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MODELING PRODUCTIVITY OF CRIMEAN PINE BY USING FUZZY LOGIC APPLICATIONS

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Abstract

This study was addressed to obtain a model of Crimean pine's productivity by using a fuzzy logic application and compare its result to the model obtained from the application of multiple regression analysis in the Dedegul mountain district of the Beysehir watershed in the Mediterranean region, Turkey. In the study, environmental variables (slope position, altitude and soil depth) which are significantly related to site index were taken attention for modeling the productivity. Even thought the regression coefficient of the obtained model by performing multiple regression analysis was relatively high with 72.6 %, the productivity model obtained by using fuzzy logic approach was much better with an explained variance of 85.79 %. The results show that fuzzy logic application seems to be more suitable approach compared to multiple regression analysis due to the fact that it can explain not only linear but also nonlinear relationships.

Keywords: Black pine, Fuzzy logic, Site index, Height growth, Environmental factors

INTRODUCTION

Ecosystems are fuzzy systems due to complicated interrelationships between living organisms and environmental factors. Therefore linguistic and quantitative expressions are often insufficient to describe the relationships among the factors composed of the ecosystems. Some expressions used in ecosystem classification such as drought, semi drought, semi humid or humid are the most important indicators of fuzziness.

The expressions used by the people are uncertain due to the fact that the expressions display variability according to the people. Various commons of different people about the same topic concerning the ecological studies in particular ecosystem classification studies indicate the best example for fuzziness. Because the brains of the human beings display different behavior in the uncertain conditions, and evaluate the cases in different approaches.

Inventory information and assessments are always insufficient in order to explain the facts which have occurred in ecological systems. That is why the relationships among the factors composed of the ecosystems can be manipulatively interpreted by the people. In fact, manipulations are intensive and the human being factor for the expressions is dominant in the ecological studies. The most important reason of this is due to fact that the ecosystems are open systems.

Ecology science is, therefore, much more available to the commands compared to other scientific disciplines. In particular, interpretations are often more intensive in the ecological studies which doesn't contain the quantitative assessments. This case causes occurrences of much more manipulative interpretations. That is probably why statistic methods have been commonly used in ecology discipline in order to prevent the manipulations. However statistical methods are based on classic logic and include accurate classes. Because of this, integration of fuzzy logic applications with statistical methods gives an opportunity to the more objective assessments by using experiences and information of professionals in relevant issue. In this case, datum can be evaluated without manipulative expressions and the relationships can be better interpreted and understood by relevant people. Fuzzy logic has already begun to use in some statistical methods due to those explained reasons.

Zadeh (1965), introduced fuzzy sets and fuzzy logic as an extension of classical set theory for the first time in 1965. The importance of fuzzy logic has been increased since this date and it began to use in many areas such as information systems, control systems and optimization. In particular the common use of fuzzy logic in control systems was enabled by Mamdani and his colleges (Mamdani 1974; Mamdani and Assilian 1975; Mamdani 1976).

Fuzzy logic can be applied not only linear systems but also nonlinear systems. Fuzzy logic is, therefore, highly related to the real life. With regard to the ecosystems, the relationships among abiotic and biotic factors are often nonlinear. Besides, presences of outlying and abnormal observations cause the occurrence more complicated relationships in the ecosystems. Fuzzy logic is a suitable approach in ecological studies because of decreasing the estimation errors originated from abnormal observations as well as providing explanations of the nonlinear relationships.

Site index (SI) has been often used to define the productivity of forest ecosystems. From ecological perspective, numerous studies have been generated to examine the interrelationships between site index of essential tree species and environmental factors by using various statistical methods in Turkey (Zech and Çepel 1972; Eruz 1984; Daşdemir 1987; Sevgi 2003; Özkan et al. 2005; Özkan and Gülsoy 2009). But, none of those studies did not made by using fuzzy logic approaches.

In the light of above explanations, to present an example study of fuzzy logic applications intended for productivity-environmental topic, this study was conducted in the Crimian pine (*Pinus nigra* Arn.) forests of the Dedegul mountain district, Mediterranean region (Turkey).

MATERIAL AND METHODS

The study area, Dedegül mountainous district, lies in the Beyşehir Watershed area between 38° 03' and 37° 26' north latitudes and between 31° 46' and 31° 15' east longitudes (Figure 1). In the district, the lower slope of Dedegül Mountain is underlain by schists, but the other part is underlain by limestone. The major soil types are; brown forest soils which have developed on the schists, and reddish, reddish brown Mediterranean soils which have developed on the limestones. The dominant wind direction in the area is south and northeast. The southly winds coming from Emerdin mountain-Helvaova depression are warm and humid. The northeastly winds coming from Beysehir lake are cold and humid (Özkan and Kantarcı 2008). The district has a humid climate, mesothermal with slightly oceanic influence but with strong water deficit in summer. Consequently the area experiences a transitional climate between Mediterranean and Continental. *Pinus nigra* forest dominates in the area and is accompanied by; *Juniperus excelsa, Juniperus foetidissima, Sorbus umbellata, Quercus cerris, Juniperus oxycedrus, Populus tremula* (Özkan et al. 2008).

Species and subspecies of *Pinus nigra* have a significant distribution mainly at Mediterranean part such as *Pinus nigra* subsp. *lariocio* (Southern Italy, Corsica Sicily), *Pinus nigra* subsp. *salzmannii* (Mid and South Spain, Pyrenees mountains) *Pinus nigra* subsp. *dalmatica* (Islands and Northwestern shores of former Yugoslavia), *Pinus nigra* subsp. *nigra* (From Austria to mid-Italy, Greece and former Yugoslavia), *Pinus nigra* subsp. *pallasiana* (Balkans, South Carpathian mountains, Crimean, Turkey, Cyprus and Syria) (Bussotti 2002). *Pinus nigra* is a typical tree species at mountainous regions of Mediterranean basin (Mayer and Aksoy 1998).

A study dealing with site index of Crimean pine-environmental factors relations had been carried out by using simple and multiple regression analysis in this district before (Özkan et al. 2008). In that study, it was found that the significant abiotic factors affecting on site index are altitude, slope position and soil depth and the result of multiple regression analysis applied with those variables versus SI was an R^2 of 0.72 with a standard error of 4.01 (Table 1, Figure 2). Meanwhile, it must be pointed that the other environmental factors such as soil skeleton, aspect, soil texture don't show linear or nonlinear significant relations with SI. Hence, in this study, our input variables are altitude, slope position and soil depth versus site index as an output for fuzzy logic applications.

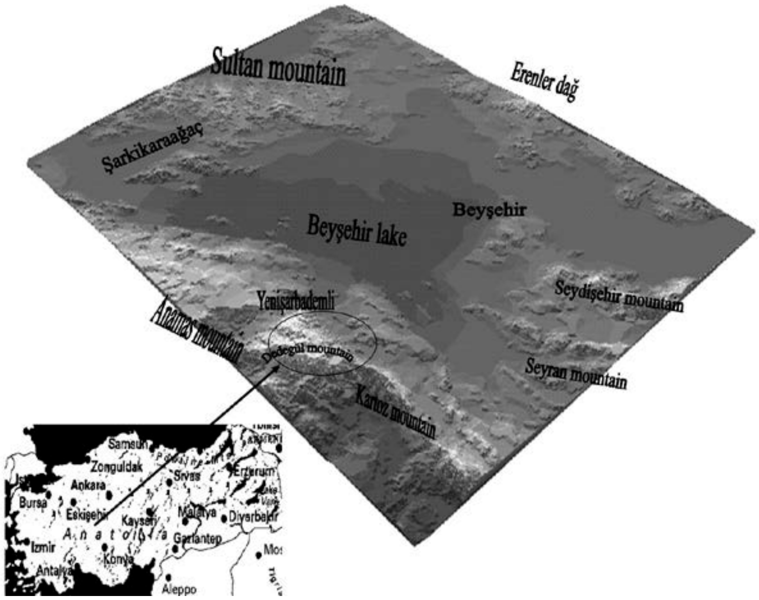


Figure 1: The map of the study area.

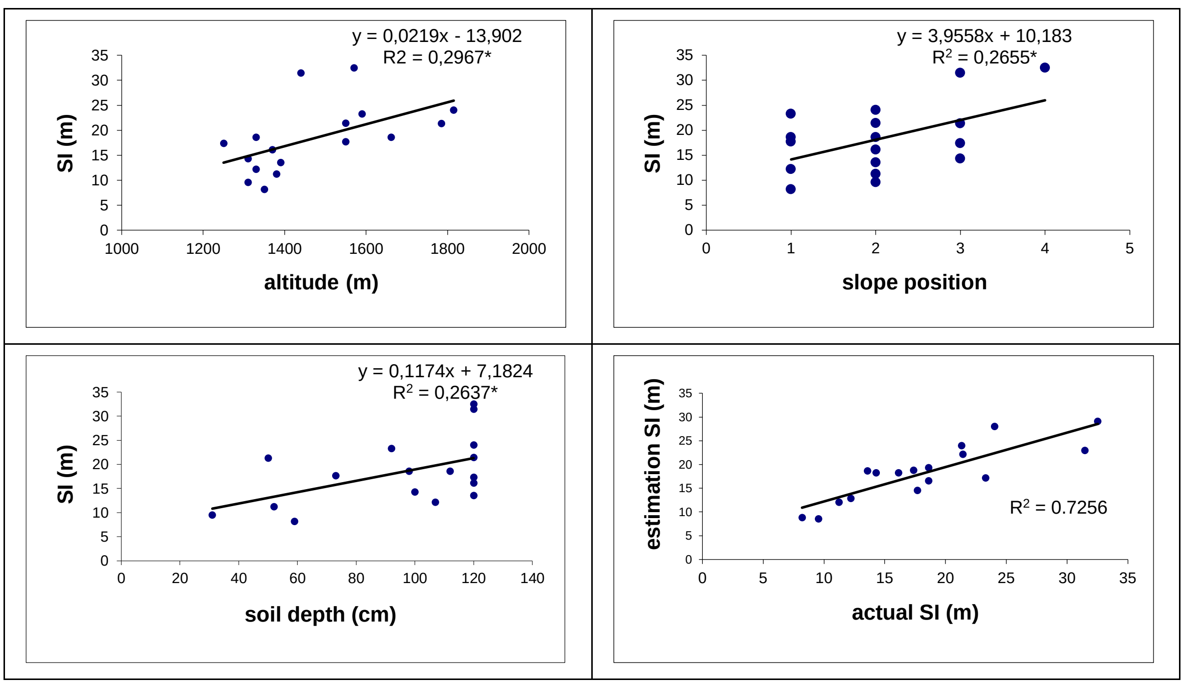


Figure 2: The results of simple and multiple regression analysis (Özkan et al. 2008).

Table 1: The statistical results of multiple regression analysis

Model		Unstandardized Coefficients		Standardized Coefficients			
		B	Std. Error	VIF	Beta		
1	(Constant)	-29.632	9.350			-3.169	0.007
	Slope position	3.232	1.150	1.063	0.421	2.810	0.015
	Soil depth	0.094	0.034	1.063	0.409	2.773	0.017
	Altitude	0.022	0.006	1.000	0.547	3.772	0.002

There are two main types of sets as the 'crisp sets' and the 'fuzzy sets'. A crisp set can be defined by a membership function:

$$\mu_s(X) = \begin{cases} 1 \text{ if } X \in S \\ 0 \text{ if } X \notin S \end{cases} \quad (1)$$

Function 1 is the degree of membership to a crisp set S. In crisp sets a function of this type is also known characteristic function. Fuzzy sets are used to produce the rational and sensible clustering. For fuzzy sets there exists a degree of membership μs (X) that is defined on [0, 1] (Kandel 1992; Iliadies 2005).

The process of fuzzy inference involves: *membership functions*, *fuzzy logic operators* and *if-then rules*. There are two types of fuzzy inference systems, Mamdani-type and Sugeno-type that can be implemented in the Fuzzy. We preferred to use Mamdani's fuzzy inference method because it is the most commonly seen fuzzy methodology and it expects the output membership functions to be fuzzy sets.

To identify the memberships functions and the rules intended for estimating of site index, not only the results of the statistical analysis but also our experiences based on observations and measurements were taken into consideration in the district.

Semi-Trapezoidal (Function 2), Trapozadial (Function 3), and Triangular (Function 4) membership functions were applied in order to produce different cases of Degrees of Membership in this study (Figure 3).

Out of the Fuzzy operators, Fuzzy AND was preferred. In another words, the minimum operator for the intersection reported by Zadeh (1965) was used in this study. The fuzzy set operator is as follows (An et al. 1981).

$$\mu_{AND}(X) = \text{MIN}[\mu_A(X), \mu_B(X)]$$

Finally the estimation values set of SI taken from fuzzy applications was related to the actual values set of SI using simple regression analysis for comparing to the result of multiple regression analysis.

RESULTS

As mentioned before, altitude, slope position and soil depth (input variables) are significant factors affecting on SI (output variable). To determine the linguistic values (LV) of the variables, each input variable was assessed individually in accordance with the variation of SI. To better understanding and determining of the linguistic values of the variables, quadric regression analysis was performed.

Determination of the Memberships

In general, the Crimean pine is widespread from 1200 m to 1800 m in the study area. While determining the membership functions, that altitudinal interval was taken into consideration. Quadric regression analysis between altitude and SI seems to be slightly convex (Figure 4a). SI increases from 1200 m to 1600 m clearly. After 1600 m. the increase of SI decreases. Hence, by comparison with other LV, the altitudinal interval of the last LV was taken wider (Figure 4b).

Variation of SI shows an increase from 1 (ridge) to 4 (lower slope). Herein, increase of SI is less from the ridge to the upper slope then increases gradually from that point (Figure 5a). That is why intersection areas of linguistic values of slope position were decreases gradually from the ridge to the lower slope (Figure 5b).

After application quadric regression between SI and soil depth, it seems to not to change the linear relations between them (Figure 6a). Hence, the interval values of the membership plots of soil depth were divided into equal (Figure 6b).

SI was divided into 7 equal plots from the worst to the best gradually and shown in Figure 7.

Fuzzy Rules and Performance Evaluation

As for determining the rules, multiple regression equation which given in Table 1 and observations were considered. Namely, at first the equation was evaluated to determine the rules. Totally 80 rules coming from four altitudes MF plots, four slope position MF plots and five soil depth MF plots were written by taking into consideration. In another words, the rules for all cases were identified.

In generally the results of the equation for estimation of the MF plots of SI were accurate in predictive compared to the MI plots of accurate values of SI. However some results were considerable deviations. For example, in case of changing of the soil depth by keeping constant 1300-1500 altitudinal interval (A2) and the middle slope positions (S3), The estimation values of SI seems to be less than accurate productivity.

Whereas accurate SI of Crimean pine is higher than estimation values of SI. Because, the area between 1300-1500 meters are optimum for Crimean pine from the climatic conditions point of view in the study area. The reason of this information loss was originated from linear multiple regression model. That is why; fourteen of the rules from eighty rules determined by the regression model were changed. All rules were given in Table 2.

To validate our algorithm and to demonstrate its strength, estimation values of SI and accurate values of SI were related with each other and regression coefficient was found at 85.79 % (Figure 8) while regression coefficient of multiple regression model is 72.56 %.

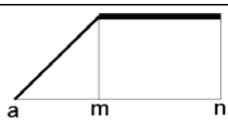
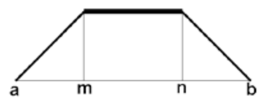
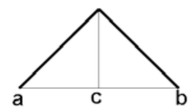
		
$\mu_s(X)=\begin{cases}0 \text{ if } X<a\\(X-a)/(m-a) \text{ if } X\in[a,m]\\1 \text{ if } X\in[m,n]\end{cases}$	$\mu_s(XX)=\begin{matrix}0 \text{ if } X<a\\(X-a)/(m-a) \text{ if } X\in\\1 \text{ if } X\in\\(b-X)/(b-n) \text{ if } X\in\\0 \text{ if } X>b\end{matrix}$	$\mu(X)=\begin{matrix}0 \text{ if } X<a\\(X-a)/(c-a) \text{ if } X\in\\(b-X)/(b-c) \text{ if } X\in\\0 \text{ if } X>b\end{matrix}$
(2)	(3)	(4)

Figure 3: Membership functions.

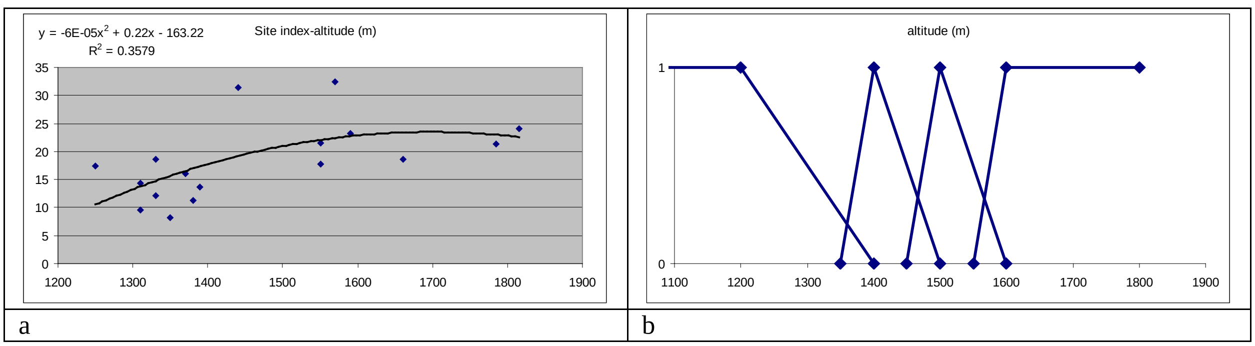


Figure 4: The quadric relation between altitude and SI (a) and, the membership function plots of altitude (b).

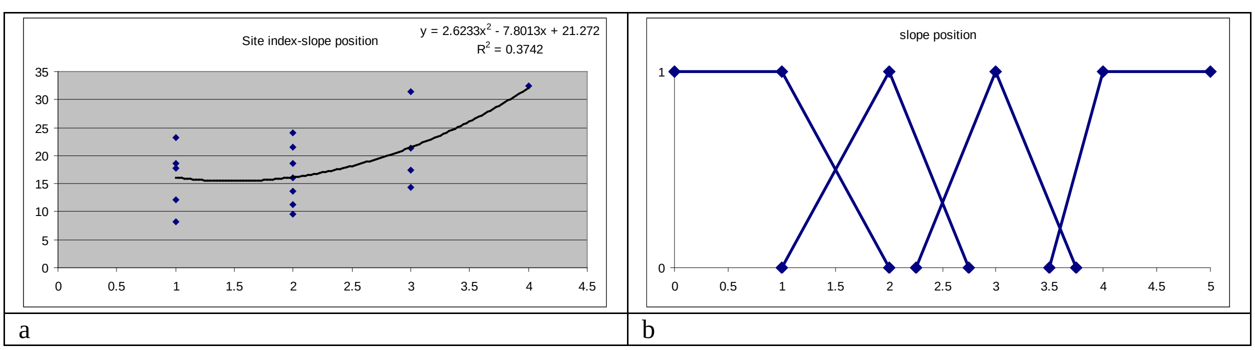
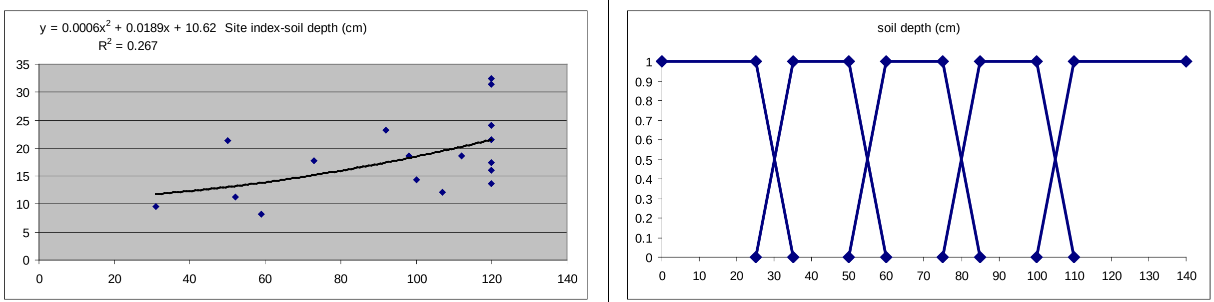


Figure 5: the quadric relation between slope position and SI (a) and, the membership function plots of slope position (b).



a b

Figure 6: the quadric relation between soil depth and SI (a) and, the membership function plots of soil depth (b) (the linguistic variables and soil depth representation as fuzzy set).

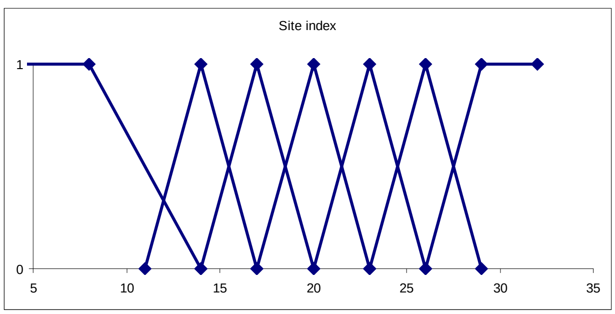


Figure 7: The membership function plots of SI.

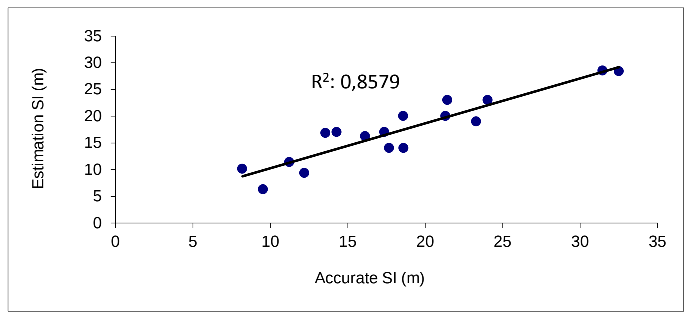


Figure 8: The relationship between Accurate SI and Estimation SI.

DISCUSSION AND CONCLUSION

SI (productivity) is strongly related to environmental factors. The chief environmental factors effecting on SI can be vary for a given species in various regions or districts. Besides, the size of the focal area, number of observations or samplings and selection place of sample plots can be affected the results dealing with SI-environmental factors. Regardless of them, the assessment method is also important to reach sufficient results. Many researches have performed statistical methods such as simple and multiple regression analysis (Eruz 1984), partial regression analysis (Ercanlı 2008), principle component analysis, discriminate analysis (Daşdemir 1987; Özkan and Gülsoy 2009), regression tree analysis (McKenney and Pedlar 2003) with the aim of explaining of SI-environmental relationships. Unlike all of these statistical methods, fuzzy logic applications are flexible and give opportunity by joining experiences and observations without data set. Because of those reasons, this study was done using fuzzy logic application in contemplation of taking more successful results.

Table 2: The rules defined based on the observations and the relationships.

Rules	Slope position	Altitude	Soil depth	Site index	Rules	Slope position	Altitude	Soil depth	Site index
1	S1	A1	SD1	SI1	41	S3	A1	SD1	SI1
2	S1	A1	SD2	SI1	42	S3	A1	SD2	SI1
3	S1	A1	SD3	SI2	43	S3	A1	SD3	SI2
4	S1	A1	SD4	SI2	44	S3	A1	SD4	SI3
5	S1	A1	SD5	SI3	45	S3	A1	SD5	SI3
6	S1	A2	SD1	SI1	46	S3	A2	SD1	SI3
7	S1	A2	SD2	SI1	47	S3	A2	SD2	SI4
8	S1	A2	SD3	SI1	48	S3	A2	SD3	SI5
9	S1	A2	SD4	SI2	49	S3	A2	SD4	SI6
10	S1	A2	SD5	SI3	50	S3	A2	SD5	SI7
11	S1	A3	SD1	SI1	51	S3	A3	SD1	SI3
12	S1	A3	SD2	SI1	52	S3	A3	SD2	SI4
13	S1	A3	SD3	SI2	53	S3	A3	SD3	SI4
14	S1	A3	SD4	SI2	54	S3	A3	SD4	SI5
15	S1	A3	SD5	SI3	55	S3	A3	SD5	SI6
16	S1	A4	SD1	SI2	56	S3	A4	SD1	SI4
17	S1	A4	SD2	SI2	57	S3	A4	SD2	SI4
18	S1	A4	SD3	SI3	58	S3	A4	SD3	SI5
19	S1	A4	SD4	SI4	59	S3	A4	SD4	SI6
20	S1	A4	SD5	SI4	60	S3	A4	SD5	SI6
21	S2	A1	SD1	SI1	61	S4	A1	SD1	SI3
22	S2	A1	SD2	SI1	62	S4	A1	SD2	SI4
23	S2	A1	SD3	SI1	63	S4	A1	SD3	SI5
24	S2	A1	SD4	SI2	64	S4	A1	SD4	SI6
25	S2	A1	SD5	SI2	65	S4	A1	SD5	SI7
26	S2	A2	SD1	SI1	66	S4	A2	SD1	SI3
27	S2	A2	SD2	SI2	67	S4	A2	SD2	SI4
28	S2	A2	SD3	SI2	68	S4	A2	SD3	SI5
29	S2	A2	SD4	SI3	69	S4	A2	SD4	SI5
30	S2	A2	SD5	SI3	70	S4	A2	SD5	SI6
31	S2	A3	SD1	SI2	71	S4	A3	SD1	SI4
32	S2	A3	SD2	SI2	72	S4	A3	SD2	SI5
33	S2	A3	SD3	SI3	73	S4	A3	SD3	SI5
34	S2	A3	SD4	SI4	74	S4	A3	SD4	SI6
35	S2	A3	SD5	SI5	75	S4	A3	SD5	SI7
36	S2	A4	SD1	SI3	76	S4	A4	SD1	SI5
37	S2	A4	SD2	SI3	77	S4	A4	SD2	SI5
38	S2	A4	SD3	SI4	78	S4	A4	SD3	SI6
39	S2	A4	SD4	SI5	79	S4	A4	SD4	SI7
40	S2	A4	SD5	SI5	80	S4	A4	SD5	SI7

According to the results obtained from the study, in comparison with multiple regression analysis, fuzzy logic application seems to be more favorable in estimation of site index.

Information loss in the results of the applied multiple regression analysis was due to fact that the method could not explain non-linear relationships. The productivity in the middle altitudinal belt of the study area is the best. Although, prediction values of the equation obtained from regression analysis show considerable differences from actual values. After the correction of this by using fuzzy logic applications, the relation coefficient between predicted values of SI and actual values of it became closer. In another words, more sufficient results were obtained by joining the observations and experiences by means of fuzzy logic applications unlike other statistical methods. Based on the results obtained in the study, fuzzy logic approach appears especially promising in terms of researches intended for productivity-environmental relationships in natural ecosystems.

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Yapılandırılmış Özet

Bu çalışma Akdeniz bölgesi, Beyşehir gölü havzası-Dedegül dağları yetişme ortamı yöresinde gerçekleştirilmiş olup, bulanık mantık uygulamaları ile karaçamın verimliliğini tahmin etmek için bir model geliştirmek ve elde edilen modelin çoklu regresyon analizi ile elde edilmiş model ile karşılaştırılmasını yapmak amacıyla yürütülmüştür.

Çalışmanın yapıldığı Dedegül dağları yöresi 38° 03' ve 37° 26' kuzey enlemleri ile 31° 46' ve 31° 15' doğu boylamları arasında bulunmaktadır (Çizelge 1). Yörede oligosen şistler ile kireçtaşı anakayası yaygın durumdadır. Kahverengi orman toprakları genelde oligosen şişstler üzerinde gelişmişken, kırmızı-kahverengi orman toprakları ise kireçtaşları üzerinde gelişmiştir. Yörede Akdeniz iklimi ile karasal iklim arasında bir geçiş iklimi hüküm sürmektedir. Yörede karaçam hakim tür olup, bunun dışında yaygın olarak bulunan diğer türler boylu ardıç, kokulu ardıç, diken ardıç, saçlı meşe ve titrek kavaktır.

Dedegül dağları yöresinde daha evvelden yapılan bir çalışmada karaçamın boy gelişimi üzerinde etkili olan faktörler olarak yamaç konumu, yükselti ve toprak derinliği olarak bulunmuş ve bu faktörlere göre boy gelişimi çoklu regresyon analizi ile modellenmiştir (Özkan ve ark. 2008). Bu modelin R^2 değeri 0.72 olarak bulunmuştur. Bu çalışmada aynı değişkendenler kullanılarak karaçamın boy gelişimini modellemek için bulanık mantık uygulamaları devreye sokulmuştur. Bulanık mantık çıkarımı üyelik fonksiyonlarının belirlenmesi, bulanık mantık operatörleri ve eğer-ise kurallarını içermektedir. İki tip bulanık mantık çıkarımı vardır. Bunlar Mandani tipi ve Sugeno tipidir. Bu çalışmada Mamdani tipi çıkarım kullanılmıştır. Üyelik fonksiyonlarının belirlenmesinde her bir değişkenin boy ile doğrusal-doğrusal olmayan ilişkileri dikkate alınmamış, kuralların yazılmasında arazi gözlemleri de devreye sokulmuştur. Çalışmada Yarı ikizkenar yamuk, ikizkenar yamuk ve üçken üyelik fonksiyonları kullanılmıştır (Şekil 3). Çalışmada 80 adet kural belirlenmiş ve bunlar Tablo 2'de verilmiştir.

Girdilerin hepsi yapıldıktan sonra, kestirim değerleri alınmıştır. Daha sonra kestirim değerleri ile gerçek değerler arasında regresyon analizi yapılmış ve sonuçta R^2 değeri 0.8579 olarak bulunmuştur.

Çalışma sonucunda, regresyon analizi ile elde edilmiş modelin açıklama payı % 72.6 ile oldukça yüksek olmasına rağmen, bulanık mantık uygulamaları ile % 85,79 ile çok daha yüksek açıklama payına sahip bir model elde edilmiştir. Bu sonuçlar bulanık mantık uygulamalarının çoklu regresyon analizi ile karşılaştırıldığında çok daha tatmin edici olduğunu göstermektedir. Zira bulanık mantık çoklu regresyon analizi gibi sadece doğrusal ilişkileri değil aynı zamanda doğrusal olmayan ilişkileri de açıklama yeteneğine sahiptir.

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