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Neutrosophical Plant Hybridization in Decision-Making Problems

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Abstract: Florentin Smarandache [15] developed the neutrosophic set theory to study inconsistency, incomplete, and uncertainty information by using truth-membership, indeterminacy-membership, and falsity-membership functions. One of the main objectives of this chapter is to develop a new methodological approach of neutrosophic sets in multi-criteria decision-making problems. This method considers neutrosophic sets with their unions in the direct direction and the complements of given neutrosophic sets with their intersections are also considered in the reverse direction. Using these collections, single-valued neutrosophic score functions are computed in both directions. After this process, all the alternatives are ranked in the ascending order arrangement to find the best alternatives not only in each region but also in the entire region. Another main objective is to solve a numerical example of plant hybridization by using single-valued neutrosophic score functions to demonstrate the effectiveness of the - proposed method. This numerical example is the first example of plant hybridization in the - neutrosophic environment, which is to find the best hybrid plants with an increased quantity of - yield. The uniqueness of this method is the dependence of single-valued neutrosophic score - function and independence of any other neutrosophic measures
or distance functions, etc.

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1 Introduction

The world life of every human being has some problems of uncertainty, imprecise, incomplete, and inconsistent information. Fuzzy set theory is one of the wide frameworks for uncertainty. In the year 1965, A. Zadeh [1] initiated this theory to analyze imprecise, incomplete mathematical information and this set is a generalization of a crisp set that considers the membership degree of each element from the crisp set. Adlassnig [2] applied the fuzzy logic to the computerized diagnosis system and analyzed the medical relationships. This theory [3, 4, 5, 6, 7, 8] has been scientifically used in various fields such as control systems, medical diagnosis, and Engineering respectively by M. Sugeno [3], P. R. Innocent [4], T. J. Roos [5]. To handle the fuzzy problems, different types of similarity measures are introduced by the researchers [6, 7, 8]. By considering the degree of non-membership of an element along with the degree of membership, K. Atanassov [9] introduced intuitionistic fuzzy sets as a generalization of a fuzzy set. S. De et al. [10], Szmidt and Kacprzyk [11] were applied the intuitionistic fuzzy sets in medical diagnosis. Biswas et al. [12] defined intuitionistic fuzzy cosine similarity measure to study professionals' health problems. Khatibi and Montazer [13] compared the relations of intuitionistic fuzzy sets, fuzzy sets with the application in medical pattern recognition. Hung and Tuan [14] reported that the approach of [10] has some questionable results on the false diagnosis of the patient's symptoms. It generally recognized the available information's about the patients and medical relationships are inherently uncertain. There may be indeterminacy components for data mining in real-life problems. The neutrosophic logic can be used in this situation, which is a generalization of fuzzy, intuitionistic, boolean, paraconsistent logics, etc. Florentin Smarandache [15, 16] developed the concept of neutrosophic logic and set which deals with three various components such as truth-membership, indeterminacy membership and falsity-membership whose values are real standard or a nonstandard subset of unit interval $]0^-, 1^+[$. The single-valued neutrosophic set was first initiated by Wang et al. [17] in 1998, which is a neutrosophic set, can be used in real-life engineering and scientific applications. Majumdar and Samanta [18] defined some similarity measures of single-valued neutrosophic sets in decision-making problems.

Neutrosophic set is an effective and useful tool to describe problems with uncertainty, imprecise, incomplete, and inconsistent information. In this regard, Smarandache and Pramanik [19] widely founded the solutions of neutrosophic decision-making problems. The multi-attributed decision-making (MADM) and multi-criteria decision-making (MCDM) problems have a wide scope in the research area of neutrosophic sets utilization. J. Ye and S. Ye [20, 21, 22] solved the multi-attributed decision-making problems by using single-valued similarity measure, tangent similarity measure, and distance based-similarity measures in neutrosophic environments. Biswas et al. [23] proposed the cosine similarity measure for solving multiple-attribute decision problems in neutrosophic single-valued sets. S. Broumi and F. Smarandache [24] introduced some kinds of similarity measures of the neutrosophic sets. In the neutrosophic environment, the cotangent similarity measure is introduced by Pramanik and Mondal [25]. V. Ulucay et al. [26]

defined a hybrid distance-based similarity measure for refined neutrosophic sets with its application in medical diagnosis. N. Nabeeh et al. [27, 28] introduced a new neutrosophic technique and integrated neutrosophic-TOPSIS approach for personal selections in multi-criteria decision-making problems. Following this, M. Abdel-Basset et al. [29, 30, 31] solved the supplier selection and smart medical device selection by using the TOPSIS approach, which includes many conflicting criteria in the MCDM problems. Gaussian single-valued neutrosophic numbers and its application are invented in the MADM problem by F. Karaaslan [32]. B. C. Giri, et al. [33] introduced the TOPSIS method for the MADM problem based on interval trapezoidal neutrosophic numbers. S. Aal et al. [34] formulated the two ranking methods based on single-valued triangular neutrosophic numbers to evaluate the quality of the systems. Recently the concept of the difference of two neutrosophic sets is defined by G.Jayaparthasarathy et al. [35] with the real-life application by using single-valued neutrosophic scores function. Furthermore, Hossein with his collaborators [36] introduced an ELECTRE approach to finding the best alternative for multi-attribute decision-making problems in a refined neutrosophic environment. Under the neutrosophic environment, every above-mentioned researcher founded the best alternatives or the alternatives with the alternatives or the alternatives with the attributes for the entire region (problem). We may here ask some questions "Is it possible to find the best alternatives not only in the entire region but in each region?" and "Can we formulate a new method to identify the alternatives in each and entire region?"

The hybridization would cross different plants such as grasses' rice, maize, cotton, and wheat for the new hybrid plant which give different increased yield and improved grain quality in both crosses- and self-pollinated crops. In the 18th century, Mendel [37], an Augustinian who is the author of 'Experiments in Plant Hybridization', produced the F_1 hybrid by cross-breeding pea plants. The present chapter formulates a new method to answer the above questions for multi-criteria decision-making problems under neutrosophic environments. The beauty of this chapter is the proposed method uses the neutrosophic set-theoretical operation such as complements, intersections, unions, and single-valued neutrosophic score functions in both direct and reverse direction to identify the best alternatives in each and the entire region. The plant hybridization problem is solved under neutrosophic environments as a real-life application to demonstrate the effectiveness of the proposed method because the hybrid grain yields are varying place to place.

2 Preliminaries

This section presents some of the basic properties of neutrosophic sets and operations on neutrosophic sets which are used for further study.

Definition 1 [15] Let X be a non empty set. A neutrosophic set A having the form $A = \{(x, \mu_A(x),\ \sigma_A(x), \gamma_A(x)) : x \in X\}$, where $\mu_A(x), \sigma_A(x)$ and $\gamma_A(x) \in\ ]0^-, 1^+[$ represent the degree of membership (namely $\mu_A(x)$), the degree of indeterminacy (namely $\sigma_A(x)$) and the degree of non membership (namely $\gamma_A(x)$) respectively for each $x \in X$ to the set A such that $0^- \leq \mu_A(x) + \sigma_A(x) + \gamma_A(x) \leq 3^+$ for all $x \in X$. For a non empty set X, $N(X)$ denotes the collection of all neutrosophic sets of X.

Definition 2. [16] The following statements are true for neutrosophic sets A and B on X:

i. $\mu_A(x) \leq \mu_B(x)$, $\sigma_A(x) \leq \sigma_B(x)$ and $\gamma_A(x) \geq \gamma_B(x)$ for all $x \in X$ if and only if $A \subseteq B$.
ii. $A \subseteq B$ and $B \subseteq A$ if and only if $A = B$.
iii. $A \cap B = \{(x, min\{\mu_A(x), \mu_B(x)\}, min\{\sigma_A(x), \sigma_B(x)\}, max\{\gamma_A(x), \gamma_B(x)\}) : x \in X\}$.
iv. $A \cup B = \{(x, max\{\mu_A(x), \mu_B(x)\}, max\{\sigma_A(x), \sigma_B(x)\}, min\{\gamma_A(x), \gamma_B(x)\}) : x \in X\}$.
More generally, the intersection and the union of a collection of neutrosophic sets $\{A_i\}_{i\in\Lambda}$, are defined by $\bigcap_{i\in\Lambda} A_i = \{(x, inf_{i\in\Lambda}\{\mu_{A_i}(x)\}, inf_{i\in\Lambda}\{\sigma_{A_i}(x)\}, sup_{i\in\Lambda}\{\gamma_{A_i}(x)\}) : x \in X\}$ and $\bigcup_{i\in\Lambda} A_i = \{(x, sup_{i\in\Lambda}\{\mu_{A_i}(x)\}, sup_{i\in\Lambda}\sigma_{A_i}\{(x)\}, inf_{i\in\Lambda}\{\gamma_{A_i}(x)\}) : x \in X\}$.

Corollary 1 [16] The following statements are true for the neutrosophic sets A, B, C and Don X:

i. $A \cap C \subseteq B \cap D$ and $A \cup C \subseteq B \cup D$, if $A \subseteq B$ and $C \subseteq D$.
ii. $A \subseteq B \cap C$, if $A \subseteq B$ and $A \subseteq C$. $A \cup B \subseteq C$, if $A \subseteq C$ and $B \subseteq C$.
iii. $A \subseteq C$, if $A \subseteq B$ and $B \subseteq C$.

Definition 3. [35] The difference of neutrosophic sets A and B on X is a neutrosophic set on X, defined as $A \setminus B = \{(x, |\mu_A(x) - \mu_B(x)|, |\sigma_A(x) - \sigma_B(x)|, 1 - |\gamma_A(x) - \gamma_B(x)|)\ x \in X\}$. Clearly $(1_n)^c = 1_n \setminus 1_n = (0,0,1) = 0_n$ and $(0_n)^c = 1_n \setminus 0_n = (1,1,0) = 1_n$, here the neutrosophic empty set is $0_n = \{(x, 0,0,1) : x \in X\}$ and the neutrosophic whole set is $1_n = \{(x, 1,1,0) : x \in X\}$.

Definition 4 [8] A neutrosophic set $A = \{(x, \mu_A(x), \sigma_A(x), \gamma_A(x)) : x \in X\}$ is called a single valued neutrosophic set on a non empty set X, if $\mu_A(x), \sigma_A(x)$ and $\gamma_A(x) \in [0,1]$ and $0 \leq \mu_A(x) + \sigma_A(x) + \gamma_A(x) \leq 3$ for all $x \in X$ to the set A. For each attribute, the single valued neutrosophic score function (shortly SVNSF) of A is defined as $SVNSF(A) = 1/3m[\sum_{i=1}^{m}[2 + \mu_i - \sigma_i - \gamma_i]]$. A single valued neutrosophic number is a neutrosophic set is symbolized by $< T, I, F >$ such that $T, I, F \in [0,1]$ and $0 \leq T + I + F \leq 3$.

3 Neutrosophic Methodologies in Multi-Criteria Decision-Making Problems

This section systematically develops a new methodological approach in multi-criteria decision making (MCDM) problems with single-valued neutrosophic information for neutrosophic sets structure. The following methodological approach gives the necessary steps to select the best alternatives in each division and the best alternative overall regions in the MCDM situations.

Step 1: Problem Selection Consider the multi-criteria decision-making problem shown in table 1, with m alternatives $A_1, A_2, \ldots, A_m$ and p attributes $B_1, B_2, \ldots, B_p$ for n regions $D_1, D_2, \ldots, D_n$ to identify the best alternatives of each region and the best alternative of entire regions.

Table 1 Problem Selection

D_1 Alternatives	Attributes			
	B_1	B_2	. . .	B_p
A_1	$(a_{11})_1$	$(a_{12})_1$	. . .	$(a_{1p})_1$
A_2	$(a_{21})_1$	$(a_{22})_1$	. . .	$(a_{2p})_1$
.	.	.	. . .	.
.	.	.	. . .	.
.	.	.	. . .	.
A_m	$(a_{m1})_1$	$(a_{m2})_1$	. . .	$(a_{mp})_1$
D_2 Alternatives	B_1	B_2	. . .	B_p
A_1	$(a_{11})_2$	$(a_{12})_2$	. . .	$(a_{1p})_2$
A_2	$(a_{21})_2$	$(a_{22})_2$	. . .	$(a_{2p})_2$
.	.	.	. . .	.
.	.	.	. . .	.
.	.	.	. . .	.
A_m	$(a_{m1})_2$	$(a_{m2})_2$	. . .	$(a_{mp})_2$
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
D_n Alternatives	B_1	B_2	. . .	B_p
A_1	$(a_{11})_n$	$(a_{12})_n$	. . .	$(a_{1p})_n$
A_2	$(a_{21})_n$	$(a_{22})_n$	. . .	$(a_{2p})_n$
.	.	.	. . .	.
.	.	.	. . .	.
.	.	.	. . .	.
A_m	$(a_{m1})_n$	$(a_{m2})_n$	. . .	$(a_{mp})_n$

(a_{ij}) are single valued neutrosophic numbers.

Step 2: Problem Division Divide the selected problem into n sub problems for n regions.

Step 3: Direct Direction

Step 3(a): Sub Problem Selection Select first sub problem for the corresponding region.

Step 3(b): Neutrosophic Operations For $j = 1, 2, \dots, m$, find $C_{j1} = \{(a_{j1})_1, (a_{j2})_1, \dots, (a_{jp})_1\}$ and $D_{j1} = \{(a_{j1})_1 \cup (a_{j2})_1, (a_{j1})_1 \cup (a_{j3})_1, \dots, (a_{j1})_1 \cup (a_{jp})_1, (a_{j2})_1 \cup (a_{j3})_1, \dots, (a_{j2})_1 \cup (a_{jp})_1, \dots, (a_{j(p-1)})_1 \cup (a_{jp})_1\}$ such that $(a_{jk})_1 \cup (a_{jl})_1 \notin C_{j1}$.

Step 3(c): Finding Single-Valued Neutrosophic Score Functions For $j = 1, 2, \dots, m$, find single-valued neutrosophic score functions of C_{j1} and D_{j1} are defined as follows: $SVNSF(C_{j1}) = 1/3p[\sum_{i=1}^{p}[2 + \mu_{ji} - \sigma_{ji} - \gamma_{ji}]]$, and $SVNSF(D_{j1}) = 1/3q\ [\sum_{i=1}^{q}[2 + \mu_{ji} - \sigma_{ji} - \gamma_{ji}]]$, where q is the number of elements of D_{j1}. $SVNSF(A_j) = \{SVNSF(C_{j1})$, if $SVNSF(D_{j1}) = 0$. Otherwise, $1/2[\ SVNSF(C_{j1}) + SVNSF(D_{j1})\}$.

Step 3(d): Arrangement For $j = 1, 2, \dots, m$, arrange all the single-valued neutrosophic score function's values for the alternatives $A_1, A_2, \dots, A_m$ in ascending order.

Step 3(e): Repetition Repeat step 3 (a) to 3(d) for each sub problem of the corresponding region.

Step 3(f): Direct Rank Tabulate all the direct ranks $DR(A_j)$ of the alternatives $A_1, A_2, \dots, A_m$ by giving ranks $1, 2, \dots, m-1, m$ in the ascending order to the alternatives for each regions $D_1, D_2, \dots, D_n$. Find the total direct rank $TDR(A_j)$ of each alternatives A_j by using $TDR(A_j) = \sum_{j=1}^{n} DR(A_j)$, for each $j = 1, 2, \dots, m$.

Step 4: Reverse Direction

Step 4(a): Sub Problem Selection Select first sub problem for the corresponding region.

Step 4(b): Neutrosophic Operations For $j = 1, 2, \dots, m$, find $E_{j1} = \{(a_{j1})_1{}^c, (a_{j2})_1{}^c, \dots, (a_{jp})_1{}^c\}$ and $F_{j1} = \{(a_{j1})_1{}^c \cap (a_{j2})_1{}^c, (a_{j1})_1{}^c \cap (a_{j3})_1{}^c, \dots, (a_{j1})_1{}^c \cap (a_{jp})_1{}^c, (a_{j2})_1{}^c \cap (a_{j3})_1{}^c, \dots, (a_{j2})_1{}^c \cap (a_{jp})_1{}^c, \dots, (a_{j(p-1)})_1{}^c \cap (a_{jp})_1{}^c\}$ such that $(a_{jk})_1{}^c \cap (a_{jl})_1{}^c \notin E_{j1}$.

Step 4(c): Finding Single-Valued Neutrosophic Score Functions For $j = 1, 2, \dots, m$, find single-valued neutrosophic score functions of E_{j1} and F_{j1} are defined as follows: $SVNSF(E_{j1}) = 1/3p[\sum_{i=1}^{p}[2 + \mu_{ji} - \sigma_{ji} - \gamma_{ji}]]$, and $SVNSF(F_{j1}) = 1/3q\ [\sum_{i=1}^{q}[2 + \mu_{ji} - \sigma_{ji} - \gamma_{ji}]]$, where q is the number of elements of F_{j1}. $SVNSF(A_j) = \{SVNSF(E_{j1})$, if $SVNSF(F_{j1}) = 0$. Otherwise, $1/2[\ SVNSF(E_{j1}) + SVNSF(F_{j1})\}$.

Step 4(d): Arrangement For $j = 1, 2, \dots, m$, arrange all the single-valued neutrosophic score function's values for the alternatives $A_1, A_2, \dots, A_m$ in ascending order.

Step 4(e): Repetition Repeat step 4 (a) to 4(d) for each sub problem of the corresponding region.

Step 4(f): Reverse Rank Tabulate all the reverse ranks $RR(A_j)$of the alternatives $A_1, A_2, \dots, A_m$ by giving ranks $1, 2, \dots, m-1, m$ in the ascending order to the alternatives for each regions $D_1, D_2, \dots, D_n$. Find the total reverse rank $TRR(A_j)$ of each alternatives A_j by using $TRR(A_j) = \sum_{j=1}^{n} RR(A_j)$, for each $j = 1, 2, \dots, m$.

Step 5: Decision of Sub Problems From the table of step 3(f) and step 4(f), calculate the rank difference from direct direction to reverse direction for each region. Decide the alternative with the highest positive value is the best alternative in that region and the alternative with the least value is the worst alternative in that region, here take 0 as positive.

Step 6: Determination For each $j = 1, 2, \dots, m$, calculate the values of $TDR(A_j) - TRR(A_j)$ from the table of step 3(f) and step 4(f). Arrange all these values in order as highest positive ≥ highest negative ≥ second-highest positive ≥ second-highest negative ≥ . . . ≥ least number, here take 0 as positive.

Step 7: Final Decision From the order arrangement of the values, decide the alternative which has the highest positive value is best alternative and the alternative of the highest negative value place in second and so on. The alternative with the least value is the worst alternative in the entire region.

4 The Summary of Process

The summary of the proposed process is demonstrated in the following figure1.

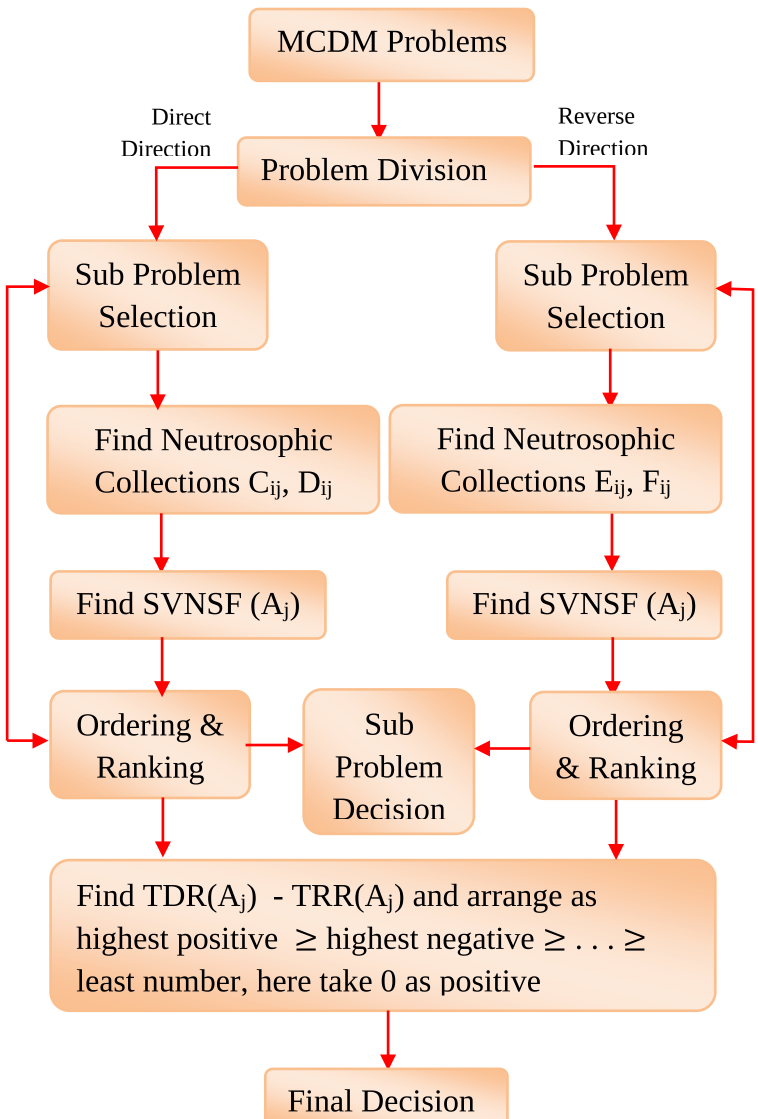

Figure.1 The summary of the proposed process

5 Numerical Examples in Multi-Criteria Decision-Making Problem

Agriculture has increased the volume of information available from modern technologies and comprises uncertainties in the increased yield and grain qualities of the plant hybridization. In the hybridization process, the difficult task is identifying the different hybrid plants with their quantity of yield under the environmental factors. This section demonstrates a agricultural problem for the effectiveness and applicability of the above-proposed approach.

Step 1: Problem Selection Consider the following table giving information about four kind of hybrid plants (alternatives) such as wheat P_1, grasses rice P_2, cotton P_3, and maize P_4 and three environmental factors (attributes) such as fertilizer B_1, water B_2, sunlight B_3 when farmers cultivated these plants in three different countries (regions) D_1, D_2, and D_3. We need to enquire which hybrid plant yield the high quantity in three environmental factors soil, water, and sunlight. The following table 2 shows the membership, the indeterminacy and the non-membership functions of hybrid plants P_1, P_2, P_3, and P_4 under environmental factors fertilizer B_1, water B_2, sunlight B_3. From table 2, we can observe that the hybrid *wheat* plant P_1 gives high yield $(\mu = 0.8, \sigma = 0.3, \gamma = 0.1)$ under the environmental factor *fertilizer* in the region D_1, but the hybrid *grasses rice* plant gives low yield $(\mu = 0.1, \sigma = 0.2, \gamma = 0.3)$ under the environmental factor *water* in region D_2.

Table 2 Problem Selection

D_1 Alternatives	Attributes		
	B_1	B_2	B_3
P_1	(0.8,0.3,0.1)	(0.7,0.2,0.1)	(0.5,0.4,0.3)
P_2	(0.9,0.1,0.1)	(0.6,0.1,0.2)	(0.7,0.3,0.1)
P_3	(0.7,0.2,0.3)	(0.1,0.2,0.9)	(0.2,0.6,0.1)
P_4	(0.6,0.1,0.4)	(0.4,0.4,0.4)	(0.2,0.3,0.4)
D_2 Alternatives	Attributes		
	B_1	B_2	B_3
P_1	(0.7,0.2,0.3)	(0.1,0.3,0.7)	(0.5,0.2,0.3)
P_2	(0.4,0.1,0.1)	(0.1,0.2,0.3)	(0.4,0.1,0.3)
P_3	(0.2,0.3,0.4)	(0.4,0.3,0.2)	(0.2,0.4,0.1)
P_4	(0.7,0.1,0.1)	(0.6,0.2,0.2)	(0.8,0.2,0.3)
D_3 Alternatives	Attributes		
	B_1	B_2	B_3
P_1	(0.6,0.1,0.2)	(0.7,0.2,0.2)	(0.7,0.3,0.1)
P_2	(0.9,0.1,0.1)	(0.2,0.3,0.1)	(0.8,0.6,0.1)
P_3	(0.8,0.2,0.6)	(0.3,0.4,0.1)	(0.6,0.5,0.4)
P_4	(0.7,0.4,0.3)	(0.4,0.6,0.1)	(0.2,0.4,0.5)

Step 2: Problem Division Here there are 3 regions D_1, D_2 and D_3, therefore divide the MCDM problem into 3 sub problems for each region as shown in table 3, table 4 and table 5.

Table 3 Sub Problem 1 for the country D_1

D_1 Alternatives	Attributes		
	B_1	B_2	B_3
P_1	(0.8,0.3,0.1)	(0.7,0.2,0.1)	(0.5,0.4,0.3)
P_2	(0.9,0.1,0.1)	(0.6,0.1,0.2)	(0.7,0.3,0.1)
P_3	(0.7,0.2,0.3)	(0.1,0.2,0.9)	(0.2,0.6,0.1)
P_4	(0.6,0.1,0.4)	(0.4,0.4,0.4)	(0.2,0.3,0.4)

Table 4 Sub Problem 2 for the country D_2

D_2 Alternatives	Attributes		
	B_1	B_2	B_3
P_1	(0.7,0.2,0.3)	(0.1,0.3,0.7)	(0.5,0.2,0.3)
P_2	(0.4,0.1,0.1)	(0.1,0.2,0.3)	(0.4,0.1,0.3)
P_3	(0.2,0.3,0.4)	(0.4,0.3,0.2)	(0.2,0.4,0.1)
P_4	(0.7,0.1,0.1)	(0.6,0.2,0.2)	(0.8,0.2,0.3)

Table 5 Sub Problem 3 for the country D_3

D_3 Alternatives	Attributes		
	B_1	B_2	B_3
P_1	(0.6,0.1,0.2)	(0.7,0.2,0.2)	(0.7,0.3,0.1)
P_2	(0.9,0.1,0.1)	(0.2,0.3,0.1)	(0.8,0.6,0.1)
P_3	(0.8,0.2,0.6)	(0.3,0.4,0.1)	(0.6,0.5,0.4)
P_4	(0.7,0.4,0.3)	(0.4,0.6,0.1)	(0.2,0.4,0.5)

Step 3: Direct Direction

Step 3(a): Sub Problem Selection Select the sub problem1 for the corresponding country D_1.

Step 3(b): Neutrosophic Operations

i. $C_{11} = \{(0.8,0.3,0.1), (0.7,0.2,0.1), (0.5,0.4,0.3)\}$ and $D_{11} = \{(0.8,0.4,0.1), (0.7,0.4,0.1)\}$.

ii. $C_{21} = \{(0.9,0.1,0.1), (0.6,0.1,0.2), (0.7,0.3,0.1)\}$ and $D_{21} = \{(0.9,0.3,0.1)\}$.

iii. $C_{31} = \{(0.7,0.2,0.3), (0.1,0.2,0.9), (0.2,0.6,0.1)\}$ and $D_{31} = \{(0.7,0.6,0.1)\}$.

iv. $C_{41} = \{(0.6,0.1,0.4), (0.4,0.4,0.4), (0.2,0.3,0.4)\}$ and $D_{41} = \{(0.6,0.4,0.4), (0.6,0.3,0.4)\}$.

Step 3(c): Finding Single-Valued Neutrosophic Score Functions

The single-valued neutrosophic score functions (shortly SVNSF) of C_{j1} and D_{j1} are defined as follows:

i. SVNSF (C_{11}) = 0.7333, SVNSF (D_{11}) = 0.75, where q = 2. SVNSF (P_1) = 0.7417.

ii. SVNSF (C_{21}) = 0.8111, SVNSF (D_{21}) = 0.8333, where q = 1. SVNSF (P_2) =0.8222.

iii. SVNSF (C_{31}) = 0.5222, SVNSF (D_{31}) = 0.6667, where q = 1. SVNSF (P_3) = 0.5945.

iv. SVNSF (C_{41}) = 0.5667, SVNSF (D_{41}) = 0.6167, where q = 2. SVNSF (P_4) = 0.5917.

Step 3(d): Arrangement $P_2 \geq P_1 \geq P_3 \geq P_4$.

Step 3(e): Repetition

Step 3e1(a): Sub Problem Selection Select the sub problem 2 to find the best alternatives for the corresponding country D_2.

Step 3e1(b): Neutrosophic Operations

i. $C_{12} = \{(0.7,0.2,0.3), (0.1,0.3,0.7), (0.5,0.2,0.3)\}$ and $D_{12} = \{(0.7,0.3,0.3), (0.5,0.3,0.3)\}$.

ii. $C_{22} = \{(0.4,0.1,0.1), (0.1,0.2,0.3), (0.4,0.1,0.3)\}$ and $D_{22} = \{(0.4,0.2,0.1), (0.4,0.2,0.3)\}$.

iii. $C_{32} = \{(0.2,0.3,0.4), (0.4,0.3,0.2), (0.2,0.4,0.1)\}$ and $D_{32} = \{(0.4,0.4,0.1)\}$.

iv. $C_{42} = \{(0.7,0.1,0.1), (0.6,0.2,0.2), (0.8,0.2,0.3)\}$ and $D_{42} = \{(0.7,0.2,0.1), (0.8,0.2,0.1), (0.8,0.2,0.2)\}$.

Step 3e1(c): Finding Single-Valued Neutrosophic Score Functions

The single-valued neutrosophic score functions of C_{j2} and D_{j2} are defined as follows:

i. SVNSF (C_{12}) = 0.5889, SVNSF (D_{12}) = 0.6667, where q = 2. SVNSF (P_1) = 0.6278.

ii. SVNSF (C_{22}) = 0.6444, SVNSF (D_{22}) = 0.6667, where q = 2. SVNSF (P_2) =0.6555.

iii. SVNSF (C_{32}) = 0.5667, SVNSF (D_{32}) = 0.6333, where q = 1. SVNSF (P_3) = 0.6.

iv. SVNSF (C_{42}) = 0.7778, SVNSF (D_{42}) = 0.8111, where q = 3. SVNSF (P_4) = 0.7389.

Step 3e1(d): Arrangement $P_4 \geq P_2 \geq P_1 \geq P_3$.

Step 3e: Repetition

Step 3e2(a): Sub Problem Selection Select the sub problem 3 to find the best alternatives for the corresponding country D_3.

Step 3e2(b): Neutrosophic Operations

i. $C_{13} = \{(0.6,0.1,0.2), (0.7,0.2,0.2), (0.7,0.3,0.1)\}$ and $D_{13} = \emptyset$.

ii. $C_{23} = \{(0.9,0.1,0.1), (0.2,0.3,0.1), (0.8,0.6,0.1)\}$ and $D_{23} = \{(0.9,0.3,0.1), (0.9,0.6,0.1)\}$.

iii. $C_{33} = \{(0.8,0.4,0.1), (0.3,0.4,0.1), (0.6,0.5,0.4)\}$ and $D_{33} = \{(0.8,0.4,0.1), (0.8,0.5,0.4)(0.6,0.5,0.1)\}$.

iv. $C_{43} = \{(0.7,0.4,0.3), (0.4,0.6,0.1), (0.2,0.4,0.5)\}$ and $D_{43} = \{(0.7,0.6,0.1)\}$.

Step 3e2(c): Finding Single-Valued Neutrosophic Score Functions

The single-valued neutrosophic score functions (shortly SVNSF) of C_{j3} and D_{j3} are defined as follows:

i. SVNSF (C_{13}) = 0.7667, SVNSF (D_{13}) = 0, where q = 0. SVNSF (P_1) = 0.3834.

ii. SVNSF (C_{23}) = 0.7333, SVNSF (D_{23}) = 0.7833, where q = 2. SVNSF (P_2) =0.7583.

iii. SVNSF (C_{33}) = 0.6222, SVNSF (D_{33}) = 0.6889, where q = 3. SVNSF (P_3) = 0.6556.

iv. SVNSF (C_{43}) = 0.5556, SVNSF (D_{43}) = 0.6667, where q = 1. SVNSF (P_4) = 0.6112.

Step 3e2(d): Arrangement $P_2 \geq P_3 \geq P_4 \geq P_1$.

Step 3(f): Direct Rank The following table 6 tabulates all the rank $DR(P_j)$ of the alternatives P_1, P_2, P_3, P_4 in ascending order for the regions D_1, D_2, D_3.

Table 6 Direct Rank Table

Country	Alternatives			
	P_1	P_2	P_3	P_4
D_1	3	4	2	1
D_2	2	3	1	4
D_3	1	4	3	2
$\mathrm{TDR}(\mathrm{P_j}) = \sum \mathrm{DR}(\mathrm{P_j})$	6	11	6	7

Step 4: Reverse Direction

Step 4(a): Sub Problem Selection Select the sub problem 1 for the corresponding country D_1.

Step 4(b): Neutrosophic Operations

i. $E_{11} = \{(0.2,0.7,0.9),(0.3,0.8,0.9),(0.5,0.6,0.7)\}$ and $F_{11} = \{(0.2,0.6,0.9),(0.3,0.6,0.9)\}$.

ii. $E_{21} = \{(0.1,0.9,0.9),(0.4,0.9,0.8),(0.3,0.7,0.9)\}$ and $F_{21} = \{(0.1,0.7,0.9)\}$.

iii. $E_{31} = \{(0.3,0.8,0.7),(0.9,0.8,0.1),(0.8,0.4,0.9)\}$ and $F_{31} = \{(0.3,0.4,0.9)\}$.

iv. $E_{41} = \{(0.4,0.9,0.6),(0.6,0.6,0.6),(0.8,0.7,0.6)\}$ and $F_{41} = \{(0.4,0.6,0.6),(0.4,0.7,0.6)\}$.

Step 4(c): Finding Single-Valued Neutrosophic Score Functions

The single-valued neutrosophic score functions of E_{j1} and F_{j1} are defined as follows:

i. SVNSF (E_{11}) = 0.2667, SVNSF (F_{11}) = 0.25, where q = 2. SVNSF (P_1) = 0.2584.

ii. SVNSF (E_{21}) = 0.1889, SVNSF (F_{21}) = 0.1667, where q = 1. SVNSF (P_2) =0.1778.

iii. SVNSF (E_{31}) = 0.4778, SVNSF (F_{31}) = 0.3333, where q = 1. SVNSF (P_3) = 0.4056.

iv. SVNSF (E_{41}) = 0.3556, SVNSF (F_{41}) = 0.3833, where q = 2. SVNSF (P_4) = 0.3695.

Step 4(d): Arrangement $P_3 \geq P_4 \geq P_1 \geq P_2$.

Step 4(e): Repetition

Step 4e1(a): Sub Problem Selection Select the sub problem 2 for the corresponding country D_2.

Step 4e1(b): Neutrosophic Operations

i. $E_{12} = \{(0.3,0.8,0.7), (0.9,0.7,0.3), (0.5,0.8,0.7)\}$ and $F_{12} = \{(0.3,0.7,0.7), (0.5,0.7,0.7)\}$.

ii. $E_{22} = \{(0.6,0.9,0.9), (0.9,0.8,0.7), (0.6,0.9,0.7)\}$ and $F_{22} = \{(0.6,0.8,0.9), (0.6,0.8,0.7)\}$.

iii. $E_{32} = \{(0.8,0.7,0.6), (0.6,0.7,0.8), (0.8,0.6,0.9)\}$ and $F_{32} = \{(0.6,0.6,0.9)\}$.

iv. $E_{42} = \{(0.3,0.9,0.9), (0.4,0.8,0.8), (0.2,0.8,0.7)\}$ and $F_{42} = \{(0.3,0.8,0.9), (0.2,0.8,0.9), (0.2,0.8,0.8)\}$.

Step 4e1(c): Finding Single-Valued Neutrosophic Score Functions

The single-valued neutrosophic score functions of E_{j2} and F_{j2} are defined as follows:

i. SVNSF (E_{12}) = 0.4111, SVNSF (F_{12}) = 0.3333, where q = 2. SVNSF (P_1) = 0.3722.

ii. SVNSF (E_{22}) = 0.3556, SVNSF (F_{22}) = 0.3333, where q = 2. SVNSF (P_2) =0.3445.

iii. SVNSF (E_{32}) = 0.4333, SVNSF (F_{32}) = 0.3667, where q = 1. SVNSF (P_3) = 0.4.

iv. SVNSF (E_{42}) = 0.2222, SVNSF (F_{42}) = 0.1889, where q = 3. SVNSF (P_4) = 0.2056.

Step 4e1(d): Arrangement $P_3 \geq P_1 \geq P_2 \geq P_4$.

Step 4(e): Repetition

Step 4e2(a): Sub Problem Selection Select the sub problem 3 for the corresponding country D_3.

Step 4e2(b): Neutrosophic Operations

i. $E_{13} = \{(0.4,0.9,0.8), (0.3,0.8,0.8), (0.3,0.7,0.9)\}$ and $F_{13} = \emptyset$.

ii. $E_{23} = \{(0.1,0.9,0.9), (0.8,0.7,0.9), (0.2,0.4,0.9)\}$ and $F_{23} = \{(0.1,0.7,0.9), (0.1,0.4,0.9)\}$.

iii. $E_{33} = \{(0.2,0.6,0.9), (0.7,0.6,0.9), (0.4,0.5,0.6)\}$ and $F_{33} = \{(0.2,0.6,0.9), (0.2,0.5,0.6), (0.4,0.5,0.9)\}$.

iv. $E_{43} = \{(0.3,0.6,0.7), (0.6,0.4,0.9), (0.8,0.6,0.5)\}$ and $F_{43} = \{(0.3,0.4,0.9)\}$.

Step 4e2(c): Finding Single-Valued Neutrosophic Score Functions

The single-valued neutrosophic score functions of E_{j3} and F_{j3} are defined as follows:

i. SVNSF (E_{13}) = 0.2333, SVNSF (F_{13}) = 0, where q = 0. SVNSF (P_1) = 0.1167.

ii. SVNSF (E_{23}) = 0.2667, SVNSF (F_{23}) = 0.05, where q = 2. SVNSF (P_2) =0.1584.

iii. SVNSF (E_{33}) = 0.3889, SVNSF (F_{33}) = 0.3511, where q = 3. SVNSF (P_3) = 0.37.

iv. SVNSF (E_{43}) = 0.4444, SVNSF (D_{43}) = 0.3333, where q = 1. SVNSF (P_4) = 0.3889.

Step 4e2(d): Arrangement $P_4 \geq P_3 \geq P_2 \geq P_1$.

Step 4(f): Reverse Rank The following table 7 tabulates all the rank R$R(P_j)$ of the alternatives P_1, P_2, P_3, P_4 in ascending order for the regions D_1, D_2, D_3.

Table 7 Reverse Rank Table

Country	Alternatives			
	P_1	P_2	P_3	P_4
D_1	2	1	4	3
D_2	3	2	4	1
D_3	1	2	3	4
$TRR(P_j) = \sum RR(P_j)$	6	5	11	8

Step 5(1): Decision of Sub Problem 1 From the table of step 3(f) and step 4(f), the rank difference of P_1, P_2, P_3, and P_4 from direct direction to reverse direction for each region are respectively $1, 3, -2$, and -2. Therefore for the country D_1, the best yield is given by the hybrid plant grasses rice, and the worst hybrid plant is wheat. The hybrid cotton and maize plants gives an equal quantity of yield.

Step 5(2): Decision of Sub Problem 2 The rank difference of P_1, P_2, P_3, and P_4 from direct direction to reverse direction for each region is respectively $-1, 1, -3$, and 3. Therefore for the country D_2, the best hybrid plant is maize. The second and third best yields are respectively given by the hybrid plants cotton and grasses rice. The hybrid wheat plant is the worst hybrid plant.

Step 5(3): Decision of Sub Problem 3 The rank difference of P_1, P_2, P_3, and P_4 from direct direction to reverse direction for each region is respectively $0, 2, 0$, and -2. Therefore for the country D_3, the best yield is given by the hybrid grasses rice plant and the second-best yield hybrid plant is maize. The lowest yield is given by the hybrid plants wheat and cotton which are giving an equal quantity of yield.

Step 6: Determination From tables 6 and 7, $TDR(P_1) - TRR(P_1) = 0$, $TDR(P_2) - TRR(P_2) = 6$, $TDR(P_3) - TRR(P_3) = -5$, $TDR(P_4) - TRR(P_4) = -1$ and here $P_2 \geq P_3 \geq P_1 \geq P_4$.

Step 7: Final Decision For the entire region, the best yield hybrid plant is grasses rice, and the worst yield hybrid plant is maize. The second-best yield hybrid plant is cotton and the hybrid wheat plant is the third-best yield plant.

6 Results and Discussion

This section analysis the result of the above problem for the proposed method.

i. From the decision of sub problems, the high quantity of yield for the countries $D_1$and D_3 are given by the hybrid plant grasses rice but the high quantity of yield for the country D_2 is given by the hybrid plant maize. That is the best yield hybrid plant for the countries D_1 and D_3 are grasses rice, but the best yield hybrid plant for the country D_2 is maize.

ii. The worst yield hybrid plant for the countries D_1 and D_2 is wheat, but the lowest yield for the country D_3 is given by the hybrid plants wheat and cotton.
iii. The hybrid cotton and maize plants give the second quantity of yield for the country D_1. The second and third quantities of yield for the country D_2 are given by the hybrid plants cotton and grasses rice. For the country D_3, the second yield hybrid plant is maize.
iv. From the observations the result of the country D_1 maybe not same for the countries D_2 and D_3. That is, the result varies from country to country.
v. Therefore for the entire region, the best yield hybrid plant is grasses rice and the worst yield hybrid plant is maize. The second yield hybrid plant is cotton and the hybrid wheat plant is the third quantity plant.

7 Limitations and Advantages

This section states some limitations and advantages of the proposed method.

i. The novelty of the present work is the first method to solve the plant hybridization problem in the neutrosophic environment.
ii. This method is new, because it uses only single-valued neutrosophic score functions (SVNSF) with single valued neutrosophic numbers in both direct and reverse directions to find the best alternatives in each and entire regions.
iii. It considers the neutrosophic sets and their unions from multi-criteria decision-making (MCDM) problems in the direct direction. The complements of these neutrosophic sets and their intersections are considered in the reverse direction.
iv. The proposed method divides the MCDM problems into small sub problems for the corresponding region.
v. From each sub problems, this method can find the best alternatives in each corresponding region. This is one of the advantages of this method.
vi. The proposed method can always find the best alternatives if the MCDM problem has only one region. This is another advantage. This new method in the MCDM problem does not use any similarity measures such as cosine similarity measures [23], tangent similarity measures [21], cotangent similarity measures [25], distance functions such as Euclidean distances [19], hamming distance [24], rank matrices [34], etc.
vii. This method needs single-valued neutrosophic sets and single valued neutrosophic score function [19]. Hence this method will be applicable in many real-life situations.
viii. This new method gives the same result of [36] even though not using neutrosophic distance functions, similarity measures.
ix. My previous method [35] funded the patients (alternatives) with their caused disease (alternatives), but the present method is an extension of the previous work. Here the method deals with plant hybridization problems in the neutrosophic environment to find the best and the worst alternatives not only in each region, but also in entire regions.
x. The decision of the proposed method has equally consistent, dependable, and reliable and the method may also be suitable for a large amount of data.

8 Future and Summary of work

This section discusses the future and summary of the proposed method.

i. Neutrosophic set theory is a new structure considering three independent membership functions to deal with the concept of incompleteness, uncertainty, and vagueness. The method of multi-criteria decision-making (MCDM) problem is an important key in the existence of multiple criteria and alternatives in solving sophisticated and complicated decision problems.
ii. This chapter derived a new neutrosophic method in multi-criteria decision-making problems to find the best alternatives in each and entire regions under the neutrosophic environment.
iii. This method considered neutrosophic sets with their unions and the complements with their intersections.
iv. The single-valued neutrosophic score functions are computed to find the best alternatives not only in each region but also in the entire region.
v. This chapter solved the plant hybridization problem as a real-life application of neutrosophic set theory to demonstrate the effectiveness of the proposed method.
vi. The present methodology may further be applied in content-based image retrieval (CBIR), dimensionality reduction in dimensional space, multimedia databases, manufacturing systems, personal selection in academia, project evaluation, supply chain management.
vii. The proposed method can alternatively be used for other multi-criteria decision-making methods such as ELECTRE, DEMTEL, PROMOTEE, TOPSIS, VIKOR methods.
viii. The techniques of this method may also be applied in fuzzy and intuitionistic fuzzy environments.

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