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Research Paper

Determination of Priority Structure through Fuzzy AHP-TOPSIS Approach in Agricultural Sector: A Comparative Study

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Abstract— The real life situation of finding an optimal crop production under conflicting criteria is uncertain, imprecise, and vague which makes it necessary to introduce fuzziness. TOPSIS is a well-known technique that has enhanced the accuracy for prioritizing the alternatives. Here the author uses the multi-criteria decision-making (MCDM) technique that includes the fuzzy TOPSIS technique and analytic hierarchy process employing triangular fuzzy numbers. This paper demonstrates the application of fuzzy AHP-TOPSIS for finding the priority of crops and obtaining the weight of the different criteria in linguistic terms which in turn proves to be very easy and involves minimal calculation. At present, there are many methods to find the priorities but one major drawback of these methods were that the methods are tedious to do. This paper proposes to saturate the mathematical calculation as much as possible and at the same time achieve the desired priority for the optimal solution. The author used a technique that combines the fuzzy analytic hierarchy process with the fuzzy TOPSIS. The result of this study could also serve as a guide for decision-makers in the agricultural sector. Later we consider the work done by Pal and Biswas, Mishra, and Singh to verify and compare the ranking and claim that the ranking of crops is almost the same thereby same profit, but the calculation done was easy to understand and less time taking.

Keywords— MCDM, AHP-TOPSIS, Linguistic Variable, Weighted priority, Fuzzy goal programming

1. Introduction

A huge portion of India's economy highly depends upon the agricultural sector, therefore becomes very important to have an optimal selection of crops. In almost decision-making problems, the decision maker stuck between the multiplicity and complexity of criteria for choosing the alternatives. Multiple criteria decision-making (MCDM) is the most traditional tool for solving such issues. But in classical methods, the weight of the criteria is known precisely and they are crisp in nature. Hwang and Yoon were the first to introduce the concept of TOPSIS to solve the MCDM problem [1][2]. But in real life, crisp data fall inadequate and imprecise therefore it become difficult to priorities given data with an exact numerical value. Zadeh and Zimmermann were the ones who came up with a theory called fuzzy set theory [3][4]. Chen further worked over the concept of TOPSIS and extended it to a fuzzy environment [5]. Bellman gave decision-making in fuzzy environment which was a revolution in this direction [6]. Lin in his work provides an improved extension of this concept [7]. In the passing year, many authors came up with applications of TOPSIS in various fields[8][9]. Also in different environments like intuitionistic fuzzy, AHP-TOPSIS is used as a decision-making tool [10][11][12]. Later a more realistic approach came into view which uses linguistic assessment in place of numerical values which has been discussed in papers [13][14][15]. It was T. L. Saaty, who introduced the concept of analytic hierarchy process (AHP) which breaks down a compound MCDM problem into a system of hierarchies with the help of fundamental scale [16][17][18]. This concept aims to compute the weight of each criterion in a linguistic term. Recently many authors worked on the concept of AHP-TOPSIS in different atmospheres [19]. A purview and inter-relation of fuzzy sets and their extension.

The paper here is briefed into the following five sections. Section I contains the introduction which consists of a literature review of the work done, and section II contains the related work going in this way. In section III, the preliminaries or the definitions which will be used by the author throughout the work are given. In section 3, the methodology of AHP-TOPSIS has been explained briefly. In section 4, a numerical illustration is given which validates the methodology with the existing methods and helps in giving comparisons with other results. Section 5 describes the section of the paper which includes results and a discussion of the work. Lastly, section VI, ends up with the conclusion and future scope.

2. Related Work

In the year 2020, M. Mathew et.al presented a paper in a conference where they gave an application of interval type-2 fuzzy AHP-TOPSIS [20]. In recent years, Garg and Kaur extended TOPSIS for group decision making in cubic intuitionistic environment [21]. Selvaraj and Majumdar, uses TOPSIS in solving multi-criteria decision-making problem with parameters from interval-valued intuitionistic fuzzy environment [22]. Marzouk et al. and James et al. gives an important application of AHP-TOPSIS which signifies the weightage of this concept [23],[24]. In the year 2021, Jaydip Bhattacharya gave some operations on intuitionistic fuzzy sets and K. Fatma applied multi criteria decision analysis to determine the suitability of crops [25][26]. Krzysztof presented a paper in which he explains various application of fuzzy TOPSIS in the last decade which firmly include all application of this concept in all possible direction [27]. Recently, Zulqarnain uses TOPSIS to select the medical clinic for disease diagnosis which shows its applicability in the medical sector as well [28]. In the year 2022, a purview and inter-relation of fuzzy sets and their various extension have been given by B. Mishra in her work [29].

3. Theory

3.1 Preliminaries

In this section, we explicitly explain some of the standard definitions and notations of fuzzy systems from Chen which have been used by the author to accomplish the work [5] .

3.1.1 "Definition: Fuzzy set

Let X be a universe of discourse then $\tilde{A}$, is called fuzzy set if it is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associate with each element x in X a real number from $[0\ 1]$. This function is known as the membership function."

3.1.2 "Definition: Convex Fuzzy set

A fuzzy set $\tilde{A}$ is called convex iff for all x_1, x_2 in X,

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2), \text{where } \lambda \in [0\ 1]".$$

3.1.3 "Definition: Normal Fuzzy set

A fuzzy set $\tilde{A}$ is called normal if $\exists\, x_i \in X,\ \mu_{\tilde{A}}(x_i) = 1$."

3.1.4 "Definition: Fuzzy Number

A fuzzy number is a subset of universe X, which is both convex and normal."

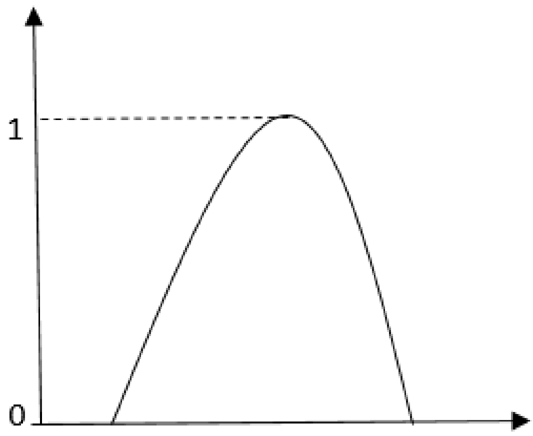

Fig 1. A fuzzy number

Fig 1 illustrates an example of a fuzzy number where horizontal line represent domain of discourse and vertical line represent the grade of membership.

3.1.5 "Definition: Triangular Fuzzy Number

A triangular fuzzy number $\tilde{x}$ denoted as (a, b, c) whose membership function is defined as

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-a}{b-a}, a \leq x \leq b \\ \frac{x-c}{b-c}, b \leq x \leq c \\ 0,\ otherwise \end{cases}"$$

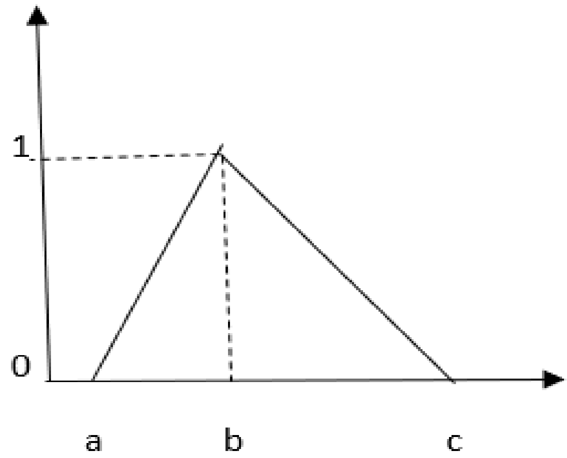

Fig 2. Triangular fuzzy number

Figure 2 illustrates triangular fuzzy number (a,b,c) where (a,b) is the left spread, (b,c) is the right spread and b is the modal value

3.1.6 "Definition: Distance between two Triangular Fuzzy Numbers

Let $x_1 = (a_1, b_1, c_1)\ and\ x_2 = (a_2, b_2, c_2)$ be two fuzzy numbers then the distance between x_1 and x_2 is defined as

$$d(x_1, x_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2)]}"$$

"Property 1: If $\widetilde{x_1}$ and $\widetilde{x_2}$ are real numbers, then the distance $d(\widetilde{x_1}, \widetilde{x_2})$ is identical to the Euclidean distance."

"Property 2: If $\widetilde{x_1}$ and $\widetilde{x_2}$ are two triangular fuzzy numbers, then they are identical if and only if $d(\widetilde{x_1}, \widetilde{x_2}) = 0$."

The methodology used in this work is of AHP-TOPSIS under the fuzzy environment given by Chen [5]. The definitions and procedure of fuzzy AHP-TOPSIS are illustrated below

4. Procedure

4.1 TOPSIS (Technique for order preference by similarity to ideal solution)

Yoon and Hwang were the ones who first developed this technique. The fundamental premise underlying the method is that the best alternative is selected from a range of possible alternatives based on how close it is to the ideal option. The optimal solution is closest to the positive ideal solution and farthest from the negative ideal solution.

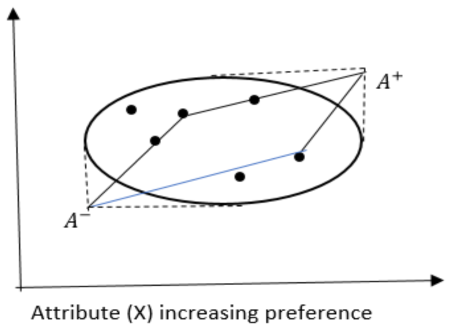

Fig. 3. Basic concept of TOPSIS method

Figure 3 gives a geometrical interpretation of the idea where black dots represent different alternatives. Here we calculate the distance of each alternative from a positive and negative ideal solution

4.2. Linguistic variable

The TOPSIS technique can be extended to a fuzzy environment by describing the weights of the criteria and ratings as linguistic variables. In dealing with situations that are excessively complex or multicriteria decision-making problems where the criteria are intangible, the concept of linguistic variables is extremely helpful.

According to Chen [5], the linguistic variables can be expressed in triangular fuzzy number as given in Tables 1&2.

Table.1. Linguistic for the importance weight of each criterion

Very low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium Low (ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium High (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1.0)
Very High (VH)	(0.9,1.0,1.0)

Table. 2. Linguistic variable for ratings

Very poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very good (VG)	(9,10,10)

4.3 Analytic Hierarchy Process (AHP)

The complex multi-criteria decision-making problem can be decomposed into a system of hierarchies based on analytic hierarchy process (AHP). The procedure outlined by Saaty [18] signifies the importance of each criterion on a scale of 1-9 given in the table.3

When the author tries to estimate dominance in making comparisons between the criterion instead of using two numbers from the scale, we assign a single number from the fundamental scale of the absolute numbers shown in Table 3.

Table 3. Fundamental scale

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally
3	Moderate Importance	Judgment slightly favors one activity over another
5	Strong Importance	Judgment strongly favors one activity over another
7	Very Strong	Judgment very strongly favored over another
9	Extreme Importance	One judgment has the highest dominance over the other

Note- Intensity 2,4,6,8 takes intermediate value while comparing activity i over j.

4.4 Calculation algorithm for AHP-TOPSIS

(i) Initially an evaluation matrix $A_{m\times n}$ is proposed which represents the comparision among n criteria.

(ii) Construction of normalized fuzzy decision matrix denoted by $\tilde{A}$ which follows the linear normalization formula given as

"$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$ where $j \in$ set of non − benefit criteria"

"$\widetilde{r_{ij}} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right)$ where $j \in$ set of non − benefit criteria"

Here $c_j^* = max_i c_{ij}$ and $a_j^- = min_i a_{ij}$

(iii) Now we construct weighted normalized fuzzy decision matrix as $\tilde{V} = [\widetilde{v_{ij}}]_{m\times n}$ where

" $\widetilde{v_{ij}} = \widetilde{r_{ij}}(.)\widetilde{w_j}$"

(iv) Now we determine the fuzzy positive ideal solution and fuzzy negative ideal solution as

$$A^+ = (\widetilde{v_1^+}, \widetilde{v_2^+}, \widetilde{v_3^+}, \dots, \widetilde{v_m^+})$$
$$A^- = (\widetilde{v_1^-}, \widetilde{v_2^-}, \widetilde{v_3^-}, \dots, \widetilde{v_m^-})$$

Where

$$\widetilde{v_j^+} = (1,1,1) \text{ and } \widetilde{v_j^-} = (0,0,0),$$

$j = 1,2 \dots, n$

(v) Initially an evaluation matrix $A_{m\times n}$ is proposed which represents the comparision among n criteria.

(vi) Construction of normalized fuzzy decision matrix denoted by $\tilde{A}$ which follows the linear normalization formula given as

"$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$ where $j \in$ set of non − benefit criteria"

"$\widetilde{r_{ij}} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right)$ where $j \in$ set of non − benefit criteria"

Here $c_j^* = max_i c_{ij}$ and $a_j^- = min_i a_{ij}$

(vii) Initially an evaluation matrix $A_{m\times n}$ is proposed which represents the comparision among n criteria.

(viii) Construction of normalized fuzzy decision matrix denoted by $\tilde{A}$ which follows the linear normalization formula given as

"$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$ where $j \in$ set of non − benefit criteria"

"$\widetilde{r_{ij}} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right)$ where $j \in$ set of non − benefit criteria"

Here $c_j^* = max_i c_{ij}$ and $a_j^- = min_i a_{ij}$

(ix) Now we construct weighted normalized fuzzy decision matrix as $\tilde{V} = [\widetilde{v_{ij}}]_{m\times n}$ where

" $\widetilde{v_{ij}} = \widetilde{r_{ij}}(.)\widetilde{w_j}$"

(x) Now we determine the fuzzy positive ideal solution and fuzzy negative ideal solution as

$$A^+ = (\widetilde{v_1^+}, \widetilde{v_2^+}, \widetilde{v_3^+}, \dots, \widetilde{v_m^+})$$
$$A^- = (\widetilde{v_1^-}, \widetilde{v_2^-}, \widetilde{v_3^-}, \dots, \widetilde{v_m^-})$$

Where

$$\widetilde{v_j^+} = (1,1,1) \text{ and } \widetilde{v_j^-} = (0,0,0),$$
$$j = 1,2 \dots, n$$

(xi) Now we calculate the separation measure of each alternatives from positive ideal solution and negative ideal solution respectively.

"$d_i^+ = \sum_{j=1}^{n} d\left(\widetilde{v_{ij}}, \widetilde{v_j^+}\right), \quad i = 1,2 \dots, m$"

"$d_i^- = \sum_{j=1}^{n} d\left(\widetilde{v_{ij}}, \widetilde{v_j^-}\right), \quad i = 1,2 \dots, m$"

Here d is the distance between two fuzzy numbers.

(xii) Finally, the closeness coefficient to ideal solution is calculated which helps to find out the ranking between the alternatives.

"$cc_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad i = 1,2 \dots., m$"

5. Result and Discussion

5.1 Result

5.1.1 Numerical Illustration

For validating the methodology, we consider the numerical taken by Pal and Biswas [30] and apply AHP-TOPSIS.
The alternatives in the MCDM problem are

1. Jute
2. Sugarcane
3. Rice
4. Wheat
5. Mustard
6. Potato

We have 8 different conflicting criteria' which were divided into benefit and non-benefit criteria. The benefit criteria are

1. land utilization
2. Production
3. Profit

and non-benefit criteria are

4. Water consumption
5. Fertilizer requirement
6. Machine hour
7. Man days
8. Cash expenditure

Firstly, we construct the pairwise comparison matrix and then intend to find the weight of the criteria, that is, the eigen vector, according to Saaty [18], which is given in table.4 and table.5 respectively.

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Table.4 Comparison matrix of the criteria

	C^1	C^2	C^3	C^4	C^5	C^6	C^7	C^8
C^1	1	1	0.33	3	5	4	6	8
C^2	1	1	0.5	5	6	7	6	8
C^3	3	2	1	7	5	8	4	3
C^4	0.33	0.2	0.14	1	0.25	0.17	7	5
C^5	0.2	0.17	0.2	4	1	3	5	7
C^6	1.25	0.14	0.13	6	0.33	1	6	4
C^7	0.17	0.17	0.25	0.14	0.2	0.17	1	9
C^8	0.13	0.13	0.33	0.2	0.14	0.25	0.11	1

Table.5 Eigen vector-criteria's weight

C^1	C^2	C^3	C^4	C^5	C^6	C^7	C^8
0.175	0.215	0.290	0.064	0.096	0.083	0.05	0.027

Now with the help of table.1 we will rank the criteria weight in linguistic term and represent each as a triangular fuzzy number which is illustrated in table-6. Also, with the help of table.2, we also represent decision matrix in linguistic term which is given in table 7.

Table-6..linguistic and fuzzy weight

Criteria	Linguistic rank	Fuzzy weight
C^1	MH	(0.5,0.7,0.9)
C^2	H	(0.7,0.9,1)
C^3	VH	(0.9,1,1)
C^4	L	(0,0.1,0.3)
C^5	M	(0.3,0.5,0.7)
C^6	ML	(0.1,0.3,0.5)
C^7	L	(0,0.1,0.3)
C^8	VL	(0,0,0.1)

Table-7. Decision matrix in linguistic term

	C^1	C^2	C^3	C^4	C^5	C^6	C^7	C^8
X_1	G	G	MG	MP	VG	F	F	MG
X_2	P	F	VG	F	MP	G	MP	MP
X_3	VG	VG	MG	F	MG	MG	MG	MG
X_4	F	MG	F	G	F	VG	G	G
X_5	MG	P	G	VG	G	VG	VG	VG
X_6	MP	MP	MP	MG	MP	VG	F	F

Finally fuzzy decision matrix with fuzzy weight is given in table.8

Table-8. Fuzzy decision matrix with fuzzy weight

	C^1	C^2	C^3	C^4
Weight	(0.5,0.7,0.9)	(0.7,0.9,1)	(0.9,1,1)	(0,0.1,0.3)
X_1	(7,9,10)	(7,9,10)	(5,7,9)	(1,3,5)
X_2	(0,1,3)	(3,5,7)	(9,10,10)	(3,5,7)
X_3	(9,10,10)	(9,10,10)	(5,7,9)	(3,5,7)
X_4	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,10)
X_5	(5,7,9)	(0,1,3)	(7,9,10)	(9,10,10)
X_6	(1,3,5)	(1,3,5)	(1,3,5)	(5,7,9)

	C^5	C^6	C^7	C^8
Weight	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0,0.1,0.3)	(0,0,0.1)
X_1	(9,10,10)	(3,5,7)	(3,5,7)	(5,7,9)
X_2	(1,3,5)	(7,9,10)	(1,3,5)	(1,3,5)
X_3	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
X_4	(3,5,7)	(9,10,10)	(7,9,10)	(7,9,10)
X_5	(7,9,10)	(9,10,10)	(9,10,10)	(9,10,10)
X_6	(1,3,5)	(9,10,10)	(3,5,7)	(3,5,7)

Now in order to obtain the ranking of alternatives (crops) to achieve optimal profit we apply AHP- TOPSIS (from step 1 to 6) over table.8. Applying step-2 we found fuzzy normalized decision matrix which is given in table-9.

Table-9- Normalized Fuzzy Decision Matrix

	C^1	C^2	C^3	C^4
X_1	(0.7,0.9,1)	(0.7,0.9,1)	(0.5,0.7,0.9)	(0.2,0.33,1)
X_2	(0,0.1,0.3)	(0.3,0.5,0.7)	(0.9,1,1)	(0.14,0.2,0.33)
X_3	(0.9,1,1)	(0.9,1,1)	(0.5,0.7,0.9)	(0.14,0.2,0.33)
X_4	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.1,0.11,0.14)
X_5	(0.5,0.7,0.9)	(0,0.1,0.3)	(0.7,0.9,1)	(0.1,0.1,0.11)
X_6	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.11,0.14,0.2)

	C^5	C^6	C^7	C^8
X_1	(0.1,0.1,0.11)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(0.11,0.14,0.2)
X_2	(0.2,0.33,1)	(0.1,0.11,0.14)	(0.2,0.33,1)	(0.2,0.33,1)
X_3	(0.11,0.14,0.2)	(0.11,0.14,0.2)	(0.11,0.14,0.2)	(0.11,0.14,0.2)
X_4	(0.14,0.2,0.33)	(0.1,0.1,0.11)	(0.1,0.11,0.14)	(0.1,0.11,0.14)
X_5	(0.1,0.11,0.14)	(0.1,0.1,0.11)	(0.1,0.1,0.11)	(0.1,0.1,0.11)
X_6	(0.2,0.33,1)	(0.1,0.1,0.11)	(0.14,0.2,0.33)	(0.14,0.2,0.33)

Now with the help of normalized fuzzy decision matrix, we calculate weighted normalized decision matrix using formula " $\widetilde{v_{ij}} = \widetilde{r_{ij}}(.)\widetilde{w_j}$". Further in order to determine the ranking we have to calculate the relative closeness coefficient which is given in table-10. Here d_i^+, d_i^- and cc_i represent positive separation measure, negative separation measure and closeness coefficient of each alternative respectively.

Table-10. Relative closeness coefficient

	d_i^+	d_i^-	cc_i
X_1	5.7451	2.5683	0.3089
X_2	6.0346	2.3489	0.2802
X_3	5.6615	2.6981	0.3228
X_4	6.437	1.8513	0.2234
X_5	6.5111	1.7525	0.2121
X_6	6.8858	1.5265	0.1815

5.2 Discussion

According to closeness coefficient, the ranking of the alternatives should be as follows

$$X_3(0.323) > X_1(0.309) > X_2(0.280) > X_4(0.223) > X_5(0.212) > X_6(0.182)$$

To validate the output obtain with AHP-TOPSIS, we did comparisons with Pal and Biswas [30], Mishra and Singh [31],[32] between the ranking(on the basis of productivity) obtain by other existing methods given in Table-11 and reach at a conclusion that even AHP-TOPSIS involves very less calculation but the result matches almost with that of the other traditional methods. The result obtain by Mishra and Singh [31] in their work on linear fractional programming problem is supposed to give the best profit among all the considered method and found that the ranking of crops given by them matches to our ranking except only at one place.

Table-11. Comparisons of Crop Ranking

Authors	Ranking of crops (according to productivity)
Pal&Biswas[30]	$X_3 > X_1 > X_2 > X_4 > X_6 > X_5$
Mishra&Singh[32]	$X_3 > X_1 > X_2 > X_6 > X_4 > X_5$
Mishra&Singh[31]	$X_3 > X_6 > X_1 > X_2 > X_4 > X_5$
Proposed Method (AHP-TOPSIS)	$X_3 > X_1 > X_2 > X_4 > X_5 > X_6$

6. Conclusion and Future Scope

In the context of determining the crop selection in an agricultural system in order to reach at a fair profitable condition, the AHP-TOPSIS proves to be an effective method. Here we have obtain the priority among the alternatives of crops listed and also the weight of the conflicting criteria using normalized matrix which is a linguistic method. Therefore, AHP-TOPSIS can be a better and convenient alternative method to acquire the desired profit in agricultural system.

In future, there is vivid scope of AHP-TOPSIS in solving many real time decision-making situations like placement in a company, transportation and assignment problems. This method can also be made even easier by reducing some of the steps and one can also work on the reliability of this method.

Data Availability
None

Conflict of Interest

We, the authors declare that we do not have any conflict of interest.

Funding Source
None

Authors' Contributions

Author-1 researched literature and conceived the study. Author-2 involved in protocol development, gaining ethical approval, and data analysis. Also author-1 wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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