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Performance rating on silvicultural activities of state forest enterprises using fuzzy TOPSIS and SAW methods

Calificación de desempeño en actividades silvícolas de empresas forestales estatales que utilizan métodos difusos TOPSIS y SAW

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SUMMARY

Silvicultural activities are the guiding practices carried out in the forest to achieve the objectives of forest enterprises. The suitability of these activities directly affects the level of achievement of the forest enterprise and thus the performance level. This article discusses how to evaluate the performance of silvicultural activities in forest enterprises. The study was carried out at the state forest enterprises belonging to Denizli forestry regional directorate in Turkey. Eight criteria were generated and also used in the study, which was related to cost, size, and amount of silvicultural activities, natural regeneration, regeneration care, thicket tending care, forest rehabilitation, artificial regeneration, cultivation care and number of staff. These criteria have been weighted by experienced forest engineers through the application of a well-structured surveying method. The criteria are weighted for they were not equally effective on the silvicultural performance of the enterprise. Forest enterprises are open to uncertainties because they work in natural environments, therefore criteria and data are defined as triangular fuzzy numbers. Study results show that the fuzzy technique for order preference by similarity to ideal solution and fuzzy simple additive weighting methods could be used to evaluate the performance of silvicultural activities of state forest enterprises. These methods have been successful in ranking enterprises from the best to the worst. Due to their advantages, these methods have the potential to be used to evaluate the performance of other forestry works.

Key words: silvicultural performance, forest management, Fuzzy TOPSIS, Fuzzy SAW, Turkey.

RESUMEN

Las actividades silvícolas son prácticas orientadoras que se efectúan en el bosque para alcanzar los objetivos de las empresas forestales. La idoneidad de estas actividades afecta directamente el nivel de logro de la empresa forestal y, por lo tanto, el nivel de rendimiento. Este artículo discute cómo evaluar el desempeño de actividades silvícolas en las empresas forestales. El estudio se realizó en las empresas forestales estatales de la Dirección Regional Forestal de Denizli en Turquía. Se generaron y usaron ocho criterios en este estudio relacionados con el costo, tamaño y cantidad de actividades silvícolas, regeneración natural, cuidado de regeneración, cuidado de matorrales, rehabilitación forestal, regeneración artificial, cuidado de cultivo y cantidad de personal. Estos criterios fueron ponderados por ingenieros forestales experimentados mediante la aplicación de un método de reconocimiento bien estructurado. Los criterios fueron ponderados, porque no fueron igualmente efectivos en el desempeño silvícola de la empresa. Las empresas forestales están abiertas a las incertidumbres, porque trabajan en entornos naturales, por lo que los criterios y los datos se definen como números difusos triangulares. Los resultados del estudio mostraron que la técnica difusa para la preferencia de orden por similitud con la solución ideal y los métodos simples de ponderación aditiva difusa podrían usarse para evaluar el desempeño de las actividades silvícolas de las empresas forestales estatales. Estos métodos han tenido éxito en clasificar a las empresas de mejor a peor. Debido a sus ventajas, estos métodos tienen el potencial de ser utilizados para evaluar el desempeño de otros trabajos forestales.

Palabras clave: desempeño silvícola, manejo forestal, Fuzzy TOPSIS, Fuzzy SAW, Turquía.

INTRODUCTION

Forestry is a multidisciplinary profession that consists of biological, technical, economic, social and administrative works to meet continuous society's demand for forest products and services (Helms 1998). As the local conditions are very variable and there are diversified sectorial objectives, forest enterprises have to meet the goals of the national forestry targets and those of the society's multiple demands. In this context, in forest resource management, silvicultural activities are gaining importance. As forestry enterprises have many objectives and very complex structure, the determination of the silvicultural performance level of these enterprises is very challenging.

Silvicultural practices can be designed for any management objective, such as timber, wildlife or biological diversity (Meadows and Stunturf 1997). The primary objective of silvicultural activities is to achieve better wood quality. The silvicultural decisions are affected by the forest species, field conditions, species composition, species associations, diameter distribution and ecological characteristics of forests such as the age of slaughter, management objectives (FAO 2017). In Turkey, state forest enterprises are executing silvicultural activities and various supporting operations to conserve and tend the existing forested lands, utilize and regenerate them and also create new forest areas.

Turkey's forest growing stock is 1.66 billion cubic meters, 98.9 % of this is the high forest, and 1.1 % is the coppice forest. Therefore, 19.08 million cubic meters of industrial wood is produced annually from these forests managed and operated by the state. In Turkey in 2018, natural regeneration of 30,735 ha, artificial regeneration of 10,102 ha, tending (regeneration tending, release cutting and tending) of 463,159 ha, and the rehabilitation of 170,425 ha were made. A total investment of $ 43.78 million was made for these activities (GDF 2019). The activity of state forest enterprises is independent in terms of budget, staff, etc. The performance measurement of these enterprises is mostly made by comparing the activities of other forest enterprises operating under similar conditions (Geray 1982). Methods such as the data envelopment analysis in Kao (2000a), the financial statements analysis in Altunel Açıkgöz (2003), and the ratio analysis in Hajdúchová *et al.* (2017) were used for evaluating the performance of forest enterprises.

On the other hand, multi-criteria decision making (MCDM) techniques are widely used both in performance evaluations and in overcoming problems related to planning in forestry (Diaz-Balteiro and Romero 2008). MCDM techniques such as Analytical Hierarchy Process (AHP) (Yılmaz *et al.* 2004, Kaya and Kahraman 2011), Analytic Network Process (ANP) (Wolfslehner *et al.* 2005), ELimination Et Choix Traduisant la REalité (ELECTRE) (Pauwels *et al.* 2007), The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Stoms *et al.* 2009, Korkmaz and Gürer 2018), Simple Additive Weighting (SAW) (Yılmaz *et al.* 2011) and Data Envelopment Analysis (DEA) (Kao 2000b) have been commonly utilized for planning of forest resources in recent years.

At the evaluation stage of the MCDM method, it is assumed that values and weights of criteria were known exactly (Chu and Lin 2009). However, some preferences including information/knowledge such as human judgments were inadequate for modeling the real-life situations. Besides, preferences for types of data such as bounded data, interval data, ordinal data and fuzzy data cannot be assessed with exact numeric data (Jahanshaloo *et al.* 2006). In such environments, decisions are being given using the fuzzy logic system that is developed by Zadeh (Zadeh 1965). The uncertainty problems were investigated with interval-valued fuzzy data/sets (Zadeh 1965, Liu 2011), triangular membership function (Chen 2000, Sun 2010, Sagar *et al.* 2013) and trapezoidal membership functions (Liu 2011).

Because they work in open conditions, forest enterprises have to work with a large number of input and output variables that are uncertain. This study is aimed at evaluating the performance of state forest enterprises in Turkey, and since there are few studies on silvicultural performance, it has been decided to examine silvicultural performance. In this context, in literature, DEA (Zhang 2002), fuzzy DEA (Şafak *et al.* 2014), ELECTRE III (Pauwels *et al.* 2007), Stochastic Frontier Analysis (SFA) (Lien *et al.* 2007) and fuzzy TOPSIS (Prato and Paveglio 2014) techniques have been used to evaluate the performance of silvicultural activities. Shape, size, violence, financial burden, advantages of the silvicultural activities differ depending on to the geographical and economic structure of each enterprise. Therefore, it is important to perform a silvicultural performance assessment using MCDM methods that take into account fuzzy logic.

In this study, it was tested whether fuzzy TOPSIS and fuzzy SAW methodology are suitable to evaluate the silvicultural performance of forest enterprises. In this context, both internal and external evaluations of the state forest enterprises affiliated to the same top institution in terms of silvicultural aspects were made. For this purpose, it was aimed to i) show which criteria can be used based on silvicultural activities, ii) determine the weights of these criteria, iii) on a real-world scale by applying these criteria determine the performance of state forest enterprises in a forest region, and iv) evaluate the applicability of these methods within the scope of the silvicultural performance analysis.

METHODS

Study area. Turkey's forest assets are 22.62 million hectares, which covers 29 % of the surface area of the country. High forest corresponds to 94.70 % of these forests and 5.30 % are operated as the coppice forest. State forests in Turkey are divided into 28 forest regions. In addition, each region is divided into an average of nine forest enterprises and each enterprise into an average of five forest districts (GDF 2019). In this study, a performance evaluation was made on the scale of forest enterprises. Denizli Forestry Regional Directorate (DFRD) has been chosen as the study area due to its physical characteristics, being in the transition zone and performing many silviculture activities. This area in the western part of Turkey has divided Acıpayam, Çal, Çameli, Denizli, Eskere, Tavas and Uşak State Forest Enterprises.

Method. To evaluate the silvicultural performance of these forest enterprises between 2016-2018, the criteria set was firstly developed to determine which activities were important and symbolize silvicultural operations. The activities of Denizli Forest Enterprise Directorate in the field of silviculture were taken into consideration in the creation of the criteria set. Expert forest engineers were used to determine the weights of these criteria. Afterwards, the fuzzy TOPSIS and fuzzy SAW methods were used to determine the silvicultural score of the highest enterprise. Which of these methods is effective was determined by producing a solution set according to both methods.

Developing criteria set. The following eight criteria were used to evaluate the silvicultural performance of these forest enterprises:

- Cost of silvicultural activities (x_1): It covers all of the cost of activities such as natural regeneration, regeneration tending, release cutting, forest rehabilitation, artificial regeneration and tending (as United States dollar ($)).
- The amount of natural regeneration area (x_2): It expresses the area (hectare) of natural regeneration that is achieved by a forest enterprise. Natural regeneration is a process by which woodlands are restocked by trees that develop from seeds that fall and germinate *in situ*.
- The amount of regeneration tending area (x_3): It expresses the area (hectare) of regeneration tending (natural growth) that is achieved by a forest enterprise. Regeneration tending is the maintenance process in young forest areas established by natural regeneration.
- The amount of release cutting area (x_4): It expresses the area (hectare) of release cutting that is achieved by a forest enterprise. Release cutting is the process of reducing the number of individuals (trees) in forest areas according to the objectives of the forest enterprise.
- The amount of forest rehabilitation area (x_5): It expresses the area (hectare) of forest rehabilitation that is achieved by a forest enterprise. Reforestation etc. silvicultural studies conducted in forests whose natural structure has been damaged for various reasons in the past.
- The amount of artificial regeneration area (x_6): It expresses the area (hectare) of artificial regeneration (reforestations) that is achieved by a forest enterprise. Artificial regeneration is generally the process of planting saplings grown in nurseries in forest areas.
- The amount of tending area (x_7): It expresses the area (hectare) of tending that is achieved by a forest enterprise. Tending is the maintenance process in young forest areas established by artificial regeneration.
- Number of staff (x_8): It expresses the total number of personnel (engineer, forest ranger, worker, etc.) in the forest enterprise. Since it is desired to have a low value in the performance evaluation of the variable of the number of staff, this variable has been normalized within the scope of cost minimization.

While these criteria show the performance of an enterprise, the expenses are expected to be the lowest and the other activities are expected to be the highest. In this context, in this study, cost minimization was taken into account in normalization of the variables of cost of silvicultural activities (x_1), and number of staff (x_8). Benefit maximization was performed in the normalization of other variables. In table 1, the data for the silvicultural performance of forest enterprises in 2016-2018 are seen.

Weighting the criteria set. An order of importance/priority was needed to find out which of the developed criteria set content was more dominant, effective or important in measuring silvicultural activities. For this; expert forest engineers -who have professional experience and can understand the technical, economic and ecological effects of forestry activities- were used. Contact was made with forest engineers (21 persons) who were considered to be in accordance with these characteristics and 14 of them voluntarily participated in this study. These expert forest engineers (14 forest engineers) consist of one forest enterprise manager, two deputy enterprise managers, three forest districts chiefs, three engineers of branch managers, four branch managers and one deputy regional director. The average working time of the expert forest engineers participating in the assessment was 17.93 years.

The expert forest engineers were asked to sort out which of the above eight criteria was more important and what the importance of the others should be. These importance data were used as weight data in Fuzzy TOPSIS and Fuzzy SAW methodology (table 2).

Fuzzy TOPSIS method. The TOPSIS method is one of MCDM methods which allows choosing among alternatives according to certain criteria. In the application of the TOPSIS method, there are some processes that numerically determine the relative importance of criteria and the performance of each alternative in terms of these criteria (Park *et al.* 2011). The method has been commonly used in recent years for solving MCDM problems. In this paper, the fuzzy TOPSIS method that was developed by Chen (2000) was used to evaluate the silvicultural performance of forest enterprises. This algorithm of fuzzy TOPSIS is explained below with general headings.

Step 1. Criteria and their weights are determined. In the determination of the importance level of each criterion were used linguistic values such as very good (0.9; 1; 1), good (0.7; 0.9; 1), medium good (0.5; 0.7; 0.9), fair (0.3; 0.5; 0.7), medium poor (0.1; 0.3; 0.5), poor (0; 0.1; 0.3) and very poor (0; 0; 0.1).

$$\widetilde{w} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n]$$

Table 1. The silvicultural data of forest enterprises between 2016-2018 years.
Datos silvícolas de las empresas forestales entre los años 2016-2018.

Forest enterprises	x_1*			x_2			x_3			x_4		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
Acıpayam	258,502	284,834	345,163	238	375	186	1,150	1,429	1,485	3,415	2,513	2,475
Çal	332,538	263,592	360,451	239	90	207	550	704	677	1,549	2,690	2,090
Çameli	216,031	218,498	185,436	292	265	211	1,250	1,238	1,054	1,172	824	646
Denizli	429,681	383,707	649,896	147	195	190	751	756	930	3,095	4,051	4,676
Eskere	127,676	126,903	144,286	144	140	160	550	638	814	552	635	631
Tavas	310,419	269,357	287,774	217	276	284	1,250	1,154	1,225	2,972	3,595	3,310
Uşak	405,970	331,107	373,671	439	312	148	1,200	1,355	1,513	2,660	2,036	2,041

Forest enterprises	x_5			x_6			x_7			x_8		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
Acıpayam	145	121	306	80	103	183	1,000	1,181	691	80	79	77
Çal	1,811	290	271	109	64	91	1,500	1,313	1,360	75	75	73
Çameli	266	154	231	1	1	1	60	49	41	44	44	43
Denizli	1,112	557	1,329	176	127	501	2,200	1,820	2,086	172	171	167
Eskere	125	105	67	22	9	1	240	188	130	40	45	42
Tavas	275	258	323	143	76	92	700	589	701	69	65	61
Uşak	684	455	518	74	161	124	1,100	990	770	147	138	146

*The average exchange rates are 3.0213 $/TL in 2016, 3.6449 $/TL in 2017, and 4.8134 $/TL in 2018.

Table 2. Criteria weights.
Criterios de ponderación.

Criteria	Lower (L)	Median (M)	Upper (U)
x_1	0.9	1.0	1.0
x_2	0.7	0.9	1.0
x_3	0.5	0.7	0.9
x_4	0.5	0.7	0.9
x_5	0.3	0.5	0.7
x_6	0.3	0.5	0.7
x_7	0.5	0.7	0.9
x_8	0.3	0.5	0.7

Step 2. Fuzzy decision matrix ($\tilde{D}$) is formulated. In Formula 1, fuzzy ($\tilde{x}_{ij}$) variables refer to the silvicultural data of forest enterprises between 2016-2018.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad [1]$$

$$\tilde{x}_{ij} = (a_{ij}, b_{ij,}\, c_{ij}) \qquad i = 1,2,\dots,m; \;\; j = 1,2,\dots,n$$

Step 3. Normalized fuzzy decision matrix ($\tilde{R}$) is formulated.

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n} \quad [2]$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij,}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \qquad j \in B;$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \qquad j \in C;$$

$$c_j^* = \max_i c_{ij} \qquad if\ j \in B;$$

$$a_j^- = \min_i a_{ij} \qquad if\ j \in C;$$

Step 4. Weighted normalized fuzzy decision matrix ($\tilde{V}$) is formulated.

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{w}_j \quad [3]$$

Step 5. The fuzzy positive-ideal solution (PIS) (A^*) and the fuzzy negative-ideal solution (NIS) (A^-) are formulated.

$$A^* = [(1;1;1); (1;1;1); \dots; (1;1;1)] \quad [4]$$

$$A^- = [(0;0;0); (0;0;0); \dots; (0;0;0)] \quad [5]$$

Step 6. Distances of each alternative from A^* and A^- are formulated.

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), \qquad i = 1,2,\dots,m \qquad [6]$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), \qquad i = 1,2,\dots,m \qquad [7]$$

Step 7. The closeness coefficients (CC_i) of each alternative are formulated.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \qquad i = 1,2,\dots,m \qquad [8]$$

Fuzzy SAW method. Fuzzy SAW method was used in addition to fuzzy TOPSIS to test whether the determined criteria set yields the same result in terms of performance. The SAW method is probably among the known and widely used method in MDMC. The method is based on the weighted average using the arithmetic mean (Abdullah and Rabiatul Adawiyah 2014). This method aims at selecting the alternative that provides the highest value (Ezquerro *et al.* 2016). Fuzzy SAW method is the combination of both fuzzy MDMC method and SAW method (Sagar *et al.* 2013).

The various steps of Fuzzy SAW method are presented as follows (Kao 2000b, Demircioğlu 2010).

Step 1. Choosing the criteria (C_j) that will be used as a reference in decision-making.

Step 2. The suitable rating of the criteria weights was assigned in terms of linguistic variables by the experts.

Step 3. Equivalents of weights in terms of triangular fuzzy numbers are determined and a fuzzy weight matrix is defined. The elements of the fuzzy weight matrix are defuzzified. In formula (9), a_j, b_j, and c_j denote the elements of the triangular fuzzy numbers in the fuzzy linguistic weight matrix.

$$d(\tilde{w}_j) = \frac{1}{3}(a_j + b_j + c_j) \; ; \; j = 1,2,\dots,n \qquad [9]$$

In formula 3, a, b, and c denote the elements of a triangular fuzzy number.

Step 4. After the defuzzified operation, the normalized values of the weights (w_j) are obtained. Here the sum of the weights is equal to 1.

$$W_j = \frac{d(\tilde{w}_j)}{\sum_{j=1}^{n} d(\tilde{w}_j)} \quad ; \quad j = 1,2,\dots,n \qquad [10]$$

$$\sum_{j=1}^{n} W_j = 1 \qquad [11]$$

Step 5. Minimization and maximization targets are taken into account, and the triangular fuzzy number equivalents of the factors are determined. Later, fuzzy decision matrix $(\tilde{D})$ is created. In formula (12), fuzzy ($\tilde{x}_{ij}$) variables refer to the silvicultural data of forest enterprises between 2016-2018.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \qquad [12]$$

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \qquad i = 1,2,\dots,m; \; j = 1,2,\dots,n$$

Step 6. Fuzzy decision matrix elements $(\tilde{D})$ are multiplied by factor weights (w_j). The calculated matrix $(d(\tilde{f}_j))$ is then defuzzified. As a result, the total results scores for each decision alternative were determined by the Fuzzy SAW method. In formula (14), r_j, s_j, and t_j denote the elements of the triangular fuzzy numbers in the calculated matrix.

$$\tilde{F} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \otimes \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \tilde{f}_1 \\ \tilde{f}_{12} \\ \vdots \\ \tilde{f}_n \end{bmatrix} \qquad [13]$$

$$(d(\tilde{f}_j) = \frac{1}{3}(r_j + s_j + t_j) \; , \; j = 1,2,\dots,n)$$

Step 7. The total result values for each decision alternative are sorted from large to small. The alternative with the highest value is considered the highest priority alternative.

In this study, matrices in the Fuzzy TOPSIS and Fuzzy SAW methods are solved using Microsoft Office Excel 2016 according to the order of operation.

RESULTS

The data of the normalized fuzzy decision matrix (table 3), which was calculated by taking into consideration the criteria for the silvicultural performance of forest enterprises in 2016-2018, were used in both the fuzzy TOPSIS and the fuzzy SAW methods as the same.

In the analysis conducted within the scope of Fuzzy SAW, minimization and maximization targets are taken into account, and the triangular fuzzy number equivalents of the factors are determined. Later, a fuzzy decision matrix $(\tilde{D})$ is created. Fuzzy decision matrix elements $(\tilde{D})$ are multiplied by factor weights (w_j). In this context, the normalized criteria weights presented in table 4 were used as factor weights (w_j). The calculated matrix $(d(\tilde{f}_j))$ is then defuzzified. As a result, in table 5, the total silvicultural performance scores for each forest enterprises were determined by fuzzy SAW method.

In the analysis conducted within the scope of Fuzzy TOPSIS, $\tilde{D}$ and $\tilde{R}$ matrices were created to evaluate the data of the silvicultural performance of the forest enterprises between 2016-2018. Later, $\tilde{V}$ matrix was formed. In this context, the weight values presented in table 2 were used in the weighted normalized fuzzy decision matrix ($\tilde{V}$). The distances of each alternative to the $\mathbf{A}^*$ and $\mathbf{A}^-$ were calculated separately with the vertex method. Calculated distance values $\mathbf{d}^*$ and $\mathbf{d}^-$ are expressed. In the final step, in table 5, the ranking order of silvicultural performance of forest enterprises was obtained. Closeness coefficients of each alternative were calculated with the equation (no 8). Thus, the ranking order of silvicultural performance of forest enterprises was obtained (table 5).

As a result (table 5), the total silvicultural performance scores for each forest enterprise were determined by fuzzy TOPSIS and fuzzy SAW method. As expected, both fuzzy TOPSIS and fuzzy SAW methods achieved the same results. In terms of silvicultural activities, Denizli forest enterprise was the best forest enterprise between 2016-2018. After Denizli forest enterprise the ranking order was Tavas, Acıpayam, Uşak, Çal, Çameli and Eskere respectively. In this period, Uşak forest enterprise has shown the worst performance in terms of silvicultural activities.

Table 3. Data of normalized fuzzy decision matrix used in fuzzy TOPSIS and fuzzy SAW methods.
Datos de la matriz de decisión difusa normalizada utilizada en los métodos difusos TOPSIS y SAW.

Forest enterprises	x_1			x_2			x_3			x_4		
	L	M	U	L	M	U	L	M	U	L	M	U
Acıpayam	0.418	0.446	0.494	0.542	0.655	1.000	0.920	0.981	1.000	0.529	0.620	1.000
Çal	0.384	0.400	0.481	0.240	0.544	0.729	0.440	0.447	0.493	0.447	0.454	0.664
Çameli	0.581	0.591	0.778	0.665	0.707	0.743	0.697	0.866	1.000	0.138	0.203	0.343
Denizli	0.222	0.297	0.331	0.335	0.520	0.669	0.529	0.601	0.615	0.906	1.000	1.000
Eskere	1.000	1.000	1.000	0.328	0.373	0.563	0.440	0.446	0.538	0.135	0.157	0.162
Tavas	0.411	0.471	0.501	0.494	0.736	1.000	0.808	0.810	1.000	0.708	0.870	0.887
Uşak	0.314	0.383	0.386	0.521	0.832	1.000	0.948	0.960	1.000	0.436	0.503	0.779
Forest enterprises	x_5			x_6			x_7			x_8		
	L	M	U	L	M	U	L	M	U	L	M	U
Acıpayam	0.080	0.217	0.230	0.365	0.455	0.640	0.331	0.455	0.649	0.500	0.545	0.557
Çal	0.204	0.521	1.000	0.182	0.398	0.619	0.652	0.682	0.721	0.533	0.575	0.587
Çameli	0.147	0.174	0.276	0.002	0.005	0.006	0.020	0.026	0.027	0.909	0.977	1.000
Denizli	0.614	1.000	1.000	0.789	1.000	1.000	1.000	1.000	1.000	0.233	0.251	0.257
Eskere	0.050	0.069	0.189	0.002	0.056	0.125	0.062	0.103	0.109	0.978	1.000	1.000
Tavas	0.152	0.243	0.463	0.184	0.472	0.813	0.318	0.324	0.336	0.580	0.677	0.689
Uşak	0.378	0.390	0.817	0.248	0.420	1.000	0.369	0.500	0.544	0.272	0.288	0.319

Table 4. Normalized criteria weights used in fuzzy SAW method.
Pesos de criterios normalizados utilizados en el método difuso SAW.

Criteria	Weight value
x_1	0.178
x_2	0.159
x_3	0.129
x_4	0.129
x_5	0.092
x_6	0.092
x_7	0.129
x_8	0.092

Table 5. Results of Fuzzy TOPSIS and Fuzzy SAW.
Resultados de Fuzzy TOPSIS y Fuzzy SAW.

Forest enterprises	Fuzzy TOPSIS		Fuzzy SAW	
	CC_n	Ranks	Final scores	Ranks
Acıpayam	0.398	3	0.586	3
Çal	0.345	5	0.512	5
Çameli	0.323	6	0.478	6
Denizli	0.448	1	0.648	1
Eskere	0.306	7	0.444	7
Tavas	0.402	2	0.592	2
Uşak	0.388	4	0.575	4

DISCUSSION

Forest enterprises are active to meet the forest products and services demands of human societies. Hörnfeldt and Ingemarson (2006) stated that the primary objectives of forest enterprises are to produce valuable products, to preserve biodiversity and to take into account public interests. During the fulfillment of duties and responsibilities, many decisions that have biological, technical, social, cultural, economic etc. aspects are taken by managers. During the planning and preparing of these decisions, multi-criteria techniques are usually used. The fuzzy TOPSIS and fuzzy SAW methods are the commonly used techniques in forestry.

In this study, the effectiveness of the decisions of seven forest enterprise directorates under similar conditions on silviculture is evaluated by fuzzy TOPSIS and fuzzy SAW methods. Thus, in terms of silvicultural activities, forest enterprises are ranked from the best to the worst. Forest enterprise directorates, which are in the last place (for example, Eskere ve Çameli), should take the example of the best forest enterprises (for example, Denizli and Tavas) to be more effective. This forest enterprise should plan its activities taking the example of the best forest enterprises.

The determination of the highest performance forest enterprise directorate is important in terms of giving an answer to some questions of interest groups about whether these enterprises are operating effectively. The interest groups demand that the taxes they pay be spent in appropriate activities by the state forest enterprise directorates, which is a public institution. Therefore, it is desirable for managers to control all the criteria used in performance measurements. However, forest resource managers may not have a direct impact on some fixed criteria such as "amount of forest area" (also some criteria in natural conditions) that affect performance. Such criteria affect the managerial ability of forest resource managers positively or negatively depending on the situation. For this reason, forest resource managers have to choose the most appropriate technology in the criteria (such as silviculture costs) that is correctly related to the work done to work effectively. Such appropriate decisions will increase the effectiveness of the managers and also forest enterprise directorates.

McKenney (2000) and FAO (2017) stated that the severity of silvicultural decisions affects topics such as the growth rate of forests, the quality of forests, the level of technology use, environmentally friendly practices, accessibility, marketing opportunities, product quality, management objectives and ownership. For this reason, forest resource managers have to choose among the combinations that provide the lowest costs, use the highest technology, take into account the most environmentally friendly practices and support rural development. This choice requires both to produce higher quality data and to use different multi-criteria decision-making techniques.

Silvicultural practices, such as natural generation or artificial regeneration, care of regeneration and cultivation, pre-commercial thinning care, rehabilitation practices and control of stand density affect both product quality and the sustainability of forest resources. Hörnfeldt and Ingemarson (2006) reported that suitable silvicultural practices help protect nature, while severe silvicultural practices increase soil erosion. As emphasized in this study, the variety and intensity of silvicultural activities directly affect the success of forest enterprises.

Nilsson *et al.* (2016) states that the decisions regarding forest resources must take into account not only economic aspects but also factors such as ecological and social values. In the analysis with multi-criteria decision-making techniques, the best silviculture plan decision is affected by targets, criteria and the weight or priority level of stakeholders. In this study, the criteria weighted by forest engineers were used to determine the forest enterprise directorates that gave the best silvicultural decision.

As with most of the multi-criteria decision-making techniques, the fuzzy TOPSIS and fuzzy SAW techniques are not desired to have too many variables. The number of variables should not be more than 9, which makes the human brain difficult to compare (Geray *et al*. 2007). For this reason, the number of variables was determined as 8 in this study. Similarly, the number of forest enterprise directorates whose performance will be measured is not desired to increase. As a matter of fact, the sum of the variable values of enterprises is converted to 1 by the normalization process. This process causes the variable values to be too close or equal due to decimal rounding in data close to each other. This situation reduces the separation ability of the fuzzy TOPSIS and fuzzy SAW techniques.

The method presented in this study has brought a useful approach to the comparison of forest enterprises that perform almost the same activity in line with the same criteria, and to determine the degree of success and ranking of success. This study for silviculture activities can be applied to other activities of forestry, and can be a guide for calculating the success of enterprises and determining the success rankings.

CONCLUSIONS

In this study, how silvicultural decisions taken by forest enterprises can be compared with MCDM techniques is discussed. In this context, the silvicultural decisions of seven state forest enterprises operating under similar conditions were compared with fuzzy MCDM techniques. For this purpose, Fuzzy TOPSIS and Fuzzy SAW methodology were used in this study. The same performance ranking was achieved in both methods.

In this study, eight criteria related to the cost of silvicultural activities, the amount of the natural regeneration area, the regeneration tending area, the release cutting area, the forest rehabilitation area, the artificial regeneration area, the tending area and the number of staff were determined and these criteria were used. The results of the study show that fuzzy TOPSIS and fuzzy SAW methods can be used to evaluate the performance of silvicultural decisions of state forest enterprises with these criteria. These methods have been successful in ranking businesses from the best to the worst. Because of their advantages, these methods have the potential to be used to evaluate the performance of forest enterprises' decisions on other issues such as wood production, forest protection, wildfire fighting, biodiversity, recreation and clean water supply.

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