



Article

Kharif Crops Selection for Sustainable Farming Practices in the Rajasthan-India Using Multiple Attribute-Based Decision-Making

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Abstract: Sustainability of agricultural practices depends on economic, environmental, and social conditions. The Rajasthan state of India has arid climatic conditions where kharif crops are commonly grown. In this work, the four major criteria are considered such as the farm area, crop yield per unit area, the cost prices, and the market sales price. Merged analytic hierarchy process (AHP) and entropy techniques have been employed to give reasonable weight coefficients for the objective and subjective weights to each criterion. Multiple attribute-based decision-making models (MADM) have been developed using three proven techniques, namely the Exprom2, the technique for order of preference by similarity to ideal solution (TOPSIS), and the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The crop *Pennisetum glaucum* emerged as the most productive kharif crop in the arid climatic conditions of Rajasthan, India under the given criteria. The sensitivity analysis of the three methods identifies the most significant criteria and validates that *Pennisetum glaucum* is the first ranked crop despite the interchange of the weights. The methodology used in this study may be applied across the globe to select appropriate crops for maximizing the profit, optimizing the natural resources, and promoting sustainable agricultural practices. This study may be used to enhance the agricultural gross domestic product (GDP) to make the agriculturalists self-sufficient and to help the state policymakers in making effective regional policies.

Keywords: agricultural gross domestic product; arid region crops; farming; kharif crops; sustainable agricultural practices; crop ranking; multi-criteria decision making

1. Introduction

The kharif crops such as rice, *Sorghum*, *Zea mays*, cotton, ragi, *Pennisetum glaucum*, sugarcane, jute, etcetera, grow in dry and arid conditions. The soil and its nutrient value is an important component of sustainable farming [1]. Despite modern agricultural techniques, the high rate of population growth renders the crop yield inadequate [2]. The choice of a specific arrangement of crop patterns relies upon numerous criteria that differ from region to region [3]. The conception of the index was included in sustainability for the set of selected criteria and existing weather parameters by Dillon et al. [4]. Roy and Weng [5] examined the indicators of sustainable agriculture in Bangladesh. Sorensen et al. [6] suggested a cultivation selection method in the agricultural topography. Multiple attribute-based decision-making (MADM) techniques had been applied in diverse fields such as hydrologic sciences, ecological systems, agricultural systems, water resources systems, water supply, storage, and recycling [7–9]. MADM techniques have been successfully applied in energy sectors [10], industrial and automation engineering systems [11], robotics [12], etcetera. Srinivas et al. [13] published a MADM study related to the water quality of the river Ganga for the diffusion of trace metal. Agarwal and Garg [14] employed the MADM technique for the assessment of groundwater quality. Krol et al. [15] evaluated the sustainability of the maize cultivation in Poland using multi-criteria decision analysis and found that the same sowing method was not the best practice for small and large farm field, hence the criteria is of utmost importance for decision making. Mallick et al. [16] implemented a fuzzy-analytic hierarchy process (AHP) technique to evaluate landslide susceptibility. The study suggests that the criteria weighting must be normalized and the results obtained from the MADM techniques must be validated using sensitivity analysis. Other applications of MADM include the construction industry, information technology, and green chamber farming. A two-phase AHP-TOPSIS was applied to identify a suitable concrete mixture for high performance [17] and sustainable construction material and was determined by applying three MADM methods, namely optimal scoring method, AHP, and TOPSIS [18]. The ranking of cloud-based learning techniques was suggested by applying AHP [19]. A fuzzy based MADM model was studied to identify sustainable green chamber farming practices [20] to rank the vegetable cash crops based on several criteria and a model was suggested to aid the stakeholders to identify the best farming practices.

India is an agriculture-based economy. The state of Rajasthan, India is dominated by desert and has a predominantly arid climate where water resources are scarce due to low mean annual rainfall. Rajasthan's agricultural sector accounts for 22.5 percent of its GDP. The soil texture is a mix of clay, loam, and sand [21,22].

The objective of this study is to develop the MADM model for identifying the most suitable kharif crop in Rajasthan, considering the vital criteria for sustainable agricultural practices. Table 1 gives the data collected from the different departments of the state government of Rajasthan [21,22] for the Financial Year 2018–19 to 2019–20 and through the survey undertaken by the stakeholders for the most favored kharif crops. The survey form and the analysis are given as a supplementary file. The production cost includes the cost of plowing, seeds, fertilizers, water, cutting of the crop, labor, and transportation. The government of Rajasthan fixes the minimum sales price (MSP) of the crop for each crop cycle depending upon the cost of production, yield, and market demand. The MSP is a minimum of 1.5 times the cost of production. After the crop harvesting, the farmer is free to sell the crop to the government at MSP or in the open market (facilitated and monitored by the government). The sales price included in Table 1 is the highest MSP or open market average price (since it varies daily), which is obtained by the survey from the stakeholders. The production cost and the sales prices may vary in each crop cycle depending upon the crop yield, the cost of production, the MSP, and the market demand.

The decision-makers (stakeholders) are farmers, service providers, regulators, the agriculture research institute, seed and fertilizer suppliers, agriculture brokers, and consumers. The policymakers include the department of agriculture, government of Rajasthan, ministry of agriculture, the agriculture minister, the minister of state, the department of irrigation, etcetera.

Table 1. Model simulation of attributes of kharif crops in the Rajasthan–India for the financial years 2018–19 to 2019–20.

Crop Code	Types of Crops (Popular Local Names)	Area of Crop Field (ACF) [Ha]	Production of Crop Field (PCF) [kg/Ha]	Production Cost (PC) [USD/Ha]	Sale Price (PS) [USD per kg]
A1	<i>Sorghum</i> (Joar)	516,043	583	130	0.5
A2	<i>Pennisetum glaucum</i> (Bajra)	4,236,288	886	123	0.4
A3	<i>Zea mays</i> (Maize)	855,895	2033	206	0.2
A4	<i>Vigna mungo</i> (Black Gram/urad)	839,289	624	92	0.6
A5	<i>Vigna radiate</i> (Green Gram/moong)	2,249,619	432	90	0.5

2. Materials and Methods

2.1. Study Area

The important criteria considered in this study were the crop field areas, the yield of the crops, cultivation cost, and the market sales price of the crop. Figure 1 gives the ranking process of the kharif crops by MADM techniques.

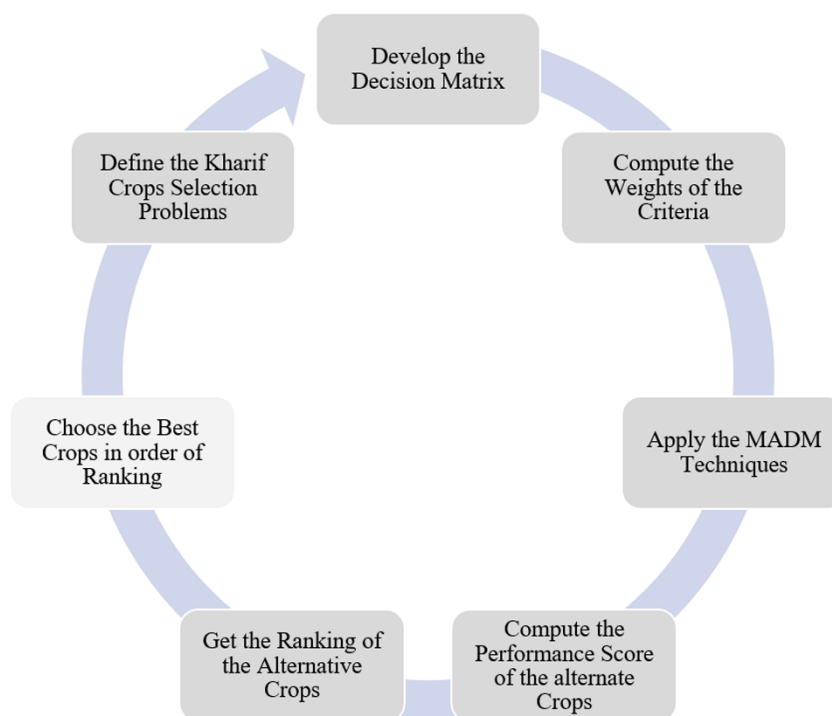


Figure 1. Ranking process of kharif crops.

2.2. The MADM Methods

2.2.1. Criteria Weighting

The entropy and analytic hierarchy process (AHP) techniques were merged to obtain the normalized objective and subjective weights of the criteria. For the k^{th} criteria, the synthesis weight w_k is given as follows:

$$w_k = \frac{\alpha_k \times \beta_k}{\sum_{j=1}^n \alpha_k \times \beta_k} \quad k = 1, 2, \dots, n \tag{1}$$

In Equation (1), the k^{th} criteria has the weight α_k computed by AHP method and the β_k is computed by entropy method [23].

2.2.2. AHP Technique

The AHP technique was proposed by Saaty [24]. The pairwise matrix A is used to compare the set of n alternatives according to the relative importance of the weights.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{1n} & \cdots & a_{nn} \end{bmatrix}, a_{ii} = 1, a_{ij} = \frac{1}{a_{ji}}, a_{ji} \neq 0 \tag{2}$$

In Equation (2), a_1, a_2, \dots, a_n represent the criteria. The relative significance of the two criteria are ranked using the digits from 1 to 9 [25], where 1 stands for equally significant, 3 for somewhat more significant, 5 for intensely significant, 7 for demonstrably more significant, 9 for absolutely more significant and 2, 4, 6, 8 stands for a compromise between slightly different judgments. The comparative weights are obtained by determining the eigenvector w concerning λ_{max} that satisfies $Aw = \lambda_{max}w$. Here, λ_{max} is the highest eigenvalue of matrix A . The consistency index (CI) and the consistency ratio (CR) are calculated from Equations (3) and (4) to ascertain the accuracy of the comparative weights and consistency of the subjective perception. Here, n is a criteria number, the value of CI should be less than 0.1 for the results to be confident, and the random consistency index (RI) should be below 0.1 for the valid results.

$$CI = (\lambda_{max} - n) / (n - 1) \tag{3}$$

$$CR = \frac{CI}{RI} \tag{4}$$

2.2.3. Entropy Technique

The following Equation (5) gives the decision matrix A , having m alternatives (evaluation objectives) for n criteria (evaluation indexes) [12].

$$A = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{5}$$

For normalization, the dimensionless values of different criteria are computed by Equation (6) to make a comparison among them.

$$P_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \tag{6}$$

where P_{ij} is the normalized vector, a proportion of i^{th} index value under criteria j . Equation (7) is used to compute the entropy E_j of the j^{th} criteria.

$$E_j = -k \sum_{i=1}^m P_{ij} \ln(P_{ij}) \quad j = 1, 2, \dots, n \tag{7}$$

In Equation (7), constant $k = 1 / \ln m$, ensures $0 \leq E_j \leq 1$ and m is the number of choices. Equation (8) can be used to calculate the degree of divergence (d_j) of the mean information contained in each criterion.

$$d_j = |1 - E_j| \tag{8}$$

The weight of the entropy of the j^{th} criteria is given by Equation (9).

$$\beta_j = \frac{d_j}{\sum_{j=1}^n d_j} \tag{9}$$

2.2.4. Exprom2 Technique

The updated version of the Promethee II technique is known as the Exprom2 technique, which is derived from ideal and anti-ideal solutions given in Equations (10) and (11) [26]:

$$r_{ij} = [x_{ij} - \min(x_{ij})] / [\max(x_{ij}) - \min(x_{ij})] \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \tag{10}$$

$$r_{ij} = [\max(x_{ij}) - (x_{ij})] / [\max(x_{ij}) - \min(x_{ij})] \tag{11}$$

In this x_{ij} indicates the performance measure of the i^{th} alternative concerning criterion j and r_{ij} is the normalized value of the x_{ij} .

The pairwise calculation is done to get the difference in criteria value (d_j).

Equation (12) is used to calculate the preference function to measure the extent to which the alternative i dominate over the alternative i' for the j^{th} criteria.

$$P_j(i, i') = 0 \text{ if } r_{ij} \leq r_{i'j} \tag{12}$$

Here x_{ij} ($i = 1, 2, \dots, m; j = 1, 2, \dots, n$) is the value of j^{th} criteria and i^{th} alternative. To get the weights by the entropy technique, the normalized decision matrix P_{ij} is estimated by Equation (13) given by Gowda and Jayaramaiah [27].

$$P_j(i, i') = (r_{ij} - r_{i'j}) \text{ if } r_{ij} \geq r_{i'j} \tag{13}$$

Equation (14) is used to calculate the weak preference index $WP_{ij}(i, i')$.

$$WP(i, i') = \left[\sum_{j=1}^n w_j \times P_j(i, i') \right] / \sum_{j=1}^n w_j \tag{14}$$

In Equation (14), the w_j is the weight of the j^{th} criterion derived from the compromised weighting method.

The definition of the strict preference function is given by Equations (15) and (16).

$$SP_j(i, i') = [\max(0, d_j - L_j)] / [d_mj - L_j] \tag{15}$$

In this, d_mj is the difference between the ideal and anti-ideal value of the j^{th} criterion and the L_j is the limit of the preference.

$$SP(i, i') = \left[\sum_{j=1}^n W_j \times SP_j(i, i') \right] / \sum_{j=1}^n w_j \tag{16}$$

The total preference index is given by Equation (17).

$$TP(i, i') = \text{Min}[1, WP(i, i') + SP(i, i')] \tag{17}$$

The positive flow for the i^{th} alternative is calculated by Equation (18).

$$\varphi^+(i) = \frac{1}{m-1} \sum_{i=1}^m TP(i, i') (i \neq i') \tag{18}$$

The negative flow for the i^{th} alternative is calculated by the by Equation (19).

$$\varphi^-(i) = \frac{1}{m-1} \sum_{i'=1}^m TP(i, i') (i \neq i') \tag{19}$$

Here m is the number of the alternatives.

The total outranking flow for each alternative is calculated by Equation (20).

$$\varphi(i) = \varphi^+(i) - \varphi^-(i) \tag{20}$$

The best alternative is chosen based on the highest value of $\varphi(i)$.

The technique for order of preference by similarity to ideal solution method (TOPSIS)

The steps followed in the TOPSIS method are:

1. The decision matrix $(x_{ij})_{m \times n}$ with dimension, $m \times n$ is formed by n criteria and m alternatives with the interaction of each criterion and alternative given by x_{ij} .
2. The weight of each criterion is computed by comparing the relative importance of one attribute with the other (Saaty 1980) [24].
3. The matrix $(x_{ij})_{m \times n}$ is now normalized (Equation (21)):

$$R = (r_{ij})_{m \times n} \tag{21}$$

Using the normalization method (Equation (22)):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}, i = 1, 2, \dots, m, j = 1, 2, \dots, n \tag{22}$$

4. Calculate the weighted normalized decision matrix from Equations (23) and (24) in which, T is the resultant of matrix operation, t_{ij} is the matrix element corresponding to the i^{th} row and j^{th} column:

$$T = (t_{ij})_{m \times n} = (w_j r_{ij})_{m \times n}, i = 1, 2, \dots, m \tag{23}$$

$$w_j = W_j / \sum_{j=1}^n W_j, j = 1, 2, \dots, n \tag{24}$$

where $\sum_{j=1}^n w_j = 1$, W_j is the original weight given to the indicator r_{ij} , $j = 1, 2, \dots, n$.

5. Determine the worst alternative (A_w) (Equation (25)) and the best alternative (A_b) (Equation (26)):

$$A_w = \{ \langle \max(t_{ij} | i = 1, 2, \dots, m) | j \in J_- \rangle, \langle \min(t_{ij} | i = 1, 2, \dots, m) | j \in J_+ \rangle \} \equiv \{ t_{wj} | j = 1, 2, \dots, n \} \tag{25}$$

$$A_b = \{ \langle \min(t_{ij} | i = 1, 2, \dots, m) | j \in J_- \rangle, \langle \max(t_{ij} | i = 1, 2, \dots, m) | j \in J_+ \rangle \} \equiv \{ t_{wj} | j = 1, 2, \dots, n \} \tag{26}$$

In which, $J_+ = \{ j = 1, 2, \dots, n | j \}$ has a positive impact, and $J_- = \{ j = 1, 2, \dots, n | j \}$ has a negative impact.

Equation (27) is used to calculate the distance between the target alternative i and the worst condition A_w .

$$d_{iw} = \sqrt{\sum_{j=1}^n (t_{ij} - t_{wj})^2} \tag{27}$$

The alternative i and the best condition A_b (Equation (28)):

$$d_{ib} = \sqrt{\sum_{j=1}^n (t_{ij} - t_{bj})^2} \tag{28}$$

where, $i = 1, 2, \dots, m$ and; $j = 1, 2, \dots, n$ and d_{iw} and d_{ib} are the distances from the target option i to the best and worst conditions, respectively.

6. Euclidean distance S_{iw} is calculated by Equation (29) to determine the similarity to the worst condition:

$$S_{iw} = d_{iw} / (d_{iw} + d_{ib}), 0 \leq S_{iw} \leq 1, i = 1, 2, \dots, m \tag{29}$$

$S_{iw} = 1$ for the best condition, and; $S_{iw} = 0$ for the worst condition.

7. Ranking of S_{iw} ($i = 1, 2, \dots, m$) by prioritization.

2.2.5. VIKOR Technique

The VIKOR method gives a compromised solution. The main steps of the VIKOR technique [28] are:

The decision matrix is used to obtain the best i.e., $(x_{ij})_{max}$ and the worst i.e., $(x_{ij})_{min}$ values of all the criteria.,

The following equations are used to determine the standard parameters of the VIKOR method: E_i , F_i , and P_i respectively.

$$E_i = \sum_{j=1}^n W_j [(x_{ij})_{max} - (x_{ij})] / [(x_{ij})_{max} - (x_{ij})_{min}] \tag{30}$$

$$F_i = \text{Max}^n \text{ of } \{ W_j [(x_{ij})_{max} - (x_{ij})] / [(x_{ij})_{max} - (x_{ij})_{min}] \} j = 1, 2, \dots, n \tag{31}$$

The values of P_i are calculated by Equation (32).

$$P_i = \vartheta ((E_i - E_{i-min}) / (E_{i-max} - E_{i-min})) + (1 - \vartheta) ((F_i - F_{i-min}) / (F_{i-max} - F_{i-min})) \tag{32}$$

Here ϑ is the weight of the policy of the majority of the criteria, the range of this can be any value between 0 and 1 and the most common value is 0.5. The maximum and minimum values of E_i and F_i are designated by E_{i-max} , E_{i-min} , F_{i-max} , and F_{i-min} respectively.

The criteria weighting and the MADM techniques have been explicitly given in the preceding section and Figure 2 presents a summary in a flow chart. The abbreviations, mathematical operators, and symbols have been given at the end of the article for quick reference.

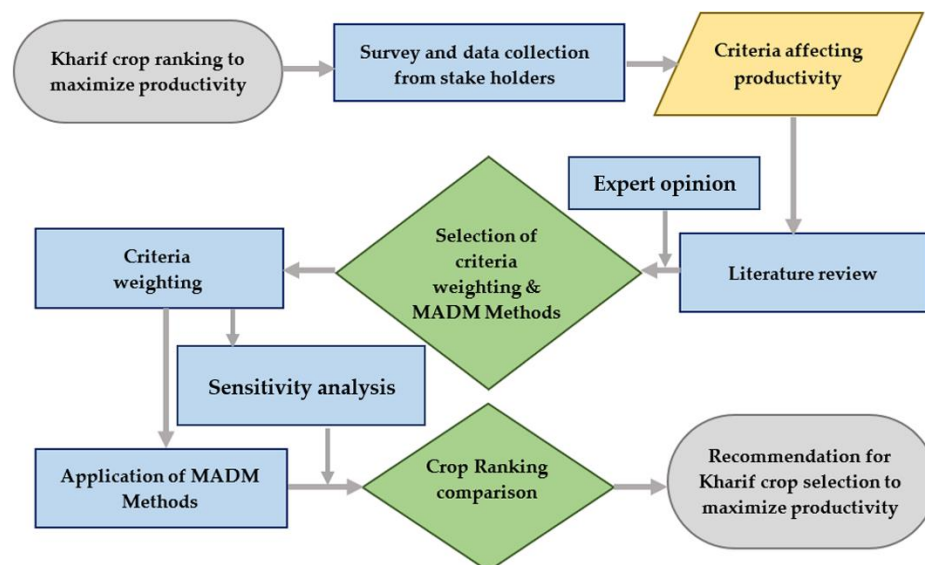


Figure 2. Flow chart summarizing the research design and methodology.

Sensitivity analysis deals with the effect of criteria weights obtained by the combined approach (AHP-entropy) on the alternatives. The basic methodology of sensitivity analysis is that the weight

of each criterion is interchanged with another. To validate the criteria weighting and compare the results obtained from the MADM techniques, sensitivity analysis was done. A similar methodology has been adopted by Ahmed et al. [17,18]. The criteria weights were obtained from a survey among the stakeholders and the recent data obtained from the government sources [21,22].

3. Results and Discussion

An effort is made to develop a MADM model using a systems approach to rank the five kharif crops (given in Table 1) in Rajasthan-India. The four major criteria considered are; area of crop field (ACF) in Ha, production of crop field (PCF) in kg/Ha, production cost (PC) USD/Ha, and sales price (SP) in USD/kg. The pairwise comparison is made by summarizing the survey from the stakeholders and the results are reported in Table 2. The higher digit indicates a higher relevance in the pairwise comparison.

Table 2. The pairwise comparison matrix for criteria.

	ACF	PCF	PC	SP
ACF	1	2	4	8
PCF	0.5	1	0.5	0.25
PC	0.25	2	1	2
SP	0.125	4	0.5	1

Table 3 summarizes the weight of each criterion using AHP, entropy and the compound weight methods. The highest weight is obtained for the ACF among the three methods.

Table 3. Criteria weighing by AHP (α_j), entropy (β_j) and compound weight (w_j).

Criteria Weighing	Parameters	ACF	PCF	PC	SP
α_j	Alpha (AHP)	0.533333	0.120833	0.175	0.170833
β_j	Beta(entropy)	0.510491	0.305634	0.088677	0.095198
w_j	Weight age	0.798482	0.10831	0.045512	0.047696

Table 4 gives the normalized decision matrix for the four criteria and five alternatives. The digits obtained from the matrix are used as inputs in the MADM techniques.

Table 4. Normalized decision matrix.

Kharif Crop Code	ACF [Ha]	PCF [kg/Ha]	PC [USD/Ha]	SP [USD per kg]
A1	0.000	0.094	0.655	0.75
A2	1.000	0.284	0.716	0.5
A3	0.091	1.000	0.000	0
A4	0.087	0.120	0.983	1
A5	0.466	0.000	1.000	0.75

Table 5 shows the results obtained from the Exprom2 method and the value of the positive flow for the i^{th} alternative, the negative flow of the i^{th} alternative, and the total flow is given in the table after calculation. The best alternative is chosen based on the highest value of $\varphi(i)$. The positive and negative flow indicates extremes. The ranking is based on the resultant of the positive and negative flow. The first rank is of *Pennisetum glaucum*, followed by *Vigna radiate*, *Zea mays*, *Vigna mungo*, and *Sorghum*. The first rank hence determines the most favorable crop under the selected criteria.

Tables 6 and 7 show the general matrix outcomes used as inputs in the MADM techniques.

Table 8 shows the result obtained from the TOPSIS method. Here, an alternative with the highest value of C_i is ranked first, and so on. On comparing the ranks of the crops obtained by the Exprom2 (Table 5), one may observe 100% consistency. This validates the results obtained under the selected criteria for the selected crops. Crop A2 (*Pennisetum glaucum*) emerges as the most suitable one.

Table 5. The positive and the negative flow of the i^{th} alternative using Exprom2.

Crop Code	$\varphi^+(i)$	$\varphi^-(i)$	$\Phi(i)$	Ranking
A1	0.021932	0.369881	-0.34794857	5
A2	0.701906	0.037601	0.66430513	1
A3	0.113957	0.330097	-0.21614008	3
A4	0.063083	0.2873	-0.22421643	4
A5	0.274138	0.150138	0.12399995	2

Table 6. Weighted and normalized decision matrix.

Crop Code	ACF	PCF	PC	SP
A1	0.083	0.026	0.020	0.023
A2	0.680	0.040	0.019	0.019
A3	0.137	0.091	0.031	0.009
A4	0.135	0.028	0.014	0.028
A5	0.361	0.019	0.014	0.023

Table 7. The ideal and non-ideal solutions.

	ACF [Ha]	PCF [kg/Ha]	PC [USD/Ha]	SP [USD per kg]
VJ ⁺	0.680	0.091	0.014	0.028
VJ ⁻	0.083	0.019	0.031	0.009

Table 8. The alternative prioritization of different criteria using the TOPSIS method.

Crop Code	S_i^+	S_i^-	Sum	C_i	Rank
A1	0.601158817	0.019246655	0.620405471	0.031022703	5
A2	0.052498111	0.598133271	0.650631382	0.919312052	1
A3	0.54359107	0.090189834	0.633780905	0.142304436	3
A4	0.549306539	0.058388685	0.607695224	0.096082185	4
A5	0.327127691	0.279359852	0.606487542	0.460619275	2

Table 9 shows the results obtained for the VIKOR method where the ranking is based on the value of P_i . The lower the value of P_i , the higher will be the rank. The first ranked alternative is *Pennisetum glaucum*, followed by others. The ranks of the crops obtained by the Exprom2, TOPSIS, and VIKOR are in 100% conformation.

Table 9. Parameters E_i , F_i and P_i of the VIKOR method estimated from Equations (30)–(32).

Crop Code	E_i	F_i	P_i	Rank
A1	0.924194	0.798482	1	5
A2	0.114391	0.077596	0	1
A3	0.818747	0.725539	0.884301	3
A4	0.825209	0.729103	0.890762	4
A5	0.546635	0.426402	0.508811	2

Figure 3 presents a comparative picture of the results obtained from the three methods. There is a perfect match between the ranks obtained from all the three techniques and *Pennisetum glaucum* has emerged as the first ranked crop.

For sensitivity analysis, nine conditions were taken into account, given in Table 10. For each condition, the rank is computed by all three methods i.e., the Exprom2, the TOPSIS, and the VIKOR respectively. In Table 10, the criteria weights are represented by w_1 (ACF), w_2 (PCF), w_3 (PC), and

w4 (PS) respectively. After fixing one criterion weight and interchanging the others, nine unique combinations (conditions) have been considered.

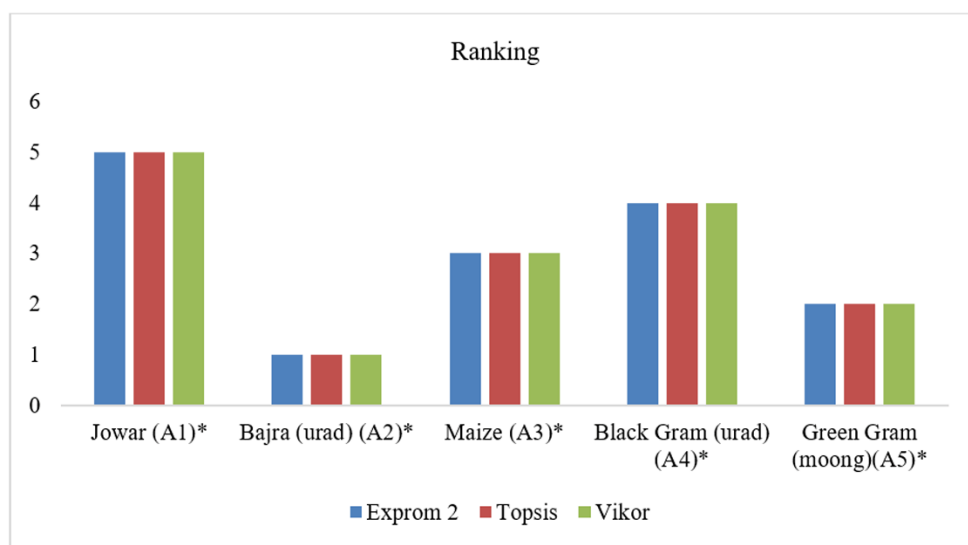


Figure 3. The three MADM method results and the comparison of the ranking.

Table 10. Different conditions for the sensitivity analysis.

Condition	Criterion Weight			
1	w1	w2	w3	w4
2	w2	w3	w1	w4
3	w3	w2	w1	w4
4	w4	w1	w2	w3
5	w1	w3	w2	w4
6	w2	w1	w3	w4
7	w1	w4	w3	w2
8	w4	w2	w3	w1
9	w1	w2	w4	w3

The sensitivity analysis based on the nine conditions for the Exprom2 method is plotted in Figure 4. Once the criteria weights have been changed, the rank also changed. Among nine conditions, *Pennisetum glaucum* (Bajra)-A2 emerged as the first ranked crop in four conditions (1, 5, 7, and 9). Among other crops, *Vigna radiate* (Green Gram/moong)-A5, ranked first in two conditions (2 and 3), *Zea mays* (Maize)-A3 ranked first in two conditions (4 and 6), *Vigna mungo* (Black Gram/urad)-A4 ranked first in one condition (8), while *Sorghum* (Joar)-A1 did not emerge at the first rank in any of the conditions. Hence, the weights w2 (PCF) and w3 (PC) are the dominant criteria and the conditions 2 and 3 are most sensitive in determining the rank of the crops.

The sensitivity analysis of the TOPSIS and the VIKOR methods are given in Figures 5 and 6 respectively. In both the Figures, conditions 2 and 3 emerge as most sensitive. The rank of crop A2 is at the first rank in four conditions in each method, consolidating and validating the ranking results given in Table 9 and Figure 3. In all three methods, the weights w2 (PCF) and w3 (PC) are the dominant criteria, conforming with the results obtained from AHP (Table 3).

The process of selecting kharif crops in the arid region of Rajasthan state in India for sustainable agriculture is complex. Especially when it is derived under the influence of a large number of criteria that influence sustainability, it poses many challenges. Without sufficient kharif crop production resources, the problem of kharif crop harvest becomes more complicated. The present methodology will, therefore, be of great help to stakeholders in agriculture in these environments. For future research, the MADM-based methodology will have more advantage, as comparison depends on experts'

subjective judgment. By using MADM-based methods, biases and vagueness in decision-making can be largely overcome. The MADM methods will help farmers and agricultural policymakers to formulate a comprehensive policy for sustainable agricultural practices, which has a potential and immediate solution to address the ongoing urgent requirement worldwide. Prospects of the research may include adaptation and mitigation options for better sustainable agricultural practices resulting from climate change problems to improve the decision-making process.

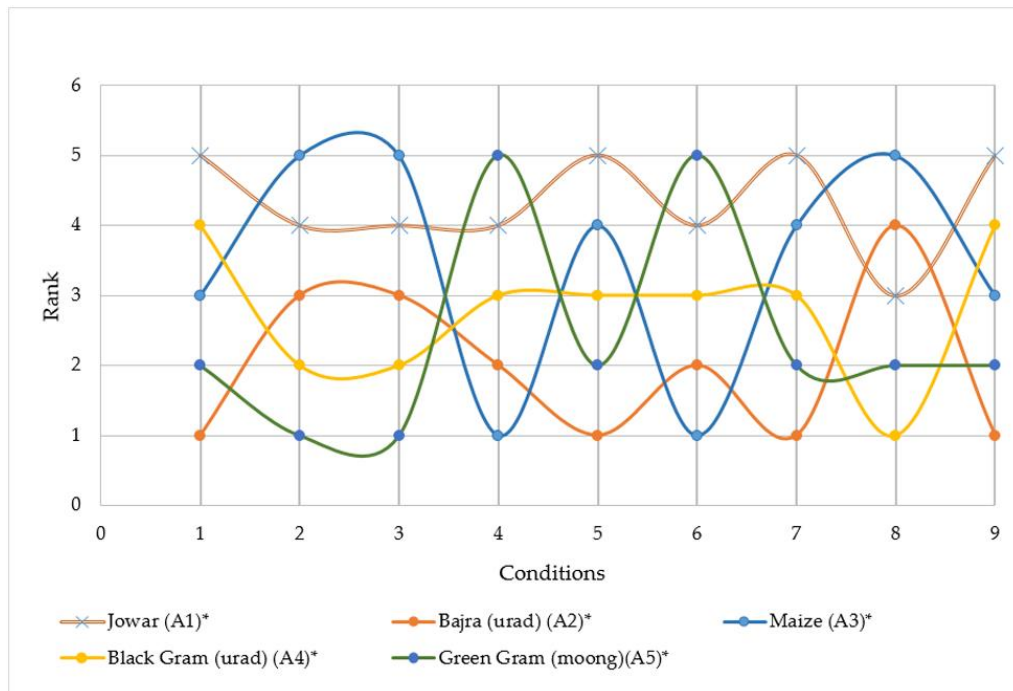


Figure 4. Sensitivity analysis of the Exprom2 model.

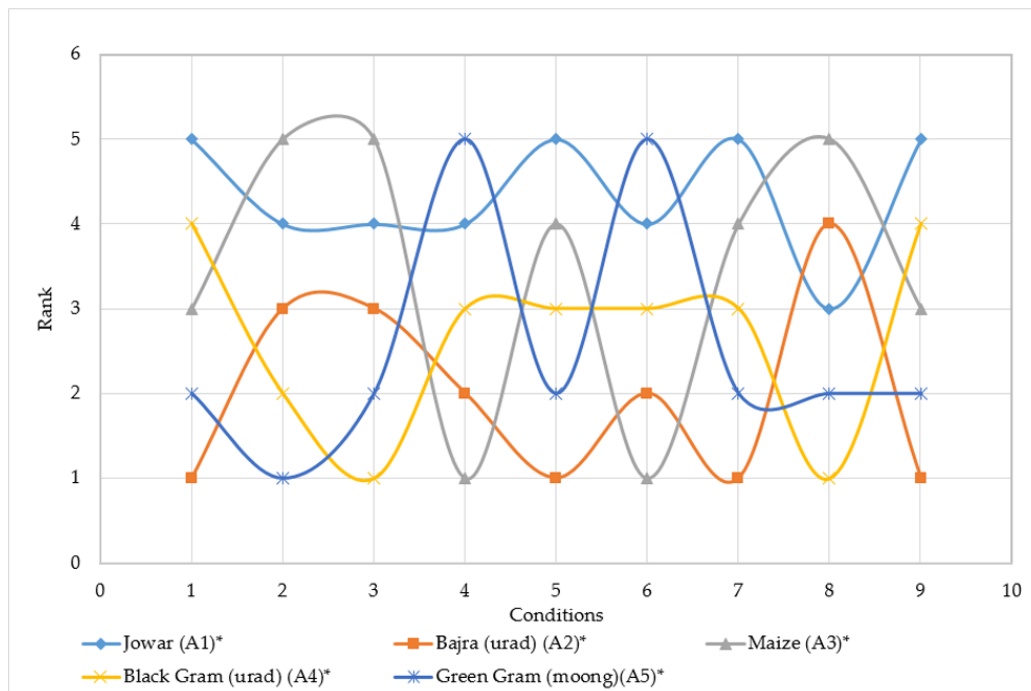


Figure 5. Sensitivity analysis of the TOPSIS model.

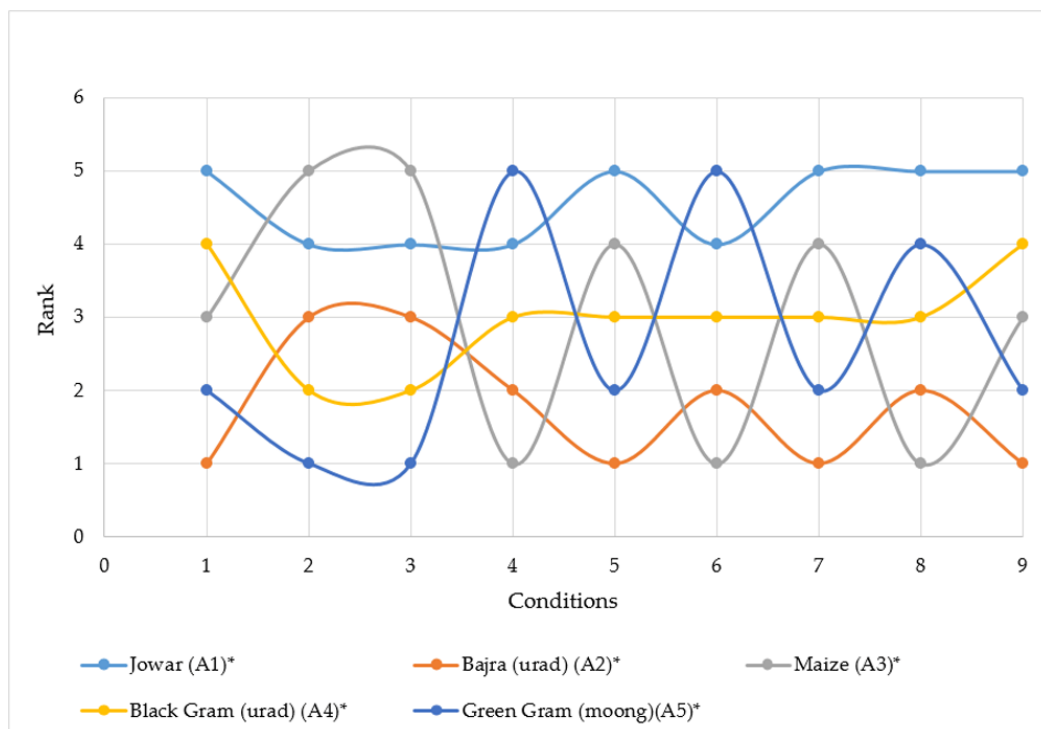


Figure 6. Sensitivity analysis of the VIKOR model.

4. Conclusions

The multi-attribute decision making (MADM) has been successfully applied for the best selection of the output under the given inputs and constraints (criteria). The applications of MADM techniques in agricultural engineering are still emerging. India is an agricultural-based and fastest-growing economy in the world. In an agriculture-dependent economy like India, precision agriculture is extremely important for an increase in productivity. These techniques may provide better decision-making rather than deciding intuitively. The study employed two criteria (subjective and objective) weighting methods and then obtained the criteria weights by normalizing, to standardize the results. The ranking of the crops has been done by three MADM methods, namely, the Exprom2, the TOPSIS, and the VIKOR to rank the crops to facilitate the farmers and the policymakers to decide on inclusion or exclusion of an attribute according to the significance of the criteria concerning the objective. Three methods were used to validate the accuracy of the results and avoid the inherent deficiency of a single MADM technique. A sensitivity analysis was done for each method to determine its impact. The government hence spends a considerable percentage of the annual GDP for supporting farmers. This study gives a scientific approach to decision making, which affects the livelihood of a large section of the society (farmer) and the overall economy of the state and the country, suggesting a replacement of conventional, preferential, or intuitive decision-making approaches.

The attributes and the criteria were kept in mind while formulating and modeling the problems. The results obtained by TOPSIS, Exprom2, and VIKOR were in good agreement for prioritizing the kharif crops. The first ranked crop is *Pennisetum glaucum*, the second is *Vigna radiate*, the third is *Zea mays*, the fourth is *Vigna mungo*, and the last one (fifth) is *Sorghum*. Results from the three MADM techniques are in exact confirmation indicating that any one of them may be used to rank the crops. The scope of the study may be global and the selected criteria may be increased as suitable. The outcome of the research work will help the policymakers and the farmers to implement sustainable farming practices, increase profit, and minimize losses due to poor decision making. Similar studies may be done changing the criteria, depending on the region and the best productive crop may be suggested to the farmers. The sensitivity analysis of the three methods validates that the PCF and PC are dominant

criteria and *Pennisetum glaucum* emerged as the first ranked crop on maximum counts in the sensitivity analysis of each method. If the government of India motivates the farmers to cultivate this crop in Rajasthan, the productivity is expected to increase.

The future recommendations are to use the MADM-based advanced techniques to handle decision-making problems for the farmers and state agriculture departments to formulate better guidelines for sustainable agricultural practices, globally. The prospects of the research may also include adaptation and mitigation options for better sustainable agricultural practices resulting from climate change problems to improve the decision-making process.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2073-4395/10/4/536/s1>, Survey form: Survey on Sustainable Agricultural Practices for Kharif Crops in the State of Rajasthan (2018–19).

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Nomenclature

Abbreviations

MADM	Multiple attribute-based decision-making model
GDP	Gross domestic product
MSP	Minimum sales price
TOPSIS	The Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje
Exprom2	The Extended PROMETHEE II
AHP	Analytic Hierarchy Process
CI	Consistency index
CR	Consistency ratio
RI	Random consistency index

Symbols

k	Criteria
w_k	Synthesis weight
α_k	Weight for k^{th} criteria, computed from AHP method
β_k	Weight for k^{th} criteria, computed from entropy method
A	Matrix
a_1, a_2, \dots, a_n	Criterion
w	Eigenvector
n	Number of criteria (evaluation indexes)
m	Alternatives (evaluation objectives)
x_{11}, x_{1n}, x_{mn}	Evaluation indexes
P_{ij}	Normalized vector, a proportion of i^{th} index under index j
E_j	Entropy of the j^{th} criteria
d_j	Degree of divergence
β_j	Weight of entropy of j^{th} criteria
r_{ij}	Normalized value of x_{ij}
$P_j(i, i')$	Preference function
$WP_{ij}(i, i')$	Weak preference index

w_j	Weight of the j^{th} criterion
$SP_j(i, i')$	Strict preference function
dm_j	Difference of ideal and anti-ideal value of j^{th} criterion
L_j	Limit of the preference
$TP(i, i')$	Total preference index
$\varphi^+(i)$	Positive flow for the i^{th} alternative
$\varphi^-(i)$	Negative flow for the i^{th} alternative
$\varphi(i)$	Total outranking flow
$(x_{ij})_{m \times n}$	Matrix formed by n criteria and m alternatives with the intersection of each alternative and criteria given by x_{ij}
R	Normalized matrix
T	Resultant of matrix operation
t_{ij}	Matrix element corresponding to i^{th} row and j^{th} column
W_j	Original weight is given to the indicator
v_j	Standard value of indicator
A_b	Best alternative
A_w	Worst alternative
J_+	Positive impact (benefit criteria)
J_-	Negative impact (cost criteria)
d_{ib}	Distance between target alternative and best condition
d_{iw}	Distance between target alternative and worst condition
S_{iw}	Similarity to the worst condition
$E_i, F_i,$ and P_i	Standard parameters of the VIKOR method
ϑ	Weight of the strategy of the majority of the criteria (decision mechanism index) ranging between 0 and 1

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