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Determining Alternative Crops with Multi Criteria Decision Making Methods within the Framework of Land Risk Criteria

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ABSTRACT
Natural, societal, and economic hazards have a negative impact on agricultural production. In the field of agriculture, productivity studies are common, but election studies are rare. The goal of the study was to figure out which product to plant based on the region's characteristics by anticipating risk factors in advance. The most appropriate crop kind to grow based on the risk variables faced in agricultural production was explored in this study. The nine risk factors in the Çukurova region, as well as three alternative crops, were determined for this study. Input costs, changes in climatic conditions, changes in yield loss due to pests, agricultural tools and machinery failure, theft, fire, crop damage due to excessive water, crop loss due to drought and lack of technical information were chosen as criteria. Citrus, cereal, and legume were chosen as alternative crops. First, using the Analytical Hierarchy Process method, the weights of the score were determined. As a consequence of the weighing, the input costs criterion had the greatest weight value of 0.29. The criterion with the lowest score was a lack of technical information (0.01). Then, using the steps of the Elimination and Choice Translating Reality English method, which is one of the Multi Criteria Decision Making methods, the best relevant alternative ranking was determined. The comparison was also done using the Technique for Order Preference by Similarity to Ideal Solutions method. The cereal alternative was the best in both methodologies as a result of their application. In the first method, legumes and citrus were chosen, however in the second method, the opposite outcome was obtained.

Keywords: Risk criteria, Alternative crops, AHP, ELECTRE, TOPSIS

1. Introduction

Economic, social, political, technological, and human hazards all have an impact on the agriculture industry, which has a very sensitive and unique structure. Some variables may be taken into account for efficient production (Rani et al. 2020). From this perspective, agriculture's effective performance in terms of human nutrition is inextricably linked to the management of hazards that endanger agricultural productivity (Tümer et al. 2010).

Controlling and examining agricultural risks can be beneficial (Harvey et al. 2014, Duong et al. 2019). Some measures must be done beforehand in order to limit the risk, alleviate its impact, or maintain the sector's survival amid unfavourable conditions. It's impossible to imagine a world without risk, and being risk averse isn't an option. However, with the right policies in place, the risk may be managed and its impact minimised (Akçaöz & Özkan 2002).

Decision making is challenging in today's continuously changing and increasingly difficult life conditions. Because there are so many factors in decision making, Multi Criteria Decision Making (MCDM) procedures are more accurate in elections. The MCDM is a set of strategies for attempting to find the best or most appropriate solution to a decision problem that fits many criteria. The MCDM strategies can be applied to a variety of situations. Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), and Elimination and Choice Translating Reality English (ELECTRE) are among the most popular (Sindhu et al. 2017; Çiçek et al. 2020). For example, Karaca (2013) recommended employing AHP, ELECTRE, and TOPSIS methodologies to choose from six dealer applicants for an automotive company in Turkey. The study by Pourkhabbaz et al. (2014) has two objectives: The first goal was to apply the Analytic Network Process (ANP) and Simple Additive Weighting (SAW) methodologies to determine the ecological capabilities of agricultural land utilization. Second, the integrated VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and AHP models were used to rank the most acceptable agricultural solutions in this territory. According to the research, the north areas of the study region (Takestan-Qazvin Plain) are unfavorable for agricultural development. Tunca et al. (2015) investigated for the appropriate method for choosing the best accounting package programme by considering three main sets of criteria and fifteen sub criteria. Ömürbek et el. (2016) used the AHP, ELECTRE, and SAW methodologies from MCDM methods to pick a building audit business in the construction sector in Isparta. Agricultural decision-making strategies use MCDM methods. Sánchez-Lozano et al. (2016) identified the Murcia coast in southern Spain as a potential location for solar photovoltaic fields. TOPSIS and ELECTRE, two MCDM methodologies, were used to explore for appropriate sites. Using MCDM methods, a very valuable database was developed for tackling complicated locations such as the evaluation and selection of viable places. Widiatmaka et al. (2016), the goal of this study was to examine at the agricultural land that was available in Bogor, Jakarta. Two steps of analysis are used in the methodology: Land suitability and land availability analysis utilizing AHP. In agriculture, Papathanasiou et al. (2016) demonstrated the deployment of a web-based decision support system that includes TOPSIS and VIKOR and allows decision makers to compare the outcomes of both methodologies. Alper & Başdar (2017) used the ELECTRE and TOPSIS methodologies to assess the financial effectiveness of factoring companies listed on the Istanbul Stock Exchange. The criterion weights in the study were obtained using the AHP approach by Yalçıner & Karaatlı (2018), while deposit bank selection was done using the TOPSIS and ELECTRE methods. Seyedmohammadi et al. (2018) used MCDM methods to assess locations appropriate for maize, rapeseed, and soybean crop growing planning in Iran. The incorporation of created framework as an effective instrument could help in executing better control over soil, land and environment losses. Deepa & Ganesan (2019) designed a decision making mechanism for determining the best crop to grow on agricultural land. The study by Tork et al. (2021) aims to use the AHP method to estimate the effectiveness and rate the possibilities for upgrading the surface water distribution system.

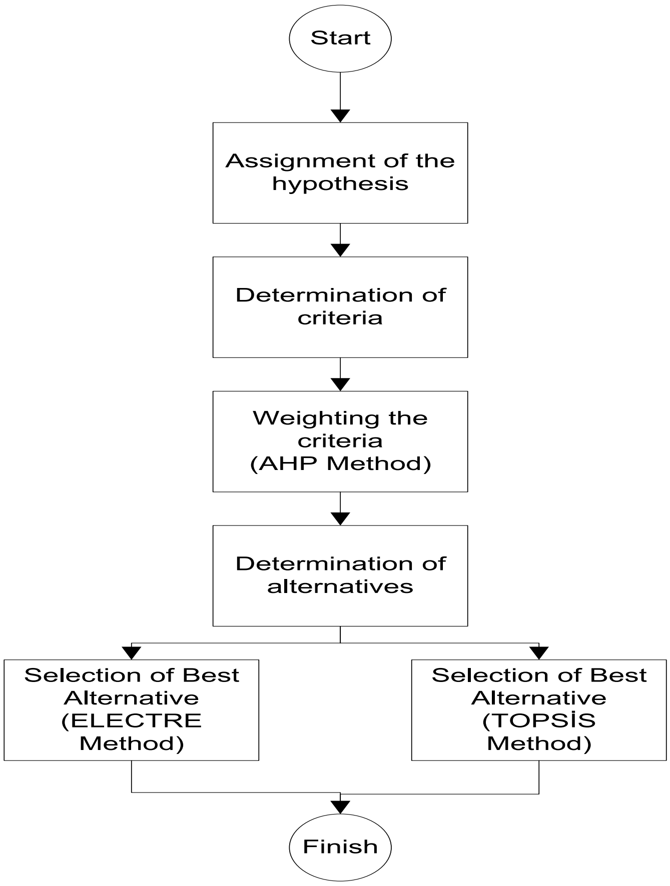

Figure 1- The flowchart of hybrid MCDM

The study's hypothesis is that risk factors in agricultural output are increasing as a result of global warming (fires, floods). Figure 1 depicts the study's hypothesis utilizing hybrid approaches. In this perspective, cereal is the most sustainable plant species with risk factors due to its high level of environmental adaptation. Cereal should be planted first among all crops, according to the study's research question. Input costs, changes in climatic conditions, changes in yield loss due to pests, agricultural tools and machinery failure, theft, fire, crop damage due to excessive water, crop loss due to drought, lack of technical information were set for criteria in this study (Akçaöz & Özkan 2002; Tümer et al. 2010). In the Çukurova region, alternative citrus, cereal, and legume crops were chosen. Weighting was accomplished using the AHP approach by scoring experts after the criteria had been determined. Then, using the ELECTRE and TOPSIS methods, the rank of obtaining optimal solution was discovered.

2. Material and Methods

The importance of MCDM in terms of guiding the decision maker cannot be overstated. In order to compute MCDM scores, one should seek expert advice. The experts' opinions are taken into account during scoring. People who have worked in agriculture in the Çukurova constituency have been interrogated.

One of the MCDM, AHP, was first suggested by Myers and Alpert in 1968 and developed as a model for solving decision-making challenges by Saaty in 1977 (Myers & Alpert 1968, Saaty 1977). The following are the steps that can only be followed to address a decision-making problem using AHP:

Step 1: The decision making problem is defined.

Step 2: The matrix of inter-factor comparison is constructed. Comparisons are made for values above the diagonal of the comparison matrix. The matrix elements on the diagonal are 1. It is used to Equation 1 for the components below the diagonal. *a* values are matrix elements which is scored in Table 1.

$$a_{ji} = \frac{1}{a_{ij}} \tag{1}$$

Table 1 shows a comparison of factors based on their respective relevance levels.

Table 1- Importance scale (Saaty 1977)

Importance	*Value definitions*
1	Equal Importance
3	Weak Importance of one over another
5	Essential or strong importance
7	Demonstrated Importance
9	Absolute Importance
2, 4, 6, 8	Intermediate value

Step 3: The significance distributions of elements are calculated as a percentage. The column vectors that generated the comparison matrix are utilised to estimate the weights and percentage significant distributions of the components, and the matrix *b* is produced in Equation 2.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

In Equation 3, the column vector, referred to as the priority matrix *w*, is obtained by taking the arithmetic mean of the row constituents of the resulting matrix *c*.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3}$$

Step 4: Consistency in factor benchmarks is measured. After calculating the total mean (λ), the Consistency Index (*CI*) can be calculated using in Equation 4. *n* is number of sampling.

$$CI = \frac{\lambda - n}{n - 1} \tag{4}$$

Step 5: For each factor, percentage significance of distributions at the decision point is obtained.

Step 6: The distribution of the results at the decision points is determined.

The ELECTRE method was first used in 1966 introduced by Benayoun et al. (1966). Below are the steps of the ELECTRE method (Triantaphyllou 2000).

Step 1: The decision matrix is composed.

Step 2: The standard decision matrix is calculated using the Equation (5). To calculate, for example, the y_{11} element of matrix Y, the b_{11} element of matrix B is obtained by dividing by the square root of the sum of squares of the one column elements of the matrix.

$$y_{ij} = \frac{b_{ij}}{\sqrt{\sum_{k=1}^{r} b_{kj}^2}} \quad (5)$$

Step 3: The weighted standard decision matrix is generated by multiplying the elements in each column of the standard decision matrix corresponding weight values. The AHP methodology mentioned above is the most popular for these weights.

Step 4: Concordance and discordance determination of sets are encountered. The decision points for the evaluation factor are compared with another one.

Step 5: Concordance and discordance matrix are calculated. The concordance index (m_{kl}) is the sum of the weights associated with the criteria contained in the concordance set. Discordance matrix index (n_{kl}) is defined the Equation (6).

$$n_{kl} = \frac{\max\limits_{j \in N_{kl}} \left| z_{kj} - z_{lj} \right|}{\max\limits_{j} \left| z_{kj} - z_{lj} \right|} \quad (6)$$

Step 6: Composing concordance superiority and discordance superiority matrices size are r*c. The concordance threshold value ($\underline{m} = \frac{1}{r(r-1)} \sum_{k=1}^{r} \sum_{l=1}^{r} m_{kl}$) and the discordance threshold value ($\underline{n} = \frac{1}{r(r-1)} \sum_{k=1}^{r} \sum_{l=1}^{r} n_{kl}$) are obtained.

Step 7: The overall dominance matrix has values of 1 or 0 depending on whether it is more or less than the concordance and discordance matrices threshold value.

Step 8: The order of importance of decision points is determined.

Hwang and Yoon devised TOPSIS in 1981, and it contained the same core methods as the ELECTRE method (Hwang & Yoon 1981). The steps of the TOPSIS method as follows;

Step 1: The decision matrix is composed.

Step 2: The standard decision matrix is calculated the Equation (5).

Step 3: The weighted standard decision matrix (x_{ij}) is created by multiplying the elements in each column of the standard decision matrix corresponding weight values.

Step 4: In order to compose an ideal set (x_j^*), the largest of the evaluation factors in the weighted standard decision matrix, are selected. The negative ideal (x_j^-) solution is composed by selecting the smallest of the evaluation factors in the weighted standard decision matrix. If our goal is minimization, the values obtained will be the exact opposite.

Step 5: Calculation of separation measures obtained from are called the ideal distinction ($T_i^* = \sqrt{\sum_{j=1}^{c} (x_{ij} - x_j^*)^2}$) and the negative ideal distinction ($T_i^- = \sqrt{\sum_{j=1}^{c} (x_{ij} - x_j^-)^2}$) measure.

Step 6: Calculation of relative proximity ($U_i^* = \frac{T_i^-}{T_i^- + T_i^*}$) of each decision point to an ideal solution, ideal and negative ideal discrimination measures are used.

3. Results and Discussion

Weighting calculations were encountered in the Çukurova region as a result of expert evaluations within the scope of risk criteria selected from the literature using the AHP technique in this study (Akçaöz & Özkan 2002; Tümer et al. 2010). The decision matrix is composed by using weights with Equations (1-3).

The challenge is complicated by the definition of criteria, and the solution may comprise inconsistencies. The definition of criteria complicates the problem and there may be inconsistencies in the solution. In furthermore, the findings may be prejudiced as expert opinion is sought. Calculating the consistency index minimizes these complications, and Equation (4) can be used to properly apply the strategy (Table 2). Table 2 indicates the Random Index (RI) numbers corresponding to the number of *n* sampling. The AHP consistency index is 0.09, which is less than the desired 0.10 value.

Table 2- Consistency values

n	*3*	*4*	*5*	*6*	*7*	*8*	*9*
RI	0.58	0.90	1,12	1.24	1.32	1.41	1.45

AHP scores were computed by a brainstorming technique while AHP matrices are generated in the study. Points are determined by a total of 3 people, two experts with 3-5 years of work experience and one expert with 5-10 years of experience working in the field of agriculture. When making the scores, the experts included other disciplines in the brainstorming when necessary. Each criterion and its weighting values are given in Table 3 (Bold values). These criteria are determined by considering citrus, legume and cereal alternatives.

Table 3- Weighting by using AHP method

Criteria	*Input costs*	*Changes in climatic conditions*	*Changes in yield loss due to pests*	*Agricultural tools and machinery failure*	*Theft*	*Fire*	*Crop damage due to excessive water*	*Crop loss due to drought*	*Lack of technical information*	*wi*	***Wi***	*V1*	*V2*
Input costs	1	1	5	5	4	3	9	7	9	3.81	**0.29**	2.95	10.30
Changes in climatic conditions	1	1	2	3	5	1	7	7	9	2.87	**0.22**	2.12	9.85
Changes in yield loss due to pests	0.20	0.50	1	2	5	2	7	3	9	1.93	**0.15**	1.51	10.42
Agricultural tools and machinery failure	0.20	0.33	0.50	1	1	2	5	7	9	1.40	**0.11**	1.05	9.93
Theft	0.25	0.20	0.20	1	1	1	3	5	9	1.03	**0.08**	0.77	9.91
Fire	0.33	1.00	0.50	0.50	1.00	1	3	5	8	1.29	**0.10**	0.95	9.74
Crop damage due to excessive water	0.11	0.14	0.14	0.20	0.33	0.33	1	1	7	0.41	**0.03**	0.30	9.81
Crop loss due to drought	0.14	0.14	0.33	0.14	0.20	0.20	1.00	1	6	0.39	**0.03**	0.30	10.13
Lack of technical information	0.11	0.11	0.11	0.11	0.11	0.13	0.14	0.17	1	0.15	**0.01**	0.13	10.80
												λmax=	10.10

The yellow background indicates the scores given by the experts.

Table 1 is principally in the first stage, in light of the scales in the Çukurova region, according to the ELECTRE method; after that, the decision matrix is in Table 4. It is proved by rating the criteria specified for the selection of each alternative crop. The importance scale in Table 1 is used to rate the decision matrix.

Table 4- Composed a decision matrix according to the ELECTRE method

Criterion/Alternatives	*Citrus*	*Cereal*	*Legume*	*Weights*
Input costs	7	3	8	0.29
Changes in climatic conditions	9	8	7	0.22
Changes in yield loss due to pests	8	7	6	0.15
Agricultural tools and machinery failure	5	9	7	0.11
Theft	9	5	7	0.08
Fire	3	9	7	0.10
Crop damage due to excessive water	7	5	9	0.03
Crop loss due to drought	5	7	9	0.03
Lack of technical information	6	3	9	0.01

Each cell in Table 5, the standard decision matrix, has been calculated and rearranged according to Equation (5) in Step 2 of the ELECTRE method.

Table 5- Standard decision matrix by ELECTRE method

Criterion/Alternatives	*Citrus*	*Cereal*	*Legume*	*Weights*
Input costs	0.63	0.27	0.72	0.29
Changes in climatic conditions	0.65	0.57	0.50	0.22
Changes in yield loss due to pests	0.66	0.57	0.49	0.15
Agricultural tools and machinery failure	0.40	0.72	0.56	0.11
Theft	0.72	0.40	0.56	0.08
Fire	0.25	0.76	0.59	0.10
Crop damage due to excessive water	0.56	0.40	0.72	0.03
Crop loss due to drought	0.40	0.56	0.72	0.03
Lack of technical information	0.53	0.27	0.80	0.01

A weighted standard decision matrix is computed by multiplying each cell by the findings of the standard decision matrix discovered using the AHP methodology (Table 6).

Table 6- Weighted standard decision matrix by ELECTRE method

Criterion/Alternatives	*Citrus*	*Cereal*	*Legume*
Input costs	0.18	0.08	0.21
Changes in climatic conditions	0.14	0.13	0.11
Changes in yield loss due to pests	0.10	0.09	0.07
Agricultural tools and machinery failure	0.04	0.08	0.06
Theft	0.06	0.03	0.04
Fire	0.03	0.08	0.06
Crop damage due to excessive water	0.017	0.012	0.022
Crop loss due to drought	0.012	0.017	0.022
Lack of technical information	0.005	0.003	0.008

The following concordance sets (m) were discovered by comparing each row to each other. For items that are not in the concordance set, discordance sets (n) were established. The concordance and discordance sets are shown in Table 7.

Table 7- Concordance and discordance sets according to ELECTRE method

Concordance Sets		**Discordance Sets**	
m_{12}	1,2,3,5,7,9	n_{12}	4,6,8
m_{13}	2,3,5	n_{13}	1,4,6,7,8,9
m_{21}	4,6,8	n_{21}	1,2,3,5,7,9
m_{23}	2,3,4,6	n_{23}	1,5,7,8,9
m_{31}	1,4,6,7,8,9	n_{31}	2,3,5
m_{32}	1,5,7,8,9	n_{32}	2,3,4,6

Table 8 shows the concordance and discordance matrix after establishing their sets.

Table 8- Calculation of concordance and discordance matrix according to ELECTRE method

	Concordance matrix				*Discordance matrix*		
	Citrus	***Cereal***	***Legume***		***Citrus***	***Cereal***	***Legume***
Citrus	-	0.78	0.45	**Citrus**	-	0.5	1
Cereal	0.24	-	0.58	**Cereal**	1	-	1
Legume	0.57	0.44	-	**Legume**	1	0.15	-

The values of concordance and discordance threshold are calculated. The concordance threshold value is 0.51 and discordance threshold value is 0.78. In Table 9, cells that are greater than the concordance and discordance superiority matrix value are given 1 otherwise 0.

Table 9- Concordance and discordance superiority matrix according to ELECTRE method

	Concordance superiority matrix				*Discordance superiority matrix*		
	Citrus	***Cereal***	***Legume***		***Citrus***	***Cereal***	***Legume***
Citrus	-	1	0	**Citrus**	-	0	1
Cereal	0	-	1	**Cereal**	1	-	1
Legume	1	0	-	**Legume**	1	0	-

By multiplying the corresponding cells of the concordance superiority matrix and the discordance superiority matrix, the total dominance matrix in Table 10 is formed.

Table 10- Total dominance matrix by ELECTRE method

	Citrus	**Cereal**	**Legume**
Citrus	-	0	0
Cereal	0	-	1
Legume	1	0	-

As a result of this finding, legumes were preferred over citrus, and the preferred cereal is likewise preferred over legumes. In this instance, cereal is the best option, followed by legume and citrus.

TOPSIS, the MCDM method, uses the same weighted standard decision matrix as the ELECTRE method's first three steps. Table 11 displays the ideal and negative ideal values. Because the risks are not requested to be of significant value, the higher number in the row is the negative ideal result.

Table 11- The ideal and negative ideal values from the weighted standard decision matrix according to the TOPSIS method

Criterion/Alternatives	***Citrus***	***Cereal***	***Legume***	***Ideal***	***Negative Ideal***
Input costs	0.18	0.08	0.21	0.08	0.21
Changes in climatic conditions	0.14	0.13	0.11	0.11	0.14
Changes in yield loss due to pests	0.10	0.09	0.07	0.07	0.10
Agricultural tools and machinery failure	0.04	0.08	0.06	0.04	0.08
Theft	0.06	0.03	0.04	0.03	0.06
Fire	0.03	0.08	0.06	0.03	0.08
Crop damage due to excessive water	0.017	0.012	0.022	0.012	0.022
Crop loss due to drought	0.012	0.017	0.022	0.012	0.022
Lack of technical information	0.005	0.003	0.008	0.003	0.008

After calculations according to TOPSIS method, ideal distinction (T^*), negative ideal distinction (T^-) and relative proximity ($T^- / (T^* + T^-)$) are shown the ranking from the largest value to the smallest value is found in Table 12.

Table 12- Ranking alternatives according to TOPSIS method

Alternatives	T^*	T^-	$T^-/(T^*+T^-)$	*Ranking*
Citrus	0.12	0.07	0.38	2
Cereal	0.07	0.14	0.68	1
Legume	0.14	0.05	0.27	3

Cereal is chosen first in the TOPSIS approach, followed by citrus and legume. This disparity is predicted because both strategies were based on subjective judgements. Depending on the approach and locality, the decision maker can pick which alternative to choose. In the Çukurova region, the subject of which product should be preferred first, given the risk concerns, is a point of contention. The resolution of this debate can be clarified with the help of MCDM methods. The answer to this case is that cereal is a better option with the help of MCDM methods.

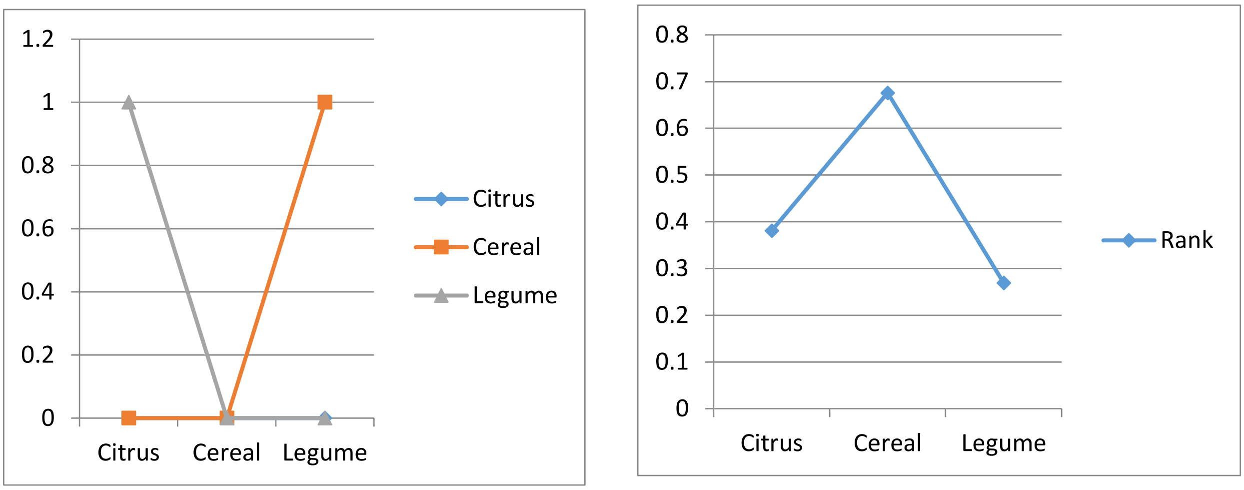

Figure 2- Benchmarking with ELECTRE and TOPSIS

Although the ELECTRE and TOPSIS approaches have identical initial phases, the final steps differ. For both techniques, cereal is the preferable crop (Figure 2). In this study, while cereal priority was observed, Gulluoglu et al. (2017), Bakal et al. (2017) and Arıoglu et al. (2018) focused on legumes (peanut, soybean) in the Mediterranean region. In terms of hazards, our results are preferable to the sort of crop they employed in their experiments. There are also studies on wheat and eucalyptus using MCDM method (Reubens et al. 2011; Sarkar et al. 2014). According to Sarkar et al. (2014), the watershed region was relatively appropriate for wheat crop development, with factors such as inadequate soil depth and inefficient drainage. The input cost criterion, on the other hand, has a high weight value in our analysis. Despite the fact that the criteria were given various weights in these researches, a MCDM method was utilized for crop selection.

4. Conclusions

In terms of environmental preservation and resource sustainability, efficient agricultural land management is critical. Taking into account the hazards in agricultural production might lead to more efficient production. MCDM methods can be used to identify risk strategies in agriculture, which is challenging and complex. The most acceptable crop type for production based on risk parameters encountered in agricultural production was explored in this study. In the Çukurova region, this research was examined at the criteria and alternatives. Input costs, changes in climatic conditions, changes in yield loss due to pests, agricultural tools and machinery failure, theft, fire, crop damage due to excessive water, crop loss due to drought, and lack of technical information were all used to determine AHP weights. The criterion weights were 0.29, 0.22, 0.15, 0.11, 0.08, 0.10, 0.03, 0.03 and 0.01, respectively. The input cost criterion was given the highest weight. The lack of technical information criterion, on the other hand, earned the lowest score. Citrus, cereal, and legume crops were chosen for the study based on geographical conditions. The ELECTRE method's most suited alternate sequencing was determined. By taking the value of cell 1 where legumes cross citrus, it was proposed that legumes would be chosen based on the entire matrix result. Similarly, by assigning a value of 1 to the cell where cereal and legume overlap, it was determined that the cell where cereal and legume intersect would be preferred over the legume in the cereal. It has also been proposed TOPSIS approach, which is another effective decision-making methodology. The respective rankings were 0.68, 0.38 and 0.27. Cereal was the first option, followed by legume. Following the use of the TOPSIS and ELECTRE methodologies, the cereal alternative was shown to be the best in both ways. The ELECTRE approach yielded legumes and citrus, whereas the TOPSIS method yielded the opposite outcome. Cereal can be determined to be the optimal choice, as indicated in our hypothesis. TOPSIS has produced more acceptable outcomes based on expert observations for the region. Another MCDM method can be used to determine the different regions for future crops to be planted. It can be integrated not only in the Çukurova region, but also in locations like the Black Sea, Marmara, and Aegean, based on risk factors. Risk variables (flood, landslide, etc.) and their degrees, for example, can be updated based on precipitation in the Black Sea region, and alternatives for cultivating tea, hazelnut, and chestnut can be calculated.

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