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A Fuzzy Multi-Criteria Assessment of Land Suitability for Land Plantation with *Eucalyptus grandis*

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Abstract

With the ever increasing human population and the industrial complexes catering for the need of this population, natural resources have been put under huge pressure. Forests are no exception; hence attempts to rebuild and rehabilitate the destructed and degraded forested areas are of high importance. Replantation of forest is a practical method for reversing the downgrading trends in the northern forests of Iran. *Eucalyptus grandis* is believed to be one of the most suitable species for afforestation in the north of Iran. We used a fuzzy multi-criteria approach towards land suitability assessment for plantation of *Eucalyptus grandis* in Gharnaveh Watershed of the Golestan Province of Iran. In the process, climatic, edaphic and topographic factors were employed as the criteria for suitability assessment. Membership functions were used to standardize factors and the analytical hierarchy process (AHP) was also applied for assigning weights to the criteria. The most important factors for plantation of the tree species was recognized as rainfall, slope and pH. The results showed that around 3570 hectares, close to 58% of the total area of the study site was suitable for plantation with *Eucalyptus grandis*. The approach used here can be utilized in other similar studies as an exemplary work for scientific site allocation for different plant species. Knowledge of the attempts towards afforestation that includes the ecological needs of the species used for afforestation is the key for the success of such efforts.

Keywords: *Eucalyptus grandis,* Spatial Analysis, Fuzzy logic, AHP

INTRODUCTION

Afforestation is the establishment of forest by seed or planting to achieve primary economical goals like timber supply whereby seedling establishment results in soil and water protection and Carbon sequestration [7]. Around 187 million hectares of afforestation has happened around the world which shows about 20 million hectares increase with respect to 1995. So, about 4.5 million hectares of afforestation is happening annually [10]. The most important question raised for forest extension is about appropriate place for afforestation and plant species establishment. Afforestation as a strategy helps to decrease climatic changes. The faster the growth of species used in afforestation, the faster the decrease in climatic changes. Because the environment is complex, one way to tackle this complexity and arrive at a conclusion with respect to afforestation is using multi-criteria evaluation. There has been no application of this method for suitable afforestation site selection in the north of Iran. So, current study is a step forward to express and apply this method in our country, Iran.

E. grandis Hill ex Maiden (pink eucalyptus) is native to the east coast of Australia. Due to various uses of the tree, this species is considered as one of the important exotic species in the world. Its yearly growth reaches around 3 m in height. It has a straight trunk and prunes itself naturally. The wood of this species is used in veneer, woodpile, packaging, pulp and paper. The ecological need of this species has been described by Garcia *et al*, [11] Valdez-Lazalde *et al*., [27] and Meskimen, G. *et al.*, [21] presented in Table 1. In conduction of any afforestation program recognition of suitable lands for plantation is required for its success. The evaluation approach always requires goals to be achieved [10]. Land suitability is evaluated through quantitative and qualitative approaches which can be performed in GIS environment [2].

In the GIS environment, environmental datasets are combined, analyzed and decisions are made and finally a land suitability map is produced [12]. Alternate methods based on fuzzy set theory or fuzzy logic has been appeared in land evaluation studies [2-26]. The advantages of fuzzy logic application to land suitability have been utilized in recent studies related to forestry by Lexer and Ruger [18-22]. Hall and Joss [12] used fuzzy-logic modeling of land suitability for hybrid poplar plantation across the prairie provinces of Canada.

One of the most common methods for assigning weights to the factors is the method developed by Saati in 1980, which is called Analytical Hierarchy Process

(AHP). AHP (Analytical Hierarchy Process) is a flexible method to take complex decisions with hierarchical structure. This method is one of the most comprehensive designed systems for decision making with multiple criteria, because it makes us able to formulate the problem hierarchically [23]. Fuzzy logic Zadeh [1] is a method related with unknown, flexible and careless data and its output is conducive with consistent classification McCartney and Odeh, [20] . In a fuzzy set, the hypothesis of non-membership is not absolute as the goals are dependent on a set of different levels. Membership function is devoted to goals that are completely compatible with any given class. The goals which are not suitable for the defined class, get a membership function near to the defined similarly class and are shown by the membership function μ [9]. The multi-criteria evaluation (MCE) approach involves methods that deal with suitability criteria (factors), constraints or limitations and expert's idea in choosing and weighing factors [9]. A review of the relevant literature has shown important criteria that may affect the growth and survival of the species in different parts of the world. We used these criteria to arrive at a collection of geographic layers that can be prepared and used for land suitability assessment for the species. As such, we found that the appropriate criteria for *Eucalyptus grandis* are annual precipitation, minimum and maximum temperature, altitude, slope, pH, Soil depth and soil texture [15]. This survey presents the results of a MCE application to afforestation with *Eucalyptus grandis* in the study area.

MATERIALS AND METHODS

Study Area

The study area is located in 55˚30′-56˚20′ eastern longitude and 37˚30′-37˚47′ northern latitude in the east of Golestan province (Fig. 1). The climate is temperate and semi-arid to semi-humid. The elevation range is 100-1400 meters above sea level and the average elevation is 394 meters. The most important forest tree species in this area are *Quercus iberica, Zelkova Carpinifolia, Parrotia Persica and Betula sp*. The most important pasture species are *Bromus danthonic, Artemisia herba alba, Kochia, Dactylus glomerata, Prastrata* and *Agropyron sp.* Gharnaveh watershed has an area of 9403 hectares of which 489 hectares is forest, 5834.47 hectares is rangeland and 3080 hectares is agriculture. Neglect of the land capability and developing land use in contrast to the land suitability results has heightened soil erosion and increased desertification. The ramifications of this process are land degradation and poverty. Loess formations cover most of the area and this augments the process of desertification. Hence, any attempt towards afforestation of the study area with proper species on proper land can be of great help in reversing the downgrading situation.

Methods

The study objectives were the followings.

1. Identifying proper lands for afforestation with *Eucalyptus grandis*, 2. Recognizing key environmental variables and their value range affecting the success of such plantation, and 3. Using MCE approach to produce the land suitability map of afforestation with *Eucalyptus grandis.*

To monitor land resources, a land use map was produced from Landsat 7 satellite imagery of the area and used to determine the land suitability for afforestation. We postulated that it is rather straightforward to infer the potential of different land use/covers for afforestation distinguished on the land use map. The first step is to identify the environmental variables that affect afforestation suitability [3-4-5-13-14-16-25]. The second step is to validate the scale and accuracy of proper environmental data in order to eliminate the variables that could not be placed in the model effectively [17]. In the third step, the selection of required factors for afforestation is made through expert and foresters' knowledge [17]. Hall and Joss suggest that climatic variables are more effective than soil variables in determining afforestation suitability at a regional scale. Other variables such as soil texture, soil pH, annual precipitation, minimum and maximum annual temperature and topography are also required for assessing environment suitability for afforestation. These variables are gathered as local dataset to be used in a MCE method of land suitability for afforestation. Climate information was obtained from three meteorological stations in the study area, the number of recorded years was different for each station and ranged between 12-34 years, and all of them

Table 1. Environmental requirements of *E. grandis* (J. Antonio Bustillos-Herrera, 2007)

Criteria	Sub-criteria	Minimum	Maximum
Climate	Annual Precipitation	1020 mm	1780 mm
	Annual Temperature	2 ˚C	30 ˚C
Soil	Texture of soil		Neutral
	pH	Acidic	
Topography	Altitude	0 m	600 m
	Slope	0 %	65 %

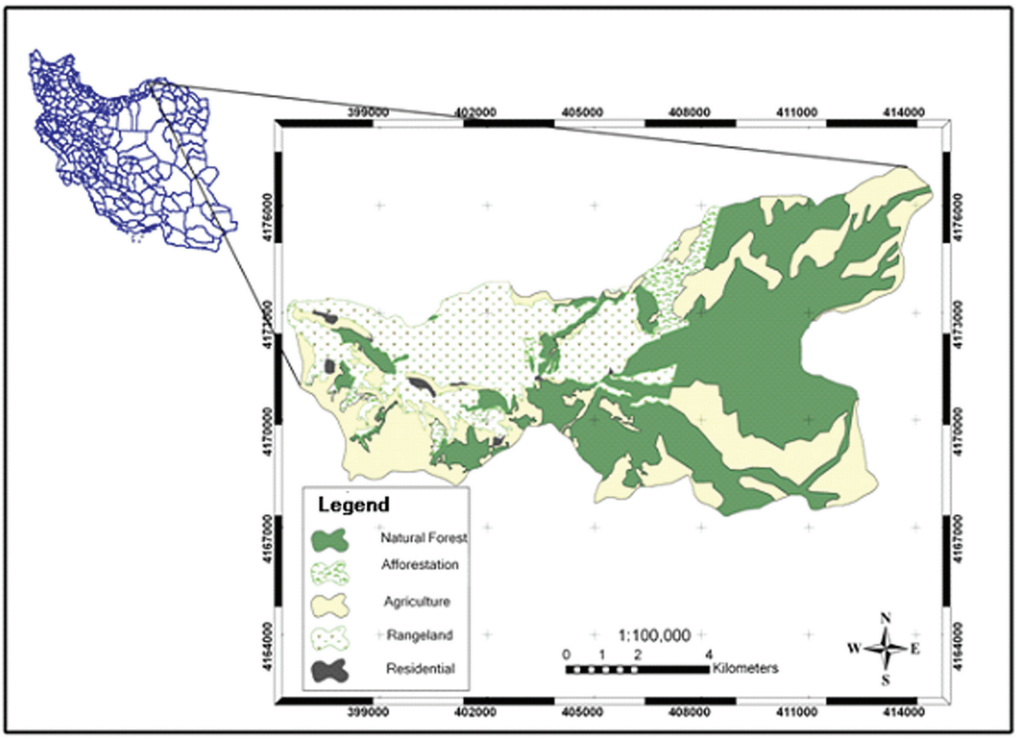

Figure 1. Case study

were highly accurate. The variables were minimum and maximum temperature, average annual relative humidity, average annual evaporation and annual temperature. In order to generate the climatic map, annual rainfall information and the minimum and maximum annual temperature were employed. Soil physical features were taken from datasets of soil sampling in the area. The number of samples for pH was 50 and for sand, silt and clay 51 samples were taken in the field. Soil texture and pH were determined by hydrometric and electrical methods, respectively. Soil pH and texture map was made in ARC VIEW 3.2 by interpolation routines. The UTM coordinates system was used to identify geographical elements on the map. The slope and altitude information were obtained from the digital elevation model (DEM) using IDRISI software [9]. The DEM used in the study has a spatial resolution of 30 m per pixel. Using satellite images which were taken in 2002, the land-cover map was prepared using Maximum likelihood classifier and training areas for five land use/land cover types including natural forest, afforestation, agriculture, rangeland and residential were defined and applied.

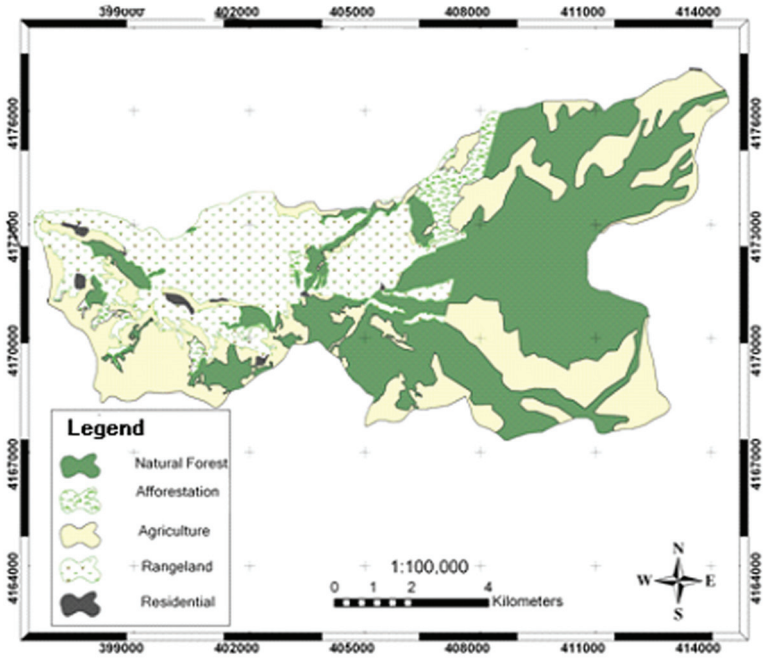

Figure 2. The land-cover map in the case study (Mashayekhan Fig2)

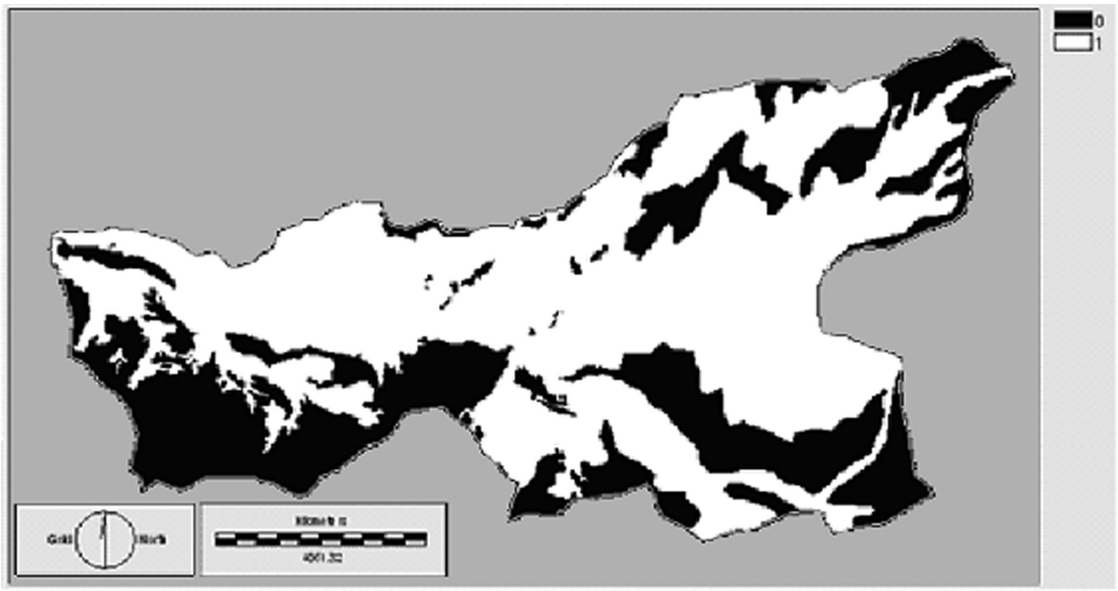

Fig.3. Constraint layer for Eucalyptus grandis (Mashayekhan Fig3)

The MCE approach includes methods that require factors and constraints be determined and their respective layers be prepared [8]. Factors are those parameters that have a range showing the suitability of the parameter while constraints are limitations imposed on the development at hand and are in the form of Boolean layers with 1 as non-limited and 0 as limited areas. The proper factors for *Eucalyptus gandis* involve annual precipitation; minimum and maximum annual temperature, altitude, slope, pH and soil texture [15]. First, the suitability levels were identified for each factor and these levels were used as a basis for making the thematic map of each factor. The required factor maps for *Eucalyptus grandis* including annual precipitation, minimum and maximum annual temperature, and altitude, slope, pH and soil texture were prepared in a GIS environment with the same spatial extent and cell resolution. In the next step, a pair-wise comparison matrix was made for weighting the factors. The most common MCE approach is the weighted linear combination [28]. At the weighting step, WEIGHT module of the IDRISI was used. Then, the EIGEN VECTOR of pair-wise comparison matrix was calculated. It is necessary that sum of the computed weights becomes unity. The matrix consistency ratio should be evaluated which shows the possibility that weights are assigned randomly. The consistency ratio of 0.1 or less is acceptable [23]. Five fuzzy layers including annual mean temperature, soil pH, annual mean precipitation, slope

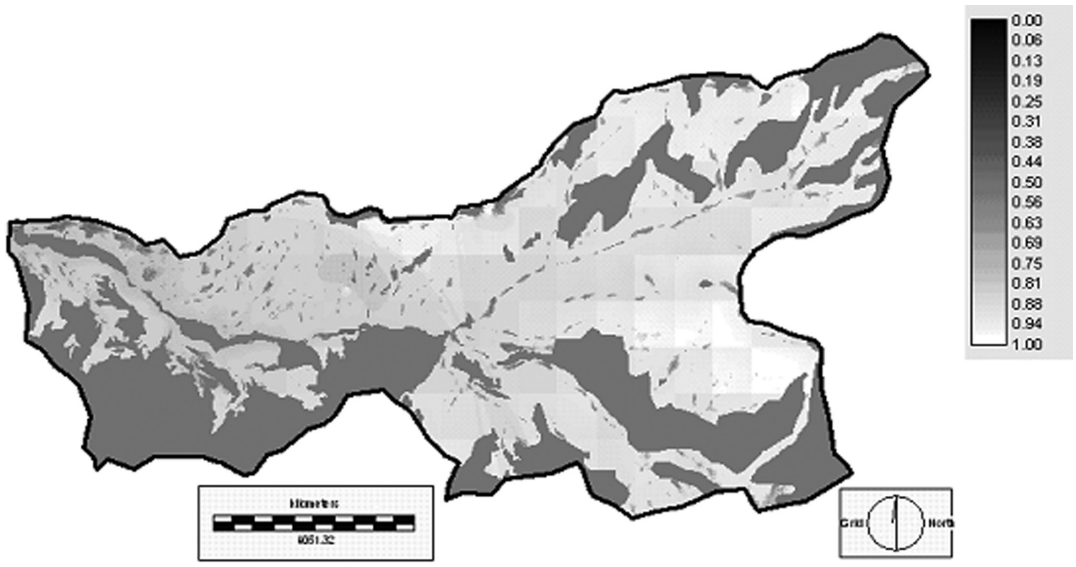

Figure 4. Distribution of the surfaces suitable for the establishment of E. grandis in the east-northern region of Golestan, Iran (Mashayekhan Fig4)

and height are provided to be used in MCE method of weighted linear combination (WLC). The formulation is given in the following::

$S=\sum_i=1$ to n W_iX_i* Π Ci (1)

Where:

S: Corresponding zone suitability

W_i: Weight for layer i

X_i: Fuzzy layer called factor

* : Multiplication sign

Π: Product sign

Ci: Boolean layer called constraint.

Distribution of constraints for *Eucalyptus grandis* is shown in Figure 3 with brighter spots showing regions in which *Eucalyptus grandis* can thrive potentially and dark spots showing areas unsuitable for *Eucalyptus grandis*.

The final suitability map was produced through combining the factors and constraints layers. In the area, constraints were urban areas, villages, roads, heavy clayey soils and slopes of more than 65%. Fuzzy membership functions were used for standardizing the criteria or the factors. The functions are used for defining the membership degree per pixel of map pertaining to the suitability of each pixel for establishment of *Eucalyptus grandis*. There are three main membership functions: linear, J shaped and S shaped, and all of them are used at a scale from 0 to 1 or 0 to 255 in membership representation. The function can be increasing, decreasing or symmetrical. The membership function with relative controlling points in Fuzzy module of the Idrisi Kilimanjaro was used to standardize the criteria [25] which are shown in Figure 5.

RESULTS

A pair-wise comparison matrix was produced and factor weighting was computed in IDRISI. The average annual temperature, annual precipitation, altitude, slope and pH were given the weights 0.234, 0.575, 0.205, 0. 316 and 0.284, respectively. Experts determined that precipitation is the most important criterion which was given a weight of 0.575. It is possible to rank every criterion or sub-criterion relatively and determine a vast area for a specific use by employing multi-criteria evaluation technique entailing AHP-Fuzzy logic approaches. Layers of annual mean temperature, soil pH, annual mean precipitation, slope and height which were turned to Fuzzy maps previously, were multiplied by their own weight and the results were added together in order to provide Fuzzy map of the suitability for plantation with *E. grandis*. The formulation is given in the following lines.

E. grandis _Fuzzy = (0.234*[Annual mean Temperatyre_Fuzzy]) +(0.284*[pH_Fuzzy])+(0.575*[Annual mean Precipitation_Fuzzy] +(0.316*[Slope_Fuzzy])+(0.205*[DEM_Fuzzy])

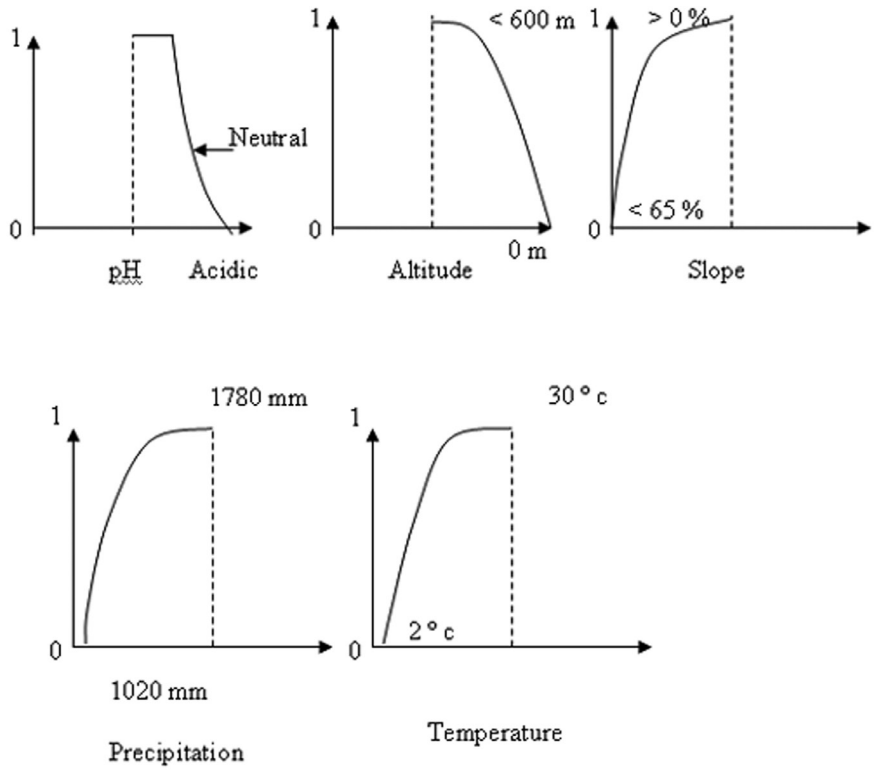

Figure 5. Membership functions used for the standardization (through fuzzy logic) of the sub-criteria associated with *E. grandis* in the area of study (J. Antonio Bustillos-Herrera). (Mashayekhan Fig5)

Using weighed factors maps and constraint maps, the land suitability map for *Eucalyptus grandis* was produced by MCE method (Fig.4). The larger values on the map show higher suitability for plantation with the tree species. Hence, the whiter the color, the more the region is suitable for *Eucalyptus grandis* afforestation. In Figure 4, the suitable areal coverage was calculated and found to be 3570 hectares which is 58 percent of the whole region. In order to improve the results, the suitability map was overlaid on land cover map derived from ETM+ imagery of the Landsat 7 satellite. Results of overlaying of suitability and land cover maps indicated that forest is the most suitable land cover for the area. This research showed that climate, soil, and environmental variables are needed for identifying suitable areas of afforestation with *Eucalyptus grandis.* In the current study, by determining appropriate environmental factors, the multi-criteria evaluation method is used as a new application to evaluate the suitability of lands in Gharnaveh watershed for afforestation with *Eucalyptus grandis.*

DISCUSSION

In this study, land suitability for afforestation with *Eucalyptus grandis* by means of determining ecological factors and using multi criteria evaluation has been defined. Because of high slope and mountainous conditions, afforestation suitability of *Eucalyptus grandis* was the least in the eastern, north eastern and south eastern parts of the watershed and was highest in the south western part of the watershed because of low slope. Afforestation suitability map of *Eucalyptus grandis* was confirmed by field visit. Afforestation suitability map produced through Fuzzy logic, provides a basis for future applications. The result of this study can be useful for similar areas. The viewpoints of afforestation experts are very important in achieving compatible results and researchers can utilize our results as a starting point for their study. According to the experts' opinions, the most important criterion, in defining lands suitability for afforestation with *Eucalyptus grandis,* is precipitation. In the area of study, we showed that MCE-GIS are proper logical methods in order to manage afforestation in the study area. Since forest surface per capita in Iran is about 0.2 ha (less than world average which is 0.6 ha per people), therefore determination of land suitability for reforestation and afforestation is essential in the country. By knowing soil, topography and studying the effects of climatic factors, we can use afforestation and choose consistent plant species to extend forests. AHP- Fuzzy logic method requires a high knowledge in comparison with traditional Boolean method. Moreover, decision maker should have sufficient information about this method to correct deviations. Results have provided valuable information for designing and decision making for afforestation activities in the region. Afforestation on massive scale is the only way to improve living conditions and productivity in arid regions. Membership functions used to standardize information layers is shown in Figure 5 in which achieving 1 is a symbol of high suitability of information layer and zero shows of unsuitability for the considered species. In regards to the growing population of Iran and ever-increasing demand to wooden materials, pressure on limited industrial forests will be decreased through afforestation with fast-growing species that can be achieved through identifying suitable land for planting given species.

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