Environmental Science and Pollution Research (2019) 26:34430–34439
https://doi.org/10.1007/s11356-019-06562-4

RESEARCH ARTICLE

Plant selection for roadside design: “the view of landscape architects”

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Received: 24 October 2018 / Accepted: 20 September 2019 / Published online: 21 October 2019

Abstract

Losses in urban green spaces due to population increase and urbanization became one of the most important problems in contemporary cities. Efforts to increase green zones require the establishment of parks and extension of planting activities in urban areas. The planting work conducted on streets, roads, avenues, and traffic islands is significant in the development of urban green spaces. Determination of the plant species that would be used in planting work and assessment of these species by experts and authorities based on scientific approaches are significant for the success of these efforts. In the present study, the issue of plant selection criteria for roadside planting was investigated with a hybrid decision-making approach based on landscape architects’ perspectives. To solve the plant selection problem of decision-makers and to obtain reliable quantitative data, a set of criteria that included 5 main and 41 sub-variables was determined. Pairwise comparison technique was used by experts for evaluation of the involved criteria. The study findings revealed that the “structural criteria” were the most effective main factor in plant selection for roadside planting, followed by the “economic and ecological” criteria. Furthermore, it was determined that the growth length and diameter of the plants (10.2%), selection of indigenous species that reflect the urban identity (7.30%), and the climatic requirements of the plants (7.20%) were the sub-criteria that should be considered in selection of the plants. In conclusion, it was determined that quantitative assessment of plant selection decisions would help planting design decisions on roadside planting.

Keywords Roadside plants · Decision-making · DEMATEL · ANP · Landscaping

Introduction

Urban green spaces are valuable components of developing the world as they potentially hold an important place in mitigation of urbanization. Parks, city forests, and roadside plants are such landscape elements that can be used in city design.

Urban green spaces

Cities are settlement forms that are created by the agglomeration of communities due to social, economic, and cultural factors. Employment and social facilities that cities provide cause irregular urbanization due to the heavy migration received by urban areas (Girti et al. 2010). Urban sprawl is a contemporary environmental problem and can be observed as unplanned urbanization, inadequate infrastructure, dense vehicle traffic, and fragmentation of ecological continuity in fringe areas of the cities. Especially, noise and visual degradation affect the quality of life and increase the stress which is an important problem of our age (Guneroglu et al. 2013). Furthermore, general health and respiration problems can be observed because of environmental degradation (Pope III et al. 2000).

The green spaces, which are indispensable urban elements, disintegrate and lose their quality due to urbanization (Ulusoy and Vural 2001). Green spaces are the most important functional elements of urban ecosystems as a part of urban landscape concept (Tian et al. 2011). However, urban green spaces are the reflection of the nature in the city. With their ecological characteristics, urban green spaces combine the nature and the city and join the urban dwellers and the city. Green zones in the urban ecosystem are effective on the urban heat island (Dihkan et al. 2015) and climate control (Chang et al. 2007), as well as providing the psychological and recreational needs of urbanites (Coley et al. 1997; Vailshery et al. 2013). They also improve the aesthetical urban character by increasing the physical comfort in cities. Thus, it is necessary to restore urban

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green spaces with ecological landscaping approaches (Bekar and Guneroglu 2016).

The most important components of the green spaces are the trees. Trees have been important natural assets for human life in various periods and ages (Şahin 1989; Kurdoğlu and Pirselimoğlu 2011). They were used for different purposes, identified with beliefs, and evaluated as symbols of certain emotions. Urban green spaces are created with the use of trees in groves, parks, botanical gardens, public institution and private gardens, cemeteries, squares, streets, and traffic islands.

Roadside planting

Beside other landscape elements, roadside linear planting holds a special place as it enhances green coverage and connects separated niches. Especially, tree planted urban streets are the most important linear planting that link other green elements. These are the areas where individuals start to establish the closest relationship with nature in urban spaces that soften the rigid image of buildings and allow for several activities. Since the entrances of the cities are urban points of prestige, the roadside planting is very important for instant impressions of the first-time visitors of the city (Aslanboğa 1986; Jim 1997). Roadside planting is conducted by planting adequate tree species to provide aesthetic, functional, and ecological features along the roadside and the pavement and at the center of the roads. These plantations became the symbol of nobility especially in the fifteenth century Renaissance gardens, and later in the seventeenth and eighteenth centuries in France, England, and Italy (Küçük and Gül 2005). Today's urban roadside planting structure dates back to the period between 1853 and 1868 in Paris, France (Ekmekçi 2007). Roadside planting can be implemented in various forms on streets and squares. Contemporary roadside planting, which became prominent in urban design due to the significance of ecological planning, provides several benefits for the cities and city dwellers. These benefits include ecological effects such as balancing urban temperatures; reducing the effects of sunlight; shading; reducing the wind speeds, retention of the dust, and CO_2 emissions and O_2 generation; increasing air humidity; balancing the water content of the soil; and providing a habitat for the fauna and flora, soil viability, erosion control, slope, and coastal stabilization (Hayasaka et al. 2012; Nowak et al. 2014; Tong et al. 2016; Baldauf 2017; Tan et al. 2017).

Furthermore, roadside planting signalizes transport axes and helps vehicles and pedestrians to navigate. In terms of road safety, planting physically separates borders and guides the vehicle and pedestrian spaces (Cackowski and Nasar 2003; Mok et al. 2006). Planting is used to screen headlamps and prevent their light to blind the eyes of the drivers cruising on the opposite direction, reducing the risk of accidents on double lane roads, single-lane road bends, and roads that are very close to each other. They provide warning signals before the traffic signs via the use of different species and planting technique. They prevent sound echoes and reduce the ambient noise with their surface properties. They buffer the impact during accidents, reducing the losses. They can also be used to shade the vehicles in a traffic jam and pedestrians and to create spaces and border the spaces.

Roadside planting should be considered with its visual qualities that improve the urban quality and aesthetic value, not only for its functional properties (Wey and Wei 2016; Fukahori and Kubota 2003). Aesthetically, autumn colors of trees and their calligraphic texture and form characteristics when they defoliate help increase the visual quality of the road environment (Chen et al. 2016). The plant designs applied in roadside planting provide nice views for the drivers, reduce their stress, and increase road safety. They link structures in various forms and with different meanings, complete or emphasize the architectural forms of buildings, and provide a background for the buildings (Wolf 2003). Roadside planting can greatly reduce pressure effect of surrounding tall buildings and balances the scale between human and enviroment (Smardon 1988). They introduce movement and dynamism to the monotonous structure of the cities (Kent 1993). They contribute to the physical and mental health of the citizens who are stressed by the intense urban lifestyle with the refreshing and relaxing effects of color green (Küçük and Gül 2005).

To benefit from the abovementioned positive effects of roadside landscaping, certain criteria should be prioritized in selecting the trees that would be used in roadside planting. Trees that are a part of forest ecosystems encounter different environmental conditions in urban ecosystems when compared to their natural habitat. Especially, the unique urban climate, land, and human-induced environmental pressures make it extremely difficult for trees to survive in urban ecosystems (Söğüt 2005). These pressures slow the plant growth and shorten their lifespan under stressful conditions when compared to conspecific plants that grow in a natural environment (Sæbø et al. 2005). Incorrect roadside planting applications could cause both temporal and economic losses. Thus, selection of plant species, planting period, and ecological conditions in the planting area are very important in road plantations.

In selection of the plant species, attention should be paid to the adaptability of the species to the urban environment and urban ecosystems. Based on the street or road type, the selection of species based on factors such as the road width, orientation, the surrounding buildings, and the height of these buildings might help eliminate future problems (Mok et al. 2006). Furthermore, factors such as aesthetical color, form, and texture properties of the utilized species are also important in terms of landscaping and visual quality (Fathi and Masnavi 2014). The aesthetic qualities of plants create effects that enhance the identity of the road and save the drivers from the monotony. Using evergreen plant species and those that do not flower or bear fruits would improve the concentration of the drivers and protect the parked vehicles. The maintenance requirements of plants are minimized by selecting plant species that are suitable for the climate of the region where the roadside planting would be designed. Another issue that needs to be considered during the selection of species is the urbanization characteristics of the roadside planting zone (Eroğlu 2010). The urban culture, experiences, and historical background should also be effective in selection of the species. In developed countries, roadside planting provides both recreational and touristic opportunities. Native tree species that characterize the city should always be prioritized in landscape designs (Akbar et al. 2003).

Today, the most important reason for the failure of urban roadside planting is the ignorance of the requirements of the trees as living organisms to fulfill their functions in the planting locations (Aslanboğa 1997). Several factors particularly play an important role in the failure of roadside planting such as unplanned applications, wrong species selection, use of unsuitable sapling material, inadequate growth environment, lack of maintenance, and preservation works. It may not always be possible to put together all the effective criteria during road planting. In this case, it may be a good idea to optimize the plant selection based on the existing conditions. These studies are an issue of high priority needed in contemporary roadside planting (Sæbø et al. 2005). Among the quantitative methods that can be used for this purpose, multi-criteria decision-making (MCDM) is a widely adopted method in decision-making processes to solve the problem based on expert opinion.

To prevent failures in roadside planting, an analytical approach based on expert views could be used in economic, ecological, and aesthetic designs. Thus, in the present study, a hybrid MCDM approach was implemented and the study focused on the determination of plant selection criteria that would be used in roadside planting. The present study is important since it emphasizes the connection between plant selection and roadside planting. Providing the specified criteria can contribute to the decision-making process in future roadside planting designs. There are several studies on the successful applications of MCDM strategies regarding environmental pollution, logistics, and adequate site selection in the literature (Chen et al. 2011a, b; Huang et al. 2011; Azizi et al. 2014; Guneroglu et al. 2016; Chang 2017). However, none of these studies focused on the issues emphasized in the present study.

Material and method

To determine the most important criteria that affect the selection of plant species for use in road planting, a hybrid methodology that included a combination of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Analytical Network Process (ANP) was used (see Appendix). Criteria that would be used in selection of plant species were compiled by searching the literature for studies on roadside planting. The weight of each criterion was determined by an expert group and overall criteria were evaluated. The criteria were evaluated by a group of experts (randomly selected 7 landscaping specialists). The study criteria and sub-criteria are presented in Fig. 1.

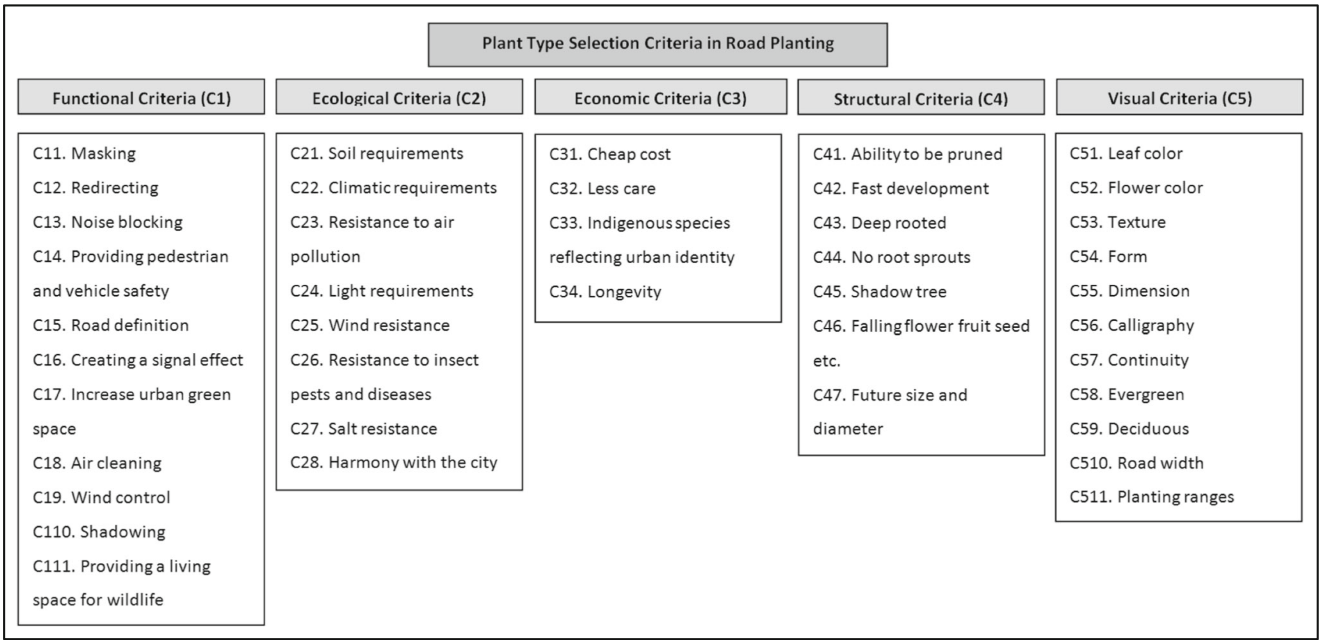

Fig. 1 Plant type selection criteria in roadside planting

DEMATEL

The DEMATEL method is a gradual approach that allows the determination of the main criteria involved in the decision-making process (Wu and Lee 2011). The graph theory-based DEMATEL method provides the opportunity to plan and solve the problems as drafts by dividing the relevant factors, which provide a better understanding of the causal relation, into cause and effect groups (Chen and Yu 2008; Yang et al. 2008; Tseng 2009; Aksakal and Dağdeviren 2010). The DEMATEL criteria can be arranged with a priority ranking based on the type of the correlations and the significance of their mutual effects. The criteria that are assumed to have a higher effect on others and have a higher priority are called causal criteria, and the criteria that are assumed to have affected more by others and have a low priority are called outcome criteria (Aksakal and Dağdeviren 2010). This technique is widely used to solve complex decision-making problems that require causal relationship analysis (Tzeng et al. 2007). In the present study, DEMATEL technique was used in consistent with the current literature. The DEMATEL method consists of 5 consecutive steps. The solution is achieved with the effect-oriented graph obtained at the end of the 5th step. The procedure of this technique can be summarized as follows. DEMATEL and ANP methods used in the study were based on the studies by Tzeng et al. (2007), Yang et al. (2008), Lee et al. (2008), Shieh et al. (2010), Aksakal and Dağdeviren (2010), Liou et al. (2007), Chen and Yu (2008), Yang and Tzeng (2011), and Chen et al. (2011a) (see Appendix).

ANP

Another technique used in this study is the ANP, a modified version of the analytic hierarchy process (AHP). The ANP method, which is based on a hierarchical decision network and inter-criteria correlations, has been used as a solution for complex decision problems (Meade and Sarkis 1998; Partovi and Corredoira 2002; Guneroglu et al. 2016). In ANP decision-making process, all criteria and sub-criteria are modeled within a network structure, and dependency and interaction ratios are evaluated for the entire network. Thus, the ANP method provides a more effective and realistic solution for decision-making problems. Saaty (2007) suggested creating a super-matrix using a 1–9 scale to determine the dependencies between the criteria in the ANP method. The super-matrix provides the opportunity to assess the mutual effects of each weighted matrix element on a network individually. The super-matrix approach enables the identification of priority decision-makers in problem solving. The ANP steps are summarized below in Appendix.

In the present study, a hybrid procedure proposed by Liou et al. (2007), Yang et al. (2008), Lee et al. (2008), Chen and Yu (2008), Yang and Tzeng (2011), and Hung (2011) entails the integration of DEMATEL and ANP was utilized. A network correlation map was designed to determine the priority factors for the plant species selection criteria for roadside planting with DEMATEL. Then, the total influence matrix T and the threshold value α were derived to form a new matrix called α-cut total influence matrix. By combining the normalized α-cut total influence matrix and the weightless super-matrix, a super-matrix was obtained. Finally, to determine the weights and priorities of the criteria, a super-matrix of a stable super-matrix was generated by taking the limit of the super-matrix.

Results and discussion

In the present study, it was assumed that the problem of selecting adequate plant species for roadside planting applications is a complex decision process that requires an analytical approach by specialists. Thus, the questionnaire that was designed to determine the plant selection criteria was evaluated by the decision-makers, who were experts in the field. An expert group of 7 individuals was selected from landscape architects based on their professional experience and academic fields. The fact that roadside planting applications are mostly related to plant designs was the main reason for the selection of landscape architects for the group of experts. The main criteria and the sub-criteria were determined by a literature review conducted by the group of experts. Among these criteria, a paired comparison scale including 5 levels in the range of 0 to 4 was used. Each digit between 0 and 4 on the scale is paired with the words "uninfluential," "low influence," "medium influence," "high influence," and "very high influence." As a result of this scoring, the quantitative data used in DEMATEL calculations were generated. A 5 × 5 matrix with diagonal values of "0" was obtained by taking the arithmetic mean of the points on the paired comparison scale obtained from the experts. This matrix was called the "direct influence matrix (M)" (Table 1).

A normalized influence matrix is formed by the direct influence matrix. The normalized influence matrix is used to obtain the total influence matrix. In Table 2, the total influence matrix obtained in the study is presented.

In the obtained total influence matrix, the values of the matrix row totals "D_i" and the matrix column totals "R_j" were

Table 1 Direct influence (relation) matrix

Criteria set	Functional	Ecological	Economic	Structural	Visual
Functional	0	0.428	2.142	1.428	0.285
Ecological	0.428	0	2.428	2.142	0.571
Economic	0.582	0.444	0	1.214	0.665
Structural	0.785	0.535	0.832	0	0.582
Visual	0.285	0.199	1.642	2.142	0

Table 2 Total influence matrix

Criteria set	Functional	Ecological	Economic	Structural	Visual	*Rj*
Functional	0.155	0.103	0.158	0.243	0.147	3.083
Ecological	0.191	0.147	0.214	0.281	0.175	3.879
Economic	0.078	0.060	0.260	0.188	0.066	2.398
Structural	0.051	0.047	0.231	0.266	0.063	2.388
Visual	0.160	0.117	0.168	0.165	0.148	2.945
Di	2.200	1.668	4.236	4.491	2.099	–

calculated to determine the sender and receiver groups. Determination of the $D_i + R_j$ and $D_i - R_j$ values provided quantification of the relationships among the many factors with potential influence on the plant selection decision process (Table 3). In the present study, the threshold value $\alpha = 0.587$ was found using the technique described in methodology.

Based on the results presented in Table 3, the most important criteria in the study is the "structural quality" factor with the highest $D + R$ value (6.879). It was determined that the "visual quality" main criterion with the smallest value (5.044) was not very influential in roadside planting.

According to Fig. 2, "economic and structural quality" criteria were effective factors for plant selection, while the activity groups with negative $(D - R)$ values were "functional, ecological, and visual quality" criteria. In the causal relationship diagram, it was observed that economic and structural quality criteria were the most important factors to be considered in plant selection. Interaction and interrelations among all factors were also quite clear during the decision-making process for plant species selection criteria in roadside planting. Furthermore, "ecological, structural, and economic quality" factors were nearly had equal influential in expert knowledge-based plant species selection. Thus, ANP was used to determine the weight and priorities of the sub-criteria for ecological, structural, and economic quality factors. In the ANP phase, a normalized total influence matrix was constructed using the paired comparisons among the sub-criteria using the 1–9 scales. At this step, the weighted super-matrix was derived by combining the α-cut total influence matrix with the weightless super-matrix. Finally, the limit of the weighted super-matrix was taken to obtain the result matrix that contains the quantitative value for each criterion (Table 4) (see Appendix section).

Environmental research is usually based on a wide variety of information types and parameters. Several different methods are used in the management of uncertainties related to the diversity of information. One of these methods, multi-criteria decision-making analysis (MCDM) is used as an adequate methodology in environmental studies for its flexibility and ability to facilitate the dialog between researchers and analysts. It has been extensively used in studies such as waste management, water management, and environmental impact assessments (Huang et al. 2011). In the present study, MCDM approach and DEMATEL and ANP methods were successfully applied in the determination of the criteria for plant selection in roadside planting. These criteria were scrutinized to provide a roadmap for decision-makers or municipal (highway) authorities to be used in decision-making about the priority criteria in the selection of plant species. The MCDM approach and the complex decisions about several parameters that are influential in plant selection were used based on expert knowledge and quantitative data.

Table 3 Sum of cause and effects groups in digraph

Criteria set	*Di* + *Rj*	*Di* − *Rj*
Functional	5.284	− 0.883
Ecological	5.547	− 2.211
Economic	6.635	1.838
Structural	6.879	2.102
Visual	5.044	− 0.846

The criteria for plant species selection were determined based on their significance ranking in the study. Subsequently, these criteria were ranked based on the sub-criteria scores and weights. The sub-criteria with the highest scores were C47, C33, C22, C34, C23, C46, C28, C26, C32, C25, C45, C21, C24, C42, C44, C27, C31, C43, and C41. The most effective 5 criteria were C47 (10.2% future size and

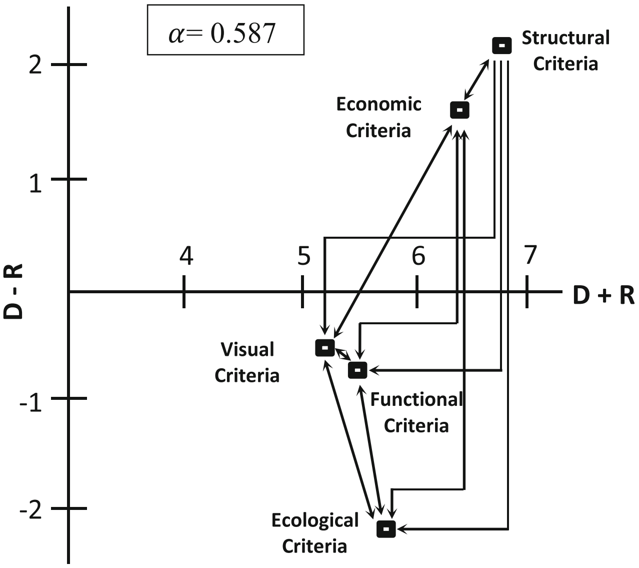

Fig. 2 Digraph map of the importance and relation level

Table 4 The final super-matrix with relative weight of each criterion

	C21	C22	C23	C24	C25	C26	C27	C28	C31	C32	C33	C34	C41	C42	C43	C44	C45	C46	C47
C21	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
C22	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*	*0.072*
C23	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*	*0.058*
C24	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
C25	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
C26	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
C27	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
C28	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
C31	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.030	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
C32	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
C33	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*	*0.073*
C34	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*
C41	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C42	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
C43	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
C44	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
C45	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
C46	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
C47	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*	*0.124*

Note: The most important criteria weights were indicated in italics

diameter), C33 (7.30% indigenous species reflecting urban identity), C22 (7.20% climatic requirements), C34 (6.40% longevity), C23 (5.80% air pollution resistance), and the least significant criterion was C41 (1.60% ability to be pruned) based on the assessments. The first 3 main factors in plant species selection criteria in roadside planting were economic, structural, and ecological criteria. Expert assessments identified that economic and structural factors had similar effects.

The necessity of taking into account the structural characteristics of plant species that will be used in roadside planting was emphasized in several studies (Küçük and Gül 2005; Yilmaz and Aksoy 2009; Tarakcı Eren and Var 2016). Studies primarily scrutinized the problems that would be experienced due to the ignorance of the future maximum size of the grown plant. In a study by Karaşah and Var (2012), the problems that arise from roadside planting that was conducted without considering the future size of the plant. It should be remembered that the plant material is a living design and it would grow to its actual size over time. This knowledge is necessary to establish the space-scale relationship accurately (Var 1997; Önder and Akbulut 2011). A successful roadside planting design in scale and proportion allows the viewing individual to move freely in that environment without considering the scale in her or his mind, feeling uncomfortable, or getting lost in that space (Leszczynski 1999).

Roadside planting creates an effect of identity especially on the first-time urban visitors and renders a clear urban character (Yang et al. 2012). Thus, the use of indigenous plant species in roadside planting is quite important (Harper-Lore 1996; Kösa and Karagüzel 2016). Furthermore, Altınçekiç and Altınçekiç (1999) emphasized that the use of indigenous species in roadside planting is a functional and economic, as well as a logical approach. It is quite obvious that the use of indigenous species is effective in reducing the budget needed for planting and maintenance (Karim and Mallik 2008; Haan et al. 2012). It is also evident that selection of perennial plants would reduce the costs related to constant renewal of roadside planting. The present study findings support the necessity of selecting indigenous and perennial plant species in roadside planting applications.

Consideration of the climatic demands of the plants is one of the most important criteria determined in the study. Due to the urbanization induced climatic changes that occur in the cities, the plants used in roadside planting should be selected based on their climatic demands. In a study, Sağlık et al. (2012) emphasized the importance of selecting suitable plant species for the urban climate. Considering the temperature difference between rural and urban sections, plant species that will be used in city centers should be resistant to drought and heat (Šerá 2008). Moreover, it should be emphasized that native ecosystems can adversely be affected by the use of exotic species (Anderson 1999).

Resistance to air pollution was determined as the 5th priority in the selection of plant species in the study. In similar studies, it was observed that air pollution resistant species were preferred in cities with high pollution rate and in the selection of plants in roads with dense vehicle traffic (Yilmaz and Aksoy 2009).

The criterion about the ability of plant species used in roadside planting to be pruned received the lowest score in the present study. In contemporary cities, erratic pruning of the trees destroy the natural form and the aesthetic value of the trees, halt the growth of the plants, and shorten their life span (Önder and Akbulut 2011). Thus, previous studies emphasized the need to avoid pruning except it is imperative (Küçük and Gül 2005). It was also indicated that it is advisable to select species that do not require intensive care and pruning in urban planting (Önder and Akbulut 2011). Similar results were obtained in the present study.

The MCDM method used in the present study produced quite effective results for quantitative determination of plant species selection criteria that can be used for roadside planting. With this method, plant species selection criteria can be developed for planting designs for different areas (roofs and vertical gardens, parks, children playgrounds, zoo gardens). Furthermore, the relationships between the features of plant species and the areas where they can be used can be evaluated with this method.

Conclusion

Roadside planting that connects green spaces and has a linear structure is one of the most important parts of the urban green spaces. In addition to softening the rigid image of the cities, they are used to achieve several ecological and functional goals. However today, it is obvious that the problems due to urbanization damage the roadside trees. Thus, it is necessary to select correct plant species during the design phase to ensure proper design and to sustain the roadside planting. It should not be forgotten that the selection of adequate plant species in plant designs has a significant impact on the success of the design. It should not be neglected that plants define the spaces, contribute to the scale of the spaces, and increase the spatial value by reflecting the seasons. These effects vary significantly between different plant species. Difficulties are experienced in selection of adequate plant species for urban planting designs. It is especially difficult to find the ideal roadside tree that is suitable for urban requirements and durable against urban pressures. Therefore, it is necessary for decision-makers and municipalities to conduct quantitative analyzes for plant species for urban roads that are resistant to environmental conditions and with adequate structural and economic properties. This would save the labor, time, and money spent on such projects. Thus, problems such as conducting several projects for the same space and bearing with the economic consequences would be minimized. The present study demonstrated that a hybrid MCDM technique could be successfully implemented in the selection of plant species that would be used in urban roadside planting. It was concluded that the structural criteria were prominent in the decision-making process for the selection plant species. It was determined that the obtained findings would provide opportunities that would facilitate plant selection based on quantitative data.

Appendix

Stepwise method of DEMATEL

Step 1: For the creation of the direct influence matrix, initially, the paired comparison of the criteria should be evaluated by the expert group using a five-level comparison scale between 0–4. The data obtained by each expert are collected under a single matrix, the averages of the expert scores for same variables are calculated, and the initial average matrix is obtained with Equation 1.

$$M = \begin{bmatrix} m_{11} & \cdots & m_{1j} & \cdots & m_{1n} \\ \vdots & & \vdots & & \vdots \\ m_{i1} & \cdots & m_{ij} & \cdots & m_{in} \\ \vdots & & \vdots & & \vdots \\ m_{n1} & \cdots & m_{nj} & \cdots & m_{nn} \end{bmatrix}_{nxn} \tag{1}$$

Step 2: In this step, the initial influence matrix is created. For this purpose, the initial average matrix M obtained in the previous step is normalized. If the initial influence matrix is accepted as D, it can be normalized as follows.

$$D_{nxn} = f \times [M]_{nxn} \tag{2}$$

where,

$$f = \min\left[\frac{1}{\max_i \sum_{j=1}^{n} |m_{ij}|}, \frac{1}{\max_j \sum_{i=1}^{n} |m_{ij}|}\right] \tag{3}$$

Step 3: In order to obtain the total influence matrix, the limit of the normalized matrix M is taken until the sum of the element values of any row or column is 1 as follows. This can be expressed mathematically as follows.

For M, M^2,M^3, $\cdots$, M^k and $M = [M_{ij}]_{nxn}$

$$\lim_{k\to\infty} M^k = [0]_{nxn} \tag{4}$$

provided that,

$0 \le M_{ij} < 1$; $0 < \sum iM_{ij} \le 1$; $0 \le \sum jM_{ij} < 1$ and $\sum iM_{ij} = 1$ or $\sum jM_{ij} = 1$

than total influence matrix T can be written as,

$$T = M + M^2 + M^3 + \cdots + M^k = M(I-M)^{-1} \tag{5}$$

$T = [t_{ij}]_{nxn}$ for $i, j = 1, 2, 3, \cdots n$ and $(I-M)(I-M)^{-1} = I$

where the total influence matrix is denoted by T and the identity matrix is denoted by I. The total influence matrix demonstrates the total mutual effects between the criteria.

Step 4: In this step, the sums of the row D and the column R are calculated so to calculate sender and receiver effects. Equations 6 and 7 can be used for this purpose.

$$D_i = \sum_{j=1}^{n} t_{ij}\ \mathit{and}\quad (i = 1, 2, 3, \cdots n) \tag{6}$$

$$R_j = \sum_{i=1}^{n} t_{ij}\quad \mathit{and}\quad (j = 1, 2, 3, \cdots n) \tag{7}$$

The sum of the columns in the total influence matrix T indicates the direct or indirect effect of a criterion D on other criteria, and the sum of the columns R gives the total direct or indirect effect of the criteria on a criterion. Using the $D - R$ and $D + R$ values, the influences of each criterion on others and its correlations with others are determined. Sender criteria with a positive $D - R$ value have a higher effect on other criteria. The $D - R$ criteria with a negative value are more affected by the other criteria. The $D + R$ values indicate the relationship between each criterion and the other criteria, and the criterion with a higher D + R value is more related to the other criteria, while the relationship of the criterion with a lower value has a lower relationship with the others (Aksakal and Dağdeviren 2010; Organ 2013).

Step 5: In the final step, a threshold value is determined by the user to remove negligible effects in order to create the digraph. The threshold value α is calculated based on the average value of the elements in the T matrix in this study. The digraph is obtained by mapping the $D + R$ and $D - R$ values that exceed the threshold value.

Stepwise method of ANP

Step 1: The super-matrix S to be created with the aim of comparing all the criteria related to the research problem with the sub-criteria is generally expressed as follows:

$$S = \begin{array}{cc|cccc} & & \begin{matrix} P_1 \\ q_{11} \cdots q_{1m_1} \end{matrix} & \begin{matrix} P_2 \\ q_{21} \cdots q_{2m_2} \end{matrix} & \cdots & \begin{matrix} P_n \\ q_{n1} \cdots q_{nm_n} \end{matrix} \\ \hline P_1 & \begin{matrix} q_{11} \\ q_{12} \\ \vdots \\ q_{1m_1} \end{matrix} & S_{11} & S_{12} & \cdots & S_{1n} \\ P_2 & \begin{matrix} q_{21} \\ q_{22} \\ \vdots \\ q_{2m_2} \end{matrix} & S_{12} & S_{22} & \cdots & S_{2n} \\ \vdots & & \vdots & \vdots & & \vdots \\ P_n & \begin{matrix} q_{n1} \\ q_{n2} \\ \vdots \\ q_{nm_n} \end{matrix} & S_{n1} & S_{n2} & \cdots & S_{nn} \end{array} \tag{8}$$

where P_n represents the set of n criteria or factors that make up the problem, and q_{nm} represents a sub-element or sub-criterion of each set of criteria. S_{ij} refers to the eigenvectors in the super-matrix structure.

Step 2: In this step, to find the weighed super-matrix, initially, the threshold total influence matrix T_α is found using the threshold value. In this step, the matrix elements that are below the threshold value in the T total influence matrix are assumed to be zero. Thus, the α-cut total influence matrix T_α is,

$\mathit{if}\quad t_{ij} < \alpha\ \mathit{then}\ t_{ij}^{\alpha} = 0\ \mathit{else}\quad t_{ij} = t_{ij}^{\alpha}$, it can be writen as,

$$T_\alpha = \begin{bmatrix} t_{11}^{\alpha} & \cdots & t_{1j}^{\alpha} & \cdots & t_{1n}^{\alpha} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha} & \cdots & t_{ij}^{\alpha} & \cdots & t_{in}^{\alpha} \\ \vdots & & \vdots & & \vdots \\ t_{n1}^{\alpha} & \cdots & t_{nj}^{\alpha} & \cdots & t_{nn}^{\alpha} \end{bmatrix} \tag{9}$$

Step 3: At this stage, the α-cut total influence matrix is normalized with the following equation (Eq. 10) and the α-cut normalized T_z matrix is found.

$\mathit{if}\qquad k_i = \sum_{j=1}^{n} t_{ij}^{\alpha}$, then the matrix T_z is as follows:

$$T_z = \begin{bmatrix} t_{11}^{\alpha}/k_1 & \cdots & t_{1j}^{\alpha}/k_1 & \cdots & t_{1n}^{\alpha}/k_1 \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha}/k_i & \cdots & t_{ij}^{\alpha}/k_i & \cdots & t_{in}^{\alpha}/k_i \\ \vdots & & \vdots & & \vdots \\ t_{n1}^{\alpha}/k_n & \cdots & t_{nj}^{\alpha}/k_n & \cdots & t_{nn}^{\alpha}/k_n \end{bmatrix} = \begin{bmatrix} t_{11}^{z} & \cdots & t_{1j}^{z} & \cdots & t_{1n}^{z} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{z} & \cdots & t_{ij}^{z} & \cdots & t_{in}^{z} \\ \vdots & & \vdots & & \vdots \\ t_{n1}^{z} & \cdots & t_{nj}^{z} & \cdots & t_{nn}^{z} \end{bmatrix} \tag{10}$$

Step 4: To obtain weighted super-matrix, the super-matrix S and normalized α-cut total influence matrix T_z must be multiplied. Thus, if the weighted super-matrix is accepted as S_w, it can be obtained with the following equation.

$$S_{w=}\ S \times T_z \tag{11}$$

Step 5: In the final step, the limit of the weighted super-matrix (Eq. 12) is exponentially reiterated until the matrix is stable and the final matrix obtained provides the priority vectors for ANP.

$$\lim_{p\to\infty} S_w^p \tag{12}$$

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