \\ \Leftrightarrow (1100110101011011) &= y_4(\text{say}) \\ y_4S &= (1000220201033031) \\ \Leftrightarrow (1100110101011011) &= y_5(= y_4) \end{aligned}$$

This results in a fixed point, i.e., the strategy $SO2$ being in ON (value addition of organic products) results in the ON-state of the strategies $SO1, WO2, WO3, WO5, WO7, ST2, ST3, WT2$

and *WT3*. Thus, the nodes which have come to ON-state can be categorized as strategic nodes.

Now consider,

$$z = (0010000000000000),$$

where only strategy *SO3* is in the ON state. We see *z*'s effect on *S*

$$zS = (1000000000000001) \\ \hookrightarrow (1010000000000001) = z_1(\text{say})$$

The final resultant is a fixed point as given by

$$(1010110101011011)$$

This makes ON the nodes *SO1*, *WO2*, *WO3*, *WO5*, *WO7*, *ST2*, *ST3*, *WT2* and *WT3*.

Thus, we see all the three nodes under SO strategies are vital when they are in the ON-state they are highly interrelated with other strategies.

Now suppose the concept *ST1* alone is ON and other states are OFF. To calculate the state vector's effect

$$a = (0001000000000000)$$

on *S*

$$aS = (0110000000000001) \\ \hookrightarrow (0111000000000001) = a_1(\text{say}) \\ a_1S = (2110000000000003) \\ \hookrightarrow (1111000000000001) = a_2$$

We find *a₂S* and continue the process. The hidden pattern of *a* is

$$(1111110101011011)$$

This node *WO1* is also a powerful strategy. Consider the state vector *b* where *WO2* is ON, given by

$$b = (0000100000000000)$$

b's effect on *S* is given as follows

$$bS = (0000000100000010) \\ \hookrightarrow (0000100100000010) = ab_1(\text{say}) \\ ab_1S = (0000100100000010) = ab_2(= ab_1)$$

b₁ is a fixed point. Node *WO2* (improve farmer's technical knowledge) is a weak strategy for it brings to ON-states only *WO5*, *WT2*, and other nodes are OFF.

5 Discussion and results

5.1 Sensitivity analysis

A sensitivity analysis was carried out for each of the strategies and their influences. The sensitivity analysis for the variables is given in Figs. 4, 5 and 6. Figure 4 shows the sensitivity analysis of strategies *SO1*, *SO2*, *SO3*, *WO1*, *WO2* and *WO3*. Similarly, the sensitivity analysis of strategies *WO5*, *WO6*, *WO7*, *ST2*, *ST3* and *WT1* is given in Fig. 5. Sensitivity analysis for strategies *WT2*, *WT3*, *WO4* and *ST1*, is shown in Fig. 6, of which strategies *WO4* and *ST1* capture the indeterminacy present.

The second expert has worked with all 16 nodes, and the results are tabulated in Table 3, which gives the following conclusions:

- The most influential strategy is *WO6*, since it brings all the strategies to ON state.
- The strategies *SO1*, *SO2*, *SO3*, *WO1*, *WT1* and *WT3* are influential and powerful.
- However, the strategies *WO2*, *WO4*, *ST1* and *WT2* are less influential.

A sensitivity analysis has also been carried out to support the conclusions from the study. Thus, according to our study, to improve the situation of organic farming, the government must first fix MSP and procure the yields from the farmers to avoid a loss; then, only consequent development or improvements can come in.

The ON-state column of Table 3 consolidates the number of strategies a particular strategy influences given by the hidden pattern, and ranking is based on it.

This study concludes that the most effective strategy that influences all the other strategies is *WO6* (MSP and centralized procurement from certified farmers), as the ON state of *WO6* makes on every other strategy in the model, indicating that all the strategies will be achieved if the strategy *WO6* is adopted. So the most effective strategy is *WO6* which ranks 1 in its influence on all other strategies. Further, the next set of effective strategies is *WO1*, *WT1*, *SO2*, *SO3* and *WT3*, which prove that marketing techniques, creating a supply chain and advertising the products, will develop organic farming. However, it is surprising to note that the concept of indeterminacy only plays a role in *WO4* and *ST1*, which are strategies related to organic certification. Further, the ranks of all other strategies are given in the last column of Table 3. The least influential nodes take ranks 6, and 7 falls under this category.

The second expert's opinion dealt with all 16 nodes (*ST*, *SO*, *WT* and *WO* strategies) as he wanted to find the integrated effect of the strategies on each other and select the most

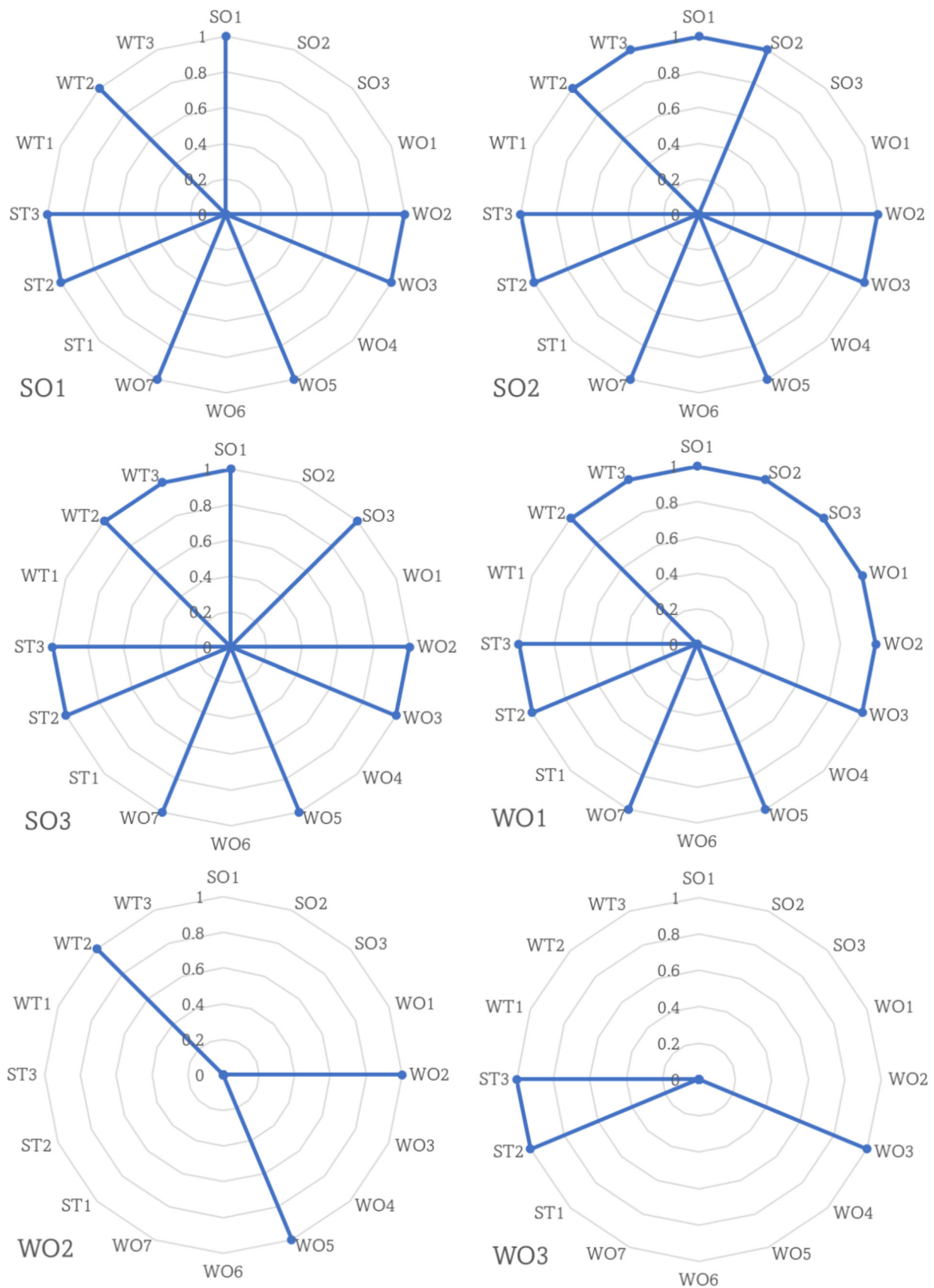


Fig. 4 Sensitivity Analysis for SO1, SO2, SO3, WO1, WO2 and WO3

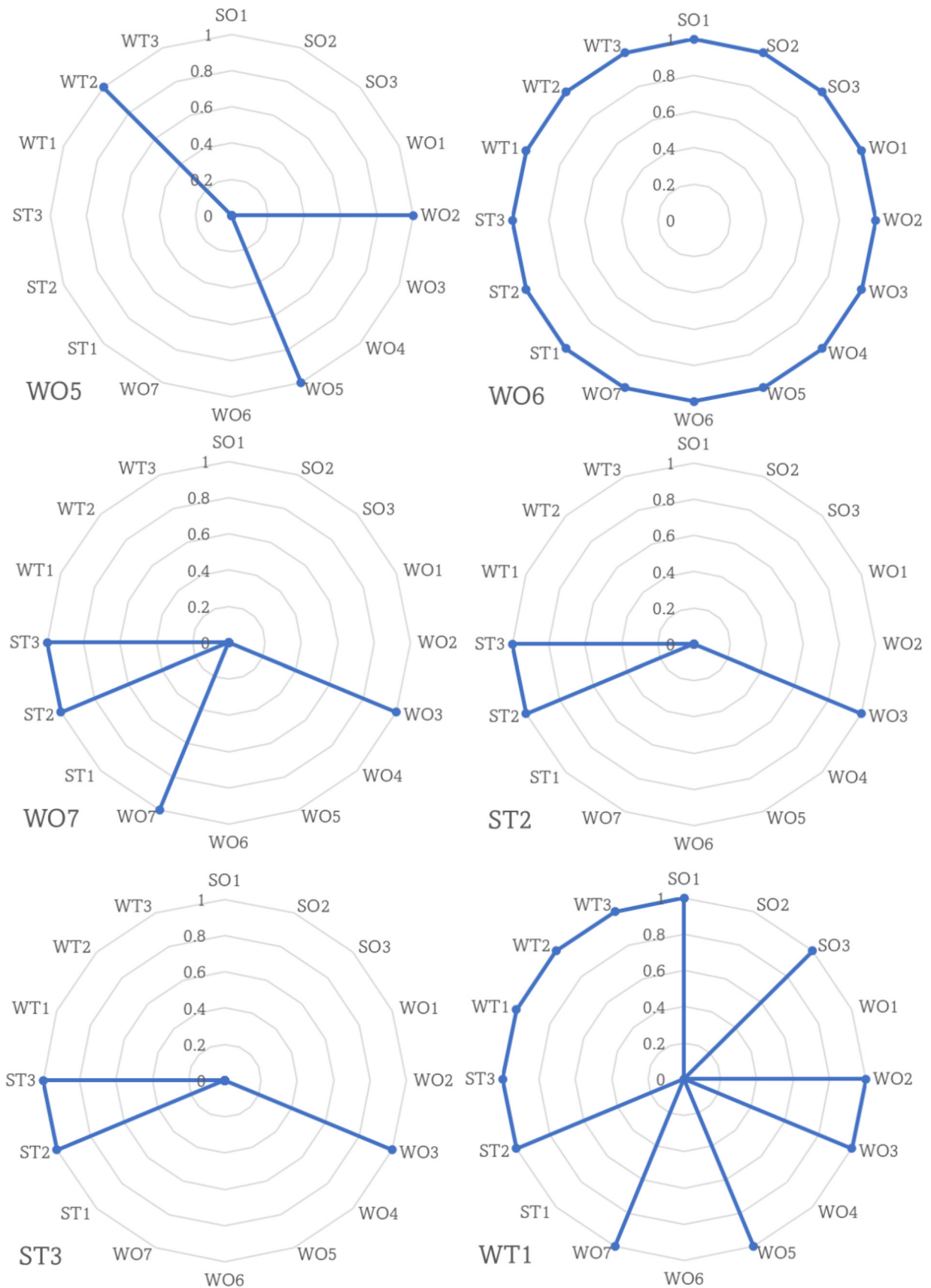


Fig. 5 Sensitivity Analysis for $WO5$, $WO6$, $WO7$, $ST2$, $ST3$ and $WT1$

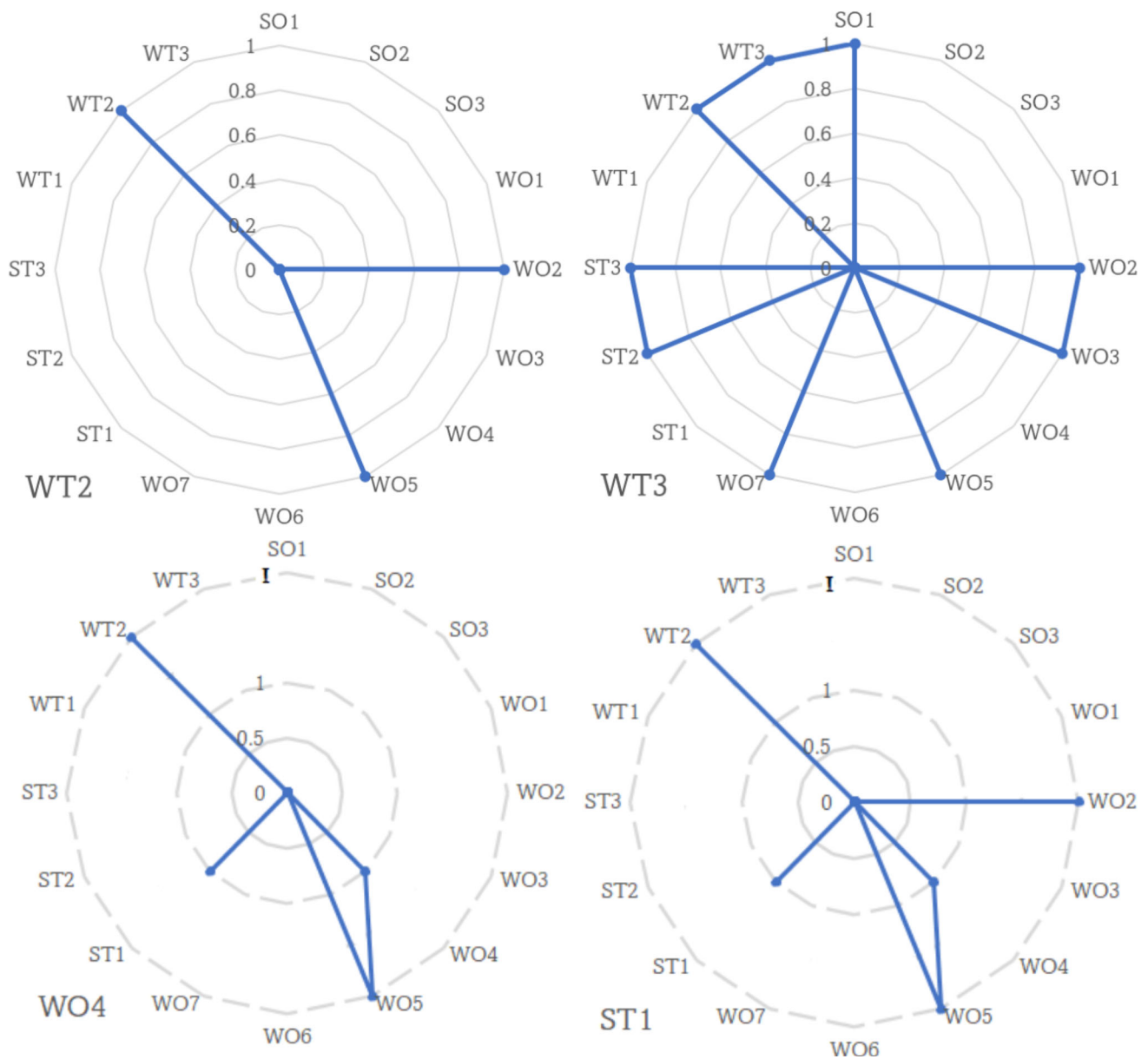


Fig. 6 Sensitivity Analysis for WT2, WT3, WO4 and ST1

effective strategy. This expert’s graph (directed) is given in Fig. 3b.

Most influential strategy: The last column of the analysis table shows the number of nodes in the ON-state. The table shows that the strategy WO6 is vital and the most effective or first-ranking strategy for organic farming. The sensitivity analysis for strategy WO6 given in Fig. 5 under WO6, also shows the same. Organic farmers need the raw (agricultural products) procurement at the minimum support price (MSP). WO6 is the most effective strategy, making ON all other 15 strategies. This sort of analysis cannot be carried out using any other methodology except the NCMs, which yield the hidden pattern of influences between the SWOT strategies.

Hence, the SWOT-NCMs model happens to be very vital, where the NCMs play a vital role in analyzing and finding the best strategy proposed by SWOT.

If the government does this, organic farmers will face lesser problems. In the present scenario in Tamil Nadu, marketing strategies need to be better known to the organic farmers; further, only the middleman gets the profit leaving the organic farmers in poverty and debt. This one help can change organic farming by leaps and bounds.

Second influential strategy: The next higher ON-state of node/ strategies is 12, achieved by the strategy WO1, establishing the supply chain. The sensitivity analysis for WO1 is given in Fig. 4, under WO1 also shows the same. Organic

farmers are not capable of high-level marketing of their products. Further, for organic farming products, the input costs are more, but the yield is less when compared to inorganic farming, whereas in inorganic farming, the yield is higher, and input costs are lower. This imbalance leads to organic farmers suffering a severe setback financially and mentally, going back to inorganic farming.

Third influential strategy: The third influential strategy is *WT1* (Disseminating validated technical and marketing information through proper official channels/means); it has made 11 nodes ON-state. Implementation of this strategy can help organic farming in being successful.

Influence of other strategies: Two effective strategies which get the fourth-ranking get a score of 10 each (fourth-ranking strategy). They are *SO2* and *SO3*. However, the strategies *SO3*, *WO1*, *WO4*, *WO6*, *ST1* and *WT1* are unaffected, as indicated by the hidden pattern given for *SO2*. The sensitivity analysis for all strategies have been given in Figs. 4, 5 and 6.

In the case of the strategy *SO3*, the nodes which become ON are the same. However, *SO2* and *SO3* are unrelated, but both in their hidden pattern have influenced only the same strategies, which is an important observation for they do not directly influence each other for, in *SO2*, *SO3* is in OFF state and in *SO3* the *SO2* is in the OFF state, but indirectly has the same effect.

As given by the hidden pattern table, the fifth influential strategy is *WT3* (consumer awareness programs). The strategies it has made ON are *SO1*, *WO2*, *WO3*, *WO5*, *WO7*, *ST1*, *ST3*, *WT2* and *WT3*.

If *SO1* (allocation of CSR funds for organic farming) is ON, it influences strategies like *SO2*, *WO2*, *WO3*, *WO5*, *WO7*, *ST2*, *ST3*, *WT2* and *WT3* related to it, as shown by the hidden pattern. It makes ON precisely eight strategies, that is, allocation of CSR funds for organic programming changes the situation of organic farming. This strategy was the most influential in the previous model, whereas this strategy is ineffective here. It reiterates the need for an integrated approach to developing the NCM.

Finally, the ON state of strategy, *WO4* makes the strategies *WO2*, *WO5*, and *WT2* as indeterminate states. So, the strategy of no cost of certification for genuine organic farmers improves farmers' technical knowledge (*WO2*), development of storage pest control methods (*WO5*) and promotes research on pest and disease control in organic farming to indeterminate state. Only promoting, encouraging and facilitating organic certification comes to ON state. The sensitivity analysis for all strategies is given in Figs. 4, 5 and 6.

Thus, these are the main conclusions from our research analysis, and we also concluded that *WO6* is the best strategy to incorporate.

5.2 Comparison with other MCDM models

Comparison of the proposed model with other existing MCDM models based on SWOT is given Table 4. Four existing MCDM models which are based on SWOT analysis are used for comparison on basis of ranking of the SWOT strategies, if the indeterminacy present in the real world is captured and if the influence of one strategy on others is analyzed.

Existing model 1 (KhezriNejhad Gharaei and Bakhshoudeh 2014): SWOT-ANP was used to analyze the factors affecting the transition from conventional farming to organic farming. Model 1 is capable of handling the strategies and ranking them.

Existing model 2 (Aghasafari et al. 2020): SWOT-fuzzy-ANP approach was used to select the most suitable strategies for developing organic farming in Iran.

Existing model 3 (Firdaus et al. 2021): SWOT-fuzzy-AHP technique was used for strategising various methods to improve organic farming in Indonesia.

Since fuzzy sets are used, models 2 and 3 are better at capturing the data and more accurate in ranking the SWOT strategies but do not consider indeterminacy or analyze the influence of one strategy over the other. The first three models worked with real-world examples from the agricultural field. Neutrosophic theory, along with SWOT, is yet to be used to analyze real-world agricultural problems.

Existing model 4 (Abdel-Basset et al. 2018): An extension of neutrosophic AHP-SWOT analysis was proposed. The drawback of this model is that it does not analyze the influence (positive or negative) of one strategy on others, but it handles the indeterminacy present by using neutrosophy.

Proposed model The SWOT-NCM model proposed in this paper alone can measure the influence of one strategy over the other strategies, as given in Table 3 and the sensitivity analysis given in Figs. 4, 5 and 6. Clearly, it satisfies both ranking the strategies and handling the indeterminacy present in the data.

The comparison Table 4 shows that the proposed model is more equipped to handle real-world data involving human experts based on multi-criteria decision making.

6 Conclusions

In this paper, the authors, for the first time, use an innovative method of combining the SWOT analysis with NCMs. Generally, researchers have used AHP, ANP, fuzzy-AHP, fuzzy-ANP or Neutrosophic AHP and Neutrosophic ANP techniques along with SWOT to analyze the strategies and obtain the conclusions. All these models analyze the strategies based on specific criteria and ignore the various interconnection between them. To the best of our knowledge, analysis of the influence of one strategy over others,

Table 4 Comparison table of proposed model with existing SWOT based MCDM models

Models	Existing model 1	Existing model 2	Existing model 3	Existing model 4	Proposed model
Ranking of Strategies	✓	✓	✓	✓	✓
Indeterminacy	✗	✗	✗	✓	✓
Influence of one strategies over other strategies	✗	✗	✗	✗	✓

Table 5 Details of Farmers

S. No	Place/ Village	District	Organic Produce	Years
1	Pushpavanam	Nagapattinam	Rice, Sesame, Groundnut, Green gram	15
2	Kelur	Tiruvannamalai	Rice	10
3	Aadhiyagai	Dindigul	All vegetables and greens	10
4	Madurai	Madurai	Rice, Vegetables, Groundnut	5
5	Vandavasi	Tiruvannamalai	Traditional rice variety	8
6	Rajapalayam	Virudhunagar	Traditional rice variety	6
7	Polur	Tiruvannamalai	Rice, Coconut, Groundnut	10
8		Tiruvarur	Rice, Sesame, Groundnut	25
9	Kumbakkonam	Tanjavur	Traditional rice variety	5
10	Orathanadu	Tanjavur	Traditional rice variety	8
11		Tanjavur	Traditional rice variety	20
12	Virudachalam	Cuddalore	Saplings	9
13	Karaikkal	Pudhucherry	Traditional rice variety	30
14	Palayamkottai	Tirunelveli	Rice, Groundnut, Coconut	8
15	Arcot	Ranipet	Traditional rice variety	18
16	Cheyar	Tiruvannamalai	Rice, Groundnut, Coconut, Sugarcane	10
17	Kannamangalam	Tiruvannamalai	Rice, Pulses	15
18	Kalasapakkam	Tiruvannamalai	Rice, Greens, Groundnut	23
19	Aadhanur	Tiruvannamalai	Rice, Greens, Groundnut, Sesame	10
20	Sevur	Vellore	Banana, Greens, Coconut, Fruit Crops	7
21	Aadhanur	Tiruvannamalai	Medicinal plants, Rice Coconut, Groundnut	10
22	Ladavaram	Tiruvannamalai	Rice, Groundnut, Vegetables	5.5
23	Polur	Tiruvannamalai	Rice, Groudnut, Vegetables	6
24	Gudiyattam	Vellore	Rice, Coconut, Groundnut, Banana	15
25	Gudiyattam	Vellore	Rice, Coconut, Vegetables, Banana	10
26	BHEL Township	Ranipet	Rice, Groundnut	8
27	Tiruvannalloor	Villipuram	Rice, Groudnut, Coconut, Sesame	10
28	Sirkali	Nagapattinam	Rice, Coconut, Groudnut Vegetables, Banana	15
29	Vandavasi	Tiruvannamalai	Rice, Groundnut, Vegetables, Banana	15
30	Gingee	Villipuram	Rice, Groundnut, Vegetables, Banana	26
31	Surakottai	Tanjavur	Rice, Sesame	15
32	Jayamkondan	Ariyalur	Rice	20

that is, whether they will positively or negatively influence the other, is not done. To analyze the interconnections between the SWOT strategies, we have proposed a new framework that combines SWOT and NCM.

The proposed SWOT-NCM model is deployed to analyze the case study of developing organic farming in Tamil Nadu, India. The SWOT analysis resulted in 16 strategies given in Table 1. The proposed SWOT-NCMs model uses NCMs on the 16 strategies using which we obtain the hidden patterns. Using it, we find the most effective strategy and rank them. The hidden pattern table finds even the least effective and indeterminate strategies. The sensitivity analysis of the 16 strategies is performed to evaluate their influence on other strategies.

This study concludes that the most effective strategy influencing all the other strategies is *WO6* (MSP and centralized procurement from certified farmers), automatically indicating that all the strategies will be fulfilled. So the most effective strategy is *WO6* (Sensitivity analysis given in Fig. 5 under *WO6*). Further, the next set of effective strategies is *WO1*, *WT1*, *SO2*, *SO3* and *WT3* (Sensitivity analysis given in Figs. 4, 5 and 6), which prove that marketing techniques, creating a supply chain and advertising the products will develop organic farming. However, it is surprising to note that the concept of indeterminacy only plays a role in *WO4* and *ST1*, which are related to strategies related to organic certification. We will analyze the problems related to organic certification separately for future research. Thus combining SWOT with NCMs gives a potential tool to list the strategies in terms of influence and interconnections and rank them.

A comparative analysis of the proposed model with four existing MCDM models was done. The proposed model was better equipped to analyze the influence of one strategy on others, along with ranking the SWOT strategies and handling indeterminacy present in the real world.

Limitation of the study: The study has geological constraints, since it only considers certain villages from Tamil Nadu. Different geological places have variable ecological and agricultural backgrounds, indicating that the SWOT analysis will vary depending on where one conducts the study.

6.1 Future works

The study can be expanded to other locations heavily dependent on agricultural growth. A new mathematical model incorporating NCMs using T2NN can be investigated in the future. Also, MCDM models employing SWOT analysis can use PFS or T2NN-based decision-making models.

Supplementary information

The list of participants is listed in Table 5.

Acknowledgements The authors thank all the participants and experts for their expertise and assistance throughout all aspects of our study.

Author Contributions JMO was involved in conceptualization; VK and IK helped in methodology; IK and JMO contributed to formal analysis and investigation, VK was involved in writing—original draft preparation; FS and IK helped in writing—review and editing; JMO contributed to resources.

Funding Jagan M. Obbineni acknowledges funding support from the Science and Engineering Research Board (SERB), Department of Science and Technology, Govt. of India under the grant numbers SRG/2020/001690 and TAR/2022/000312.

Data availability Enquiries about data availability should be directed to the authors.

Code Availability Not applicable.

Declarations

Conflict of interest The Author(s) declare(s) that there is no conflict of interest.

Consent to participate Informed consent was obtained from all individual participants involved in the study.

Consent for publication Not applicable.

Ethics approval Informed consent was obtained from all individual participants involved in the study.

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