Journal of Forests
2021 Vol. 8, No. 1, pp. 13-22.
ISSN(e): 2409-3807
ISSN(p): 2413-8398
DOI: 10.18488/journal.101.2021.81.13.22

SELECTION OF SUPERIOR CLONES BY THE MULTI-DIMENSIONAL DECISION-MAKING TECHNIQUES IN SCOTS PINE SEED ORCHARD

Erol Imren[1]
Rifat Kurt[2]
Cengiz Yucedag[3+]
Nebi Bilir[4]
Halil Baris Ozel[5]
Mehmet Cetin[6]
Hakan Sevik[7]

[1,2]*Department of Forestry Industry Engineering, Faculty of Forestry, Bartin University, Bartin, Turkey.*
[1]*Email: eimren@bartin.edu.tr*
[2]*Email: rkurt@bartin.edu.tr*
[3]*Department of Landscape Architecture, Faculty of Engineering & Architecture, Burdur Mehmet Akif Ersoy University, Burdur, Turkey.*
[3]*Email: yucedagc@gmail.com Tel: +9002482132785*
[4]*Department of Forest Engineering, Faculty of Forestry, Isparta University of Applied Sciences, Isparta, Turkey.*
[4]*Email: nebilir@hotmail.com*
[5]*Department of Forest Engineering, Faculty of Forestry, Bartin University, Bartin, Turkey.*
[5]*Email: halilbarisozel@bartin.edu.tr*
[6]*Department of Landscape Architecture, Faculty of Engineering and Architecture, Kastamonu University, Kastamonu, Turkey.*
[6]*Email: mcetin@kastamonu.edu.tr*
[7]*Department of Environmental Engineering, Faculty of Engineering and Architecture, Kastamonu University, Kastamonu, Turkey.*
[7]*Email: hsevik@kastamonu.edu.tr*

(+ Corresponding author)

Article History
Received: 9 April 2020
Revised: 11 January 2021
Accepted: 22 January 2021
Published: 4 February 2021

Keywords
Clone
Multi-dimensional decision-Making technique
Pinus sylvestris
Root collar diameter
Seedling height.

ABSTRACT

The living conditions of living beings are becoming ever more difficult due to the climate change caused by industrialization. Forests, which have a great importance in terms of natural resources, are one of the main elements which prevent this situation. Therefore, it is important to ensure the sustainability of forests and to increase their genetic and structural quality. Appropriate farms and clonal seed orchards should be established with the purpose of achieving this genetic diversity. This way, quantitative traits of clones, which are located in these seed orchards, depending on their growth performance, the cone yield can be determined. In this study, the best clones in terms of cone yield were determined through MAUT and WASPAS methods, which are some of the multiple criteria decision-making techniques. This was done by using the height and diameter measurements of 30 Scots pine (*Pinus sylvestris* L.) clones selected according to random sampling method in 3 different blocks in Erzurum region. Based on the sum product assessment and multi-attribute utility theory model results, clones 22 and 29 were determined as superior and prospective for further breeding procedures in terms of seedling height and root collar diameter. According to the entropy method, the maximum weights for seedling height and root collar diameter were obtained in Block-3 with 0.580175 and in Block-1 with 0.590017, respectively.

Contribution/Originality: This study plays important role in selecting the best clones in terms of cone yield through MAUT and WASPAS methods, which are some of the multiple criteria decision-making techniques.

1. INTRODUCTION

The adverse effects of global climate change on life are increasing each passing day. Environmental pollution increasing due to industrialization and the excessive destruction of fossil-based natural resources due to high energy need increase global warming and take away the optimum living conditions by disrupting the ecological balance. Carbon emulsion is one of the most infamous culprits that cause global warming. In order to prevent this situation, carbon gases released from various sources should be stored before they reach the atmosphere and damage the ozone layer. The forests, which are the primary resources capable of producing oxygen, have a positive effect on carbon storage in all ages. For this reason, it is the common duty of the humanity and forestry sectors across the globe to ensure the continuity of forests that are blessed with various raw materials, and that have functional benefits and to increase the genetic and structural quality of forests [1, 2]. However, according to the latest statistics announced by FAO [3] 35.6% of the world's forest resources were destroyed by fires, water and wind erosion and over logging in 2018, and in this context, a majority of the world countries transformed more than half of their natural forest resources into forests with protected status with soil and water conservation purposes.

The reduction of social pressure on natural forest resources is the leading measures to be taken in this respect. Thus, special industrial plantations, where particularly wood, paper and firewood raw materials can be supplied from, should be established with the suitable origin and clones of fast growing forest tree species.

For this purpose, it is necessary to establish important gene pools such as clonal seed orchards in order to identify appropriate clones and to grow and use seedlings from the healthy and high quality seeds collected at low cost in a short time. On the other hand, there is a need for seed orchards and seed plantations in order to preserve the existence of forest gene pools within and outside the natural range.

It is very important to assess the clones used in the seed orchards in terms of seed yield and their suitability for growing seedlings and to identify the best clones. As this clone prioritization and identification ensures low cost and saves time in terms of production, it is also very important in terms of transferring genetic gain to new generations and determining the rate [4]. Within this context, the determination of the quantitative traits of the growth performance of clones located in the seed orchard guides both the evaluation of actual ecological conditions at the point, where the seed orchard is located, and guides the sorting of the clones from the best to the worst in terms of seed yield [5].

MCDM is the method ensuring the selection of the best choice among the multiple and simultaneously applied criteria [6]. MCDM technique is a discipline including many fields such as mathematics, science, business, informatics, psychology, social sciences and economics and many different methods are developed to solve these kinds of problems [7].

The MCDM process typically defines objectives, chooses the criteria to measure the objectives, specifies alternatives, transforms the criterion scales into commensurable units, assigns weights to the criteria that reflect their relative importance, selects and applies a mathematical algorithm for ranking alternatives, and chooses an alternative [8-12]. The primary purpose of MCDM problems is to identify the best alternative that provides the highest level of satisfaction in terms of all relevant criteria [13, 14].

2. MATERIAL AND METHOD

2.1. Materials

This research was carried out in Erzurum province of Turkey in 1990 on 30 clones with Kars-Sarikamis origin in Scots pine (*Pinus sylvestris* L.) clonal seed orchards that was established as 3 random blocks. The grafted Scots pine seedlings were planted at a distance of 7 × 7 m. The soil structure of the area has a sandy-clay texture. The soil structure is fragmental and deep soil conditions prevail. In the research area, the average temperature is 5.7 °C, and the average rainfall is 763.8 mm [4, 15].

2.2. Methods

2.2.1. Field Measurements

The length and the breast height diameters were measured on a total of 270 Scots pine trees by measuring each individual block and 3 individuals belonging to each clone located in the seed orchard established as 3 blocks. Laser digital length gauge and diameter gauge are used for these measurements and mean values of the measurement values are given in Table 1.

Table-1. The weight values obtained by the entropy method.

Weighting	Block-1	Block-2	Block-3	$\sum_{j=1}^{n} w_{ij}$
Height	0.127279	0.292546	0.580175	1
Diameter	0.590017	0.306609135	0.103374	1

2.2.2. Entropy Method

The concept of entropy emerged as the measurement of irregularity and uncertainty in thermodynamics by Rudolph Clausius in 1865 [16]. This concept was then written in literature as the concept of information entropy by Claude E. Shannon in 1948 and was formulated based on probability theory [17].

In information entropy, the number or the quality of information is one of the determinants of the decision making problem's accuracy and reliability [18]. Accordingly, the objective weights of the attributes are determined by how different or differentiated the outputs of the alternatives are according to each attribute, that is to say by the "density of contrast". The more this contrast is, the more information, which is covered and transmitted by the related trait, is. As the entropy value decreases, the level of impairment in the system also decreases. The procedures for the entropy method are specified in steps. D matrix is the decision matrix with m alternatives and n criteria [19-24];

Step 1: Creating a decision matrix using the Equation 1;

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \qquad (i = 1,2, \ldots . m, \text{and } j = 1,2, \ldots . n) \qquad (1)$$

Step 2: Obtaining the normalized decision matrix $R = [r_{ij}]_{mxn}$;

Using the Equation 2; normalized decision matrix is obtained.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad i= 1, 2, \ldots m, \text{ and } j=1,2,\ldots n \qquad (2)$$

Step 3: Entropy values for each criteria are calculated by Equation 3;

$$e_j = -k \sum_{i=1}^{m} r_{ij} ln r_{ij} \qquad , \text{ j} = 1,2, \ldots \text{n} \qquad (3)$$

Where,

k: entropy coefficient ($k = \frac{1}{\ln m}$)

e_j: entropy value

Step 4: Calculation of the degree of divergence $(d_j = 1 - e_j)$;

Finally, Entropy Criterion Weights(Wj) are obtained by Equation 4.

$$W_j = \frac{1-e_j}{\sum_{i=1}^{n}(1-e_{ij})} \qquad , \text{ j} = 1,2, \ldots \text{n} \tag{4}$$

2.2.3. MAUT Method

Multi-Attribute Utility Theory (MAUT), which is a very useful method for intuitive formulating and decision making problems, is one of the multi-criteria decision making methods that was started to be used by Fishburn [25] and Keeney and Raiffa [26]. The MAUT approach can be summarized as follows [7, 24].

Step 1: Weights are assigned to the weight values (W_j) that ensure the correct evaluation of the criteria and set the priorities. The sum of all weight values should be equal to 1 as in the Equation 5.

$$\sum_{j=1}^{n} W_j = 1 \tag{5}$$

Step 2: Values are normalized using Equation 6 for utility criteria.

$$r_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \qquad , i = 1,2, \ldots . m, \text{and } j = 1,2, \ldots . n \tag{6}$$

Step 3: The final benefit value of each alternative is calculated by adding the benefits of alternatives to different properties as in the Equation 7;

$$U_i = \sum_{j=1}^{n} w_j r_{ij} \tag{7}$$

2.2.4. WASPAS Method

WASPAS (Weighted Aggregated Sum Product Assessment) is the combination of WSM (Weighted Sum Model) and WPM (Weighted Product Model), which are the multi-criteria decision making techniques [27]. The alternatives are ranked through combined optimality criteria calculated using the relevant methods. The method can also examine the consistency of alternative rankings by conducting sensitivity analysis within its own course Chakraborty and Zavadskas [28]; Yurdoglu and Kundakci [29]. Zavadskas, et al. [30] stated that the model they proposed was more accurate than other methods [30, 31]. WASPAS consist of the following steps [28, 30, 32-34].

Step 1: In the first stage, the initial criterion values are normalized using Equation 8.

$$\bar{x}_{ij} = \frac{x_{ij}}{\max x_{ij}} \qquad i = 1,2, \ldots . m, \text{and } j = 1,2, \ldots . n \tag{8}$$

Step 2: The total relative importance of the alternative i based on WSM and WPM are calculated. The Equation 9 and Equation 10 are used for these methods.

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j \tag{9}$$

$$Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \tag{10}$$

Step 3: The joint generalized criteria of weighted aggregation of additive and multiplicative methods are calculated [35, 36].

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} = 0.5 \sum_{j=1}^{n} \bar{x}_{ij} w_j + 0.5 \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \tag{11}$$

Step 5: In the last stage of the method, the Equation 12 is used to determine the relative importance of the alternatives with the WASPAS method, in order to make an accurate and effective ranking of the decision alternatives.

$$Q_i = \lambda \sum_{j=1}^{n} \bar{x}_{ij} w_j + (1-\lambda) \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \qquad \lambda = 0, \dots, 1 \tag{12}$$

3. RESULTS

3.1. Determination of the Weights through Entropy

First of all, the decision matrix was normalized by means of the Equation 2 based on the data belonging to a total of 30 clones in 3 different blocks located in the seed orchard. Then, each normalized criterion value *(r_{ij})* was multiplied by these values (r_{ij} x In_{ij}) by taking the logarithm values (In_{ij}), and *eij* values were calculated by using the Equation 3. Here, *k* was calculated as $k = \frac{1}{\ln 30} = 3.4012$. Finally, as shown in Table 1, entropy weight coefficients were determined for each block by using the Equation 4. the calculated entropy coefficients should be in the range of $0 \leq e_j \leq 1$ and their sums should be equal to 1. In the entropy results given in Table 1, Block-3 was found to be the criterion with the maximum weight for the height with the entropy coefficient of 0.580175, while the Block-1 was found to be the criterion with the maximum weight for the diameter with the entropy coefficient of 0.590017.

3.2. Determination of the Most Appropriate Clone by MAUT method

First, the best and worst value assignments were made for each criterion given in Table 2 in order to find the best results for the clones. In the next step, the normalized data using Equation 6 was multiplied by w_j weight coefficients as in Equation 7 to form the MAUT utility matrix. Results showing the best alternatives found by MAUT method are given in Table 2.

Table-2. The MAUT method results.

Clones	Multi-utility function value for Height	Multi-utility function value for Diameter	Clones	Multi-utility function value for Height	Multi-utility function value for Diameter
1	0.47277	0.473636	16	0.550362	0.545721
2	0.633162	0.639415	17	0.333549	0.549112
3	0.63868	0.118505	18	0.582989	0.654139
4	0.68717	0.159947	19	0.544916	0.61406
5	0.361475	0.332464	20	0.249092	0.436821
6	0.471949	0.406314	21	0.675481	0.583558
7	0.522163	0.319159	**22**	**0.88404**	0.528391
8	0.504255	0.633403	23	0.59111	0.642952
9	0.645299	0.639012	24	0.435501	0.357779
10	0.778461	0.600182	25	0.345148	0.203035
11	0.763972	0.635652	26	0.379954	0.704534

12	0.70258	0.727698	27	0.265754	0.539487
13	0.641148	0.554591	28	0.36766	0.438985
14	0.737819	0.519665	**29**	0.486084	**0.815224**
15	0.768794	0.782815	30	0.437014	0.752796

When Table 2 is analyzed, it is observed that the highest MAUT utility value of Scots pine clones was obtained in the clone number 22 with the weight value of 0.88404 for the height, while it was obtained in the clone number 29 with the weight value of 0.815224 for the diameter.

3.3. Determination of the Most Appropriate Clone by WASPAS Method

$Q_i^{(1)}$ and $Q_i^{(2)}$, the total relative significance of alternative *i*. based on WSM and WPM methods, respectively, were calculated using Equations 9 and Equation 10 with the criteria normalized using Equation 8 in Table 3. Afterwards, the weighted general criterion values of WSM and WPM methods (Q_i) were found with these values, by using Equation 11. Finally, the effect of λ was calculated by using Equation 12. The values of Q_i and λ (0.1-0.5-0.9) and WASPAS ranking are given in Table 3.

Table-3. WASPAS λ Effect, Q_i values and WASPAS results.

Clones	λ =0.1		λ =0.5		λ =0.9		Q_i	
	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter
1	0.7052	2.5287	0.7072	1.7403	0.7092	0.9520	0.7072	1.7403
2	0.7848	2.6347	0.7853	1.8377	0.7858	1.0407	0.7853	1.8377
3	0.7918	2.3390	0.7919	1.5612	0.7921	0.7835	0.7919	1.5612
4	0.8271	2.3686	0.8272	1.5879	0.8274	0.8073	0.8272	1.5879
5	0.6171	2.4361	0.6216	1.6532	0.6261	0.8703	0.6216	1.6532
6	0.6801	2.4919	0.6843	1.7024	0.6885	0.9129	0.6843	1.7024
7	0.7040	2.4429	0.7098	1.6566	0.7157	0.8703	0.7098	1.6566
8	0.7122	2.6384	0.7148	1.8415	0.7173	1.0447	0.7148	1.8415
9	0.7969	2.6451	0.7970	1.8489	0.7971	1.0527	0.7970	1.8489
10	0.8859	2.6092	0.8900	1.8136	0.8942	1.0181	0.8900	1.8136
11	0.8777	2.6222	0.8792	1.8255	0.8808	1.0288	0.8792	1.8255
12	0.8287	2.6725	0.8302	1.8746	0.8317	1.0768	0.8302	1.8746
13	0.7991	2.5907	0.7993	1.7978	0.7994	1.0049	0.7993	1.7978
14	0.8474	2.5641	0.8476	1.7710	0.8477	0.9780	0.8476	1.7710
15	0.8555	2.7008	0.8567	1.9031	0.8579	1.1055	0.8567	1.9031
16	0.7534	2.5689	0.7539	1.7750	0.7543	0.9811	0.7539	1.7750
17	0.6180	2.5680	0.6191	1.7737	0.6202	0.9795	0.6191	1.7737
18	0.7568	2.6438	0.7585	1.8465	0.7602	1.0491	0.7585	1.8465
19	0.7244	2.6206	0.7275	1.8255	0.7305	1.0304	0.7275	1.8255
20	0.5189	2.5363	0.5314	1.7446	0.5439	0.9528	0.5314	1.7446
21	0.8204	2.5956	0.8210	1.8010	0.8215	1.0063	0.8210	1.8010
22	0.9409	2.5597	0.9411	1.7672	0.9414	0.9748	0.9411	1.7672
23	0.7529	2.6190	0.7549	1.8237	0.7568	1.0285	0.754864	1.8237
24	0.6646	2.4685	0.6659	1.6839	0.6672	0.8993	0.665898	1.6839
25	0.6055	2.3898	0.6081	1.6076	0.6107	0.8254	0.608132	1.6076
26	0.6145	2.6627	0.6236	1.8685	0.6328	1.0742	0.623606	1.8685
27	0.5332	2.5886	0.5493	1.7936	0.5653	0.9986	0.549289	1.7936
28	0.6001	2.5371	0.6136	1.7445	0.6271	0.9519	0.613624	1.7445
29	0.6622	2.7208	0.6765	1.9231	0.6909	1.1254	0.676534	1.9231
30	0.6671	2.6867	0.6706	1.8890	0.6742	1.0912	0.670634	1.8890

When Table 3 is examined, it is observed that the best type of clone for the Scots pine seedling heights in respect to WASPAS method is the clone number 22 according to both λ values (0.9409 for λ = 0.1, 0.9411 λ = 0.5 and 0.9414 for λ = 0.) and Q_i= 0.9411 value, which is the weighted general criterion of WSM and WPM methods. As for the root collar diameter, clone number 29 is chosen as the best clone with λ (2.7208 for λ = 0.1, 1.9231 for λ = 0.5 and 1.1254 for λ = 0.9) value and Q_i = 1.9231 weight value.

4. DISCUSSION AND CONCLUSION

In the present study, a multiple criteria decision making (MCDM) model based on the entropy, the weighted aggregated sum product assessment (WASPAS) and multi-attribute utility theory (MAUT) methodologies for Scots pine clones' assessment applied to 30 promising Scots pine clones (appropriate clones for further breeding works) was presented. The developed decision model provided a final assessment of clones based on the defined criteria and decision rules within the defined utility functions. For each clone involved, a set of values for all criteria was determined. Based on the weighted aggregated sum product assessment and multi-attribute utility theory model results, the clones 22 and 29 were assessed as superior and prospective for further breeding procedures in terms of seedling height and root collar diameter, respectively. According to the entropy method, the maximum weights for seedling height and root collar diameter were obtained in Block-3 with 0.580175 and in Block-1 with 0.590017, respectively.

There are few studies using multiple criteria decision making methods in plant breeding. A research [37] used four different perspective Slovenian hop (*Humulus lupulus* L.) hybrids and a reference cultivar with desired characteristics to test the decision model with DEX-i methodology showed that A3/112 was assessed as the best even in comparison with the target cultivar R. Strobili, cone and seed production in *Pinus sylvestris* seed orchards were estimated by fuzzy logic model based on breeding zone, growth period, altitude and age Bilir and Sofu [38]. Pavlovic, et al. [39] stressed that decisions based on the DEX-HOP 1.0 model assessment offered an additional tool for experts' final decisions in selecting appropriate materials for further breeding or the commercial use of hop plants. Idris, et al. [40] examined sixteen genotypes of rice (*Oryza sativa* L.) with both a regression coefficient and a multi-criteria analysis to assess the stability of performance and to identify high yielding genotypes, and found two genotypes (NERICA 14 and YUNLU 33) as high yielding and stable genotypes across environments (locations and years) because of their high grain yield and best performance of traits. In another study [41] multi-objective decision-making model was also employed to rank the rice genotypes according to the measured various yield influencing traits and the degree of association of each trait on yield. Küçükönder, et al. [42] pointed out that the ANN model can be used as an alternative method in estimating the leaf area of tomato plant. Also in a previous research, the amount of cone in clonal seed orchards of Anatolian black pine was predicted with high efficiency through artificial neural networks [43].

The current research is the preliminary study on clone selection with multiple criteria decision making. Albeit deficiencies such as the use of qualitative data only, it was found that these methods fulfilled most of the breeders' expectations and revealed considerable advantages. Therefore, these methods can be regarded as useful tools for Scots pine clones' assessment. Further studies should be conducted by using more input data in the decision model.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: All authors contributed equally to the conception and design of the study.

REFERENCES

[1] M. Cetin, F. Adiguzel, S. Gungor, E. Kaya, and M. C. Sancar, "Evaluation of thermal climatic region areas in terms of building density in urban management and planning for Burdur, Turkey," *Air Quality, Atmosphere & Health*, vol. 12, pp. 1103-1112, 2019. Available at: https://doi.org/10.1007/s11869-019-00727-3.

[2] M. Cetin, "The effect of urban planning on urban formations determining bioclimatic comfort area's effect using satellitia imagines on air quality: A case study of Bursa city," *Air Quality, Atmosphere & Health*, vol. 12, pp. 1237-1249, 2019. Available at: https://doi.org/10.1007/s11869-019-00742-4.

[3] FAO, "The state of the world's forests 2018 - Forest pathways to sustainable development," Rome. Licence: CC BY-NC-SA 3.0 IGO, 2018. Retrieved from: http://www.fao.org/3/i9535en/i9535en.pdf

[4] H. B. Ozel and N. Bilir, "Fertility variation and status number in a clonal seed orchard of Scots Pine (Pinus sylvestris L.)," *Fresenius Environmental Bulletin*, vol. 24, pp. 2035-2038, 2015.

[5] T. Yangin and N. Bilir, "Interaction of cone production and growth characters in Brutian pine (Pinus brutia Ten.) populations," *Research and Reviews in Biotechnology and Science*, vol. 9, pp. 6-10, 2014.

[6] M. Gunes and N. Umurusman, "A decision support tool fuzzy target programming tax optimization applications in local governments," *Review of Social Economic & Business Studies*, vol. 2, pp. 242- 255, 2003.

[7] A. Ishizaka and P. Nemery, *Multi-criteria decision analysis, methods and software*. Chichester, UK: John Wiley & Sons, Ltd, 2013.

[8] B. H. Massam, "Multi-criteria decision-making techniques in planning," *Progress in Planning*, vol. 30, pp. 1-84, 1988. Available at: https://doi.org/10.1016/0305-9006(88)90012-8.

[9] A. F. Howard, "A critical look at multiple criteria decision making techniques with reference to forestry applications," *Canadian Journal of Forest Research*, vol. 21, pp. 1649-1659, 1991. Available at: https://doi.org/10.1139/x91-228.

[10] R. L. Keeney, *Value-focused thinking: A path to creative decision analysis*. Cambridge: Harvard University Press, 1992.

[11] S. A. Hajkowicz and T. Prato, "Multiple objective decision analysis of farming systems in goodwater Creek Watershed, Missouri," Research Report No. 24, Centre for Agriculture, Resources and Environmental Systems, Columbia, Missouri1998.

[12] J. Ananda and G. Herath, "A critical review of multi-criteria decision making methods with special reference to forest management and planning," *Ecological Economics*, vol. 68, pp. 2535-2548, 2009. Available at: https://doi.org/10.1016/j.ecolecon.2009.05.010.

[13] P. Chatterjee and S. Chakraborty, "Material selection using preferential ranking methods," *Materials & Design*, vol. 35, pp. 384-393, 2012. Available at: https://doi.org/10.1016/j.matdes.2011.09.027.

[14] M. Karaatli, N. Omurbek, I. Budak, and O. Dag, "Ranking of liveable cities with multi criteria decision making methods," *Selçuk University Journal of Institute of Social Sciences*, vol. 33, pp. 215-228, 2015.

[15] FGD, "The State of seed orchard in Turkey," Annual Report, Forest General Directorate, Ankara2001.

[16] H. Zhang, C.-l. Gu, L.-w. Gu, and Y. Zhang, "The evaluation of tourism destination competitiveness by TOPSIS & information entropy–a case in the Yangtze River Delta of China," *Tourism Management*, vol. 32, pp. 443-451, 2011. Available at: https://doi.org/10.1016/j.tourman.2010.02.007.

[17] A. Shemshadi, H. Shirazi, M. Toreihi, and M. J. Tarokh, "A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting," *Expert Systems with Applications*, vol. 38, pp. 12160-12167, 2011. Available at: https://doi.org/10.1016/j.eswa.2011.03.027.

[18] S. Cakir and S. Percin, "Measurement of R&D performance by integrated entropy weight-TOPSIS method in EU countries," *Uludağ University, Journal of Faculty of Economics and Administrative Sciences*, vol. 32, pp. 77-95, 2013.

[19] T. C. Wang and J. C. Hsu, "Evaluation of the business operation performance of the listing companies by applying TOPSIS method," *2004 IEEE International Conference on Systems, Man and Cybernetics*, vol. 2, pp. 1286-1291, 2004.

[20] J. Wu, J. Sun, L. Liang, and Y. Zha, "Determination of weights for ultimate cross efficiency using Shannon entropy," *Expert Systems with Applications*, vol. 38, pp. 5162-5165, 2011. Available at: https://doi.org/10.1016/j.eswa.2010.10.046.

[21] X. Li, K. Wang, L. Liu, J. Xin, H. Yang, and C. Gao, "Application of the entropy weight and TOPSIS method in safety evaluation of coal mines," *Procedia Engineering*, vol. 26, pp. 2085-2091, 2011. Available at: https://doi.org/10.1016/j.proeng.2011.11.2410.

[22] M. Islamoglu, M. Apan, and A. Oztel, "An evaluation of the financial performance of REITs in Borsa Istanbul: A case study using the entropy-based TOPSIS method," *International Journal of Financial Research*, vol. 6, pp. 124-138, 2015. Available at: https://doi.org/10.5430/ijfr.v6n2p124.

[23] K. Karakuş, D. Aydemir, A. Öztel, G. Gunduz, and F. Mengeloglu, "Nanoboron nitride-filled heat-treated wood polymer nanocomposites: Comparison of different multicriteria decision-making models to predict optimum properties of the nanocomposites," *Journal of Composite Materials*, vol. 51, pp. 4205-4218, 2017. Available at: https://doi.org/10.1177/0021998317699984.

[24] H. Gumus, D. Aydemir, E. Altuntas, R. Kurt, and E. Imren, "Cellulose nanofibrils and nano-scaled titanium dioxide-reinforced biopolymer nanocomposites: Selecting the best nanocomposites with multicriteria decision-making methods," *Journal of Composite Materials*, vol. 54, pp. 923-935, 2020. Available at: https://doi.org/10.1177/0021998319870842.

[25] P. C. Fishburn, "Methods of estimating additive utilities," *Management Science*, vol. 13, pp. 435-453, 1967. Available at: https://doi.org/10.1287/mnsc.13.7.435.

[26] R. Keeney and H. Raiffa, *Decisions with multiple objectives: Preferences and value trade-offs*. New York: Wiley, 1976.

[27] M. Madić, V. Gecevska, M. Radovanović, and D. Petković, "Multi-criteria economic analysis of machining processes using the WASPAS method," *Journal of Production Engineering*, vol. 17, pp. 1-6, 2014.

[28] S. Chakraborty and E. K. Zavadskas, "Applications of WASPAS method in manufacturing decision making," *Informatica*, vol. 25, pp. 1-20, 2014.

[29] H. Yurdoglu and N. Kundakci, "Server selection with SWARA and WASPAS methods," *Balikesir University, Journal of Social Sciences Institute*, vol. 38, pp. 253-269, 2017.

[30] E. K. Zavadskas, Z. Turskis, J. Antucheviciene, and A. Zakarevicius, "Optimization of weighted aggregated sum product assessment," *Electronics and Electrical Engineering*, vol. 122, pp. 3-6, 2012. Available at: https://doi.org/10.5755/j01.eee.122.6.1810.

[31] E. Ayyildiz and M. Murat, "Determination of education performance of the cities located in Turkey using multi-criteria decision making methods," *Urban Academy*, vol. 10, pp. 255-267, 2017.

[32] E. K. Zavadskas, J. Antucheviciene, J. Šaparauskas, and Z. Turskis, "Multi-criteria assessment of facades' alternatives: Peculiarities of ranking methodology," *Procedia Engineering*, vol. 57, pp. 107-112, 2013. Available at: https://doi.org/10.1016/j.proeng.2013.04.016.

[33] J. Saparauskas, E. K. Zavadskas, and Z. Turskis, "Evaluation of alternative building designes according to the three criteria of optimality," Proceedings of the 10th International Conference on Modern Building, Structures and Techniques, May 19-21, Vilnius, Lithuania, 2010.

[34] G. Stojić, Z. Stević, J. Antuchevičienė, D. Pamučar, and M. Vasiljević, "A novel rough WASPAS Approach for supplier selection in a company manufacturing PVC carpentry products," *Information*, vol. 9, pp. 1-16, 2018. Available at: https://doi.org/10.3390/info9050121.

[35] D. W. Miller and M. K. Starr, *Executive decisions and operations research*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc, 1969.

[36] E. Triantaphyllou and S. H. Mann, "An examination of the effectiveness of multi-dimensional decision-making methods: A decision-making paradox," *Decision Support Systems*, vol. 5, pp. 303-312, 1989. Available at: https://doi.org/10.1016/0167-9236(89)90037-7.

[37] K. Pazek, C. Rozman, V. Pavlovic, A. Cerenak, and M. Pavlovic, "The multi-criteria decision model aid for assessment of the hop cultivars (Humulus lupulus L.), Genetics, plant breeding and seed production," presented at the 44th Croatian & 4th International Symposium on Agriculture, 2009.

[38] N. Bilir and A. Sofu, "Estimation of productions for reproductive characters in seed orchards of Pinus sylvestris by fuzzy logic model approaches," presented at the Seed Orchard Conference. Jeju, Korea, 2009.

[39] M. Pavlovic, A. Cerenak, V. Pavlovic, C. Rozman, K. Pazek, and M. Bohanec, "Development of DEX-HOP multi-attribute decision model for preliminary hop hybrids assessment," *Computers and Electronics in Agriculture*, vol. 75, pp. 181-189, 2011. Available at: https://doi.org/10.1016/j.compag.2010.11.002.

[40] A. E. Idris, K. A. Mohamed, and H. I. Mohammed, "Using regression indices and multiple criteria analysis for study of some rice genotypes under interaction of variable environmental conditions," *American Journal of Experimental Agriculture*, vol. 2, pp. 407-425, 2012. Available at: https://doi.org/10.9734/ajea/2012/1193.

[41] K. A. Mohamed, A. E. Idris, H. I. Mohammed, and K. A. O. Adam, "Ranking rice (Oryza sativa L.) Genotypes using multi-criteria decision making, correlation and path coefficient analysis," *British Biotechnology Journal*, vol. 2, pp. 211-228, 2012. Available at: https://doi.org/10.9734/bbj/2012/1821.

[42] H. Küçükönder, S. Boyaci, and A. Akyüz, "A modeling study with an artificial neural network: Developing estimationmodels for the tomato plant leaf area," *Turkish Journal of Agriculture and Forestry*, vol. 40, pp. 203-212, 2016. Available at: https://doi.org/10.3906/tar-1408-28.

[43] E. Gemici, C. Yücedağ, H. B. Ozel, and E. Imren, "Predicting cone production in clonal seed orchard of Anatolian black pine with artificial neural network," *Applied Ecology and Environmental Research*, vol. 17, pp. 2267-2273, 2019. Available at: https://doi.org/10.15666/aeer/1702_22672273.