

An application of the analytic hierarchy process and fuzzy logic inference in a decision support system for forage selection

SUN JUAN^{1,2}

CHEN QUANGONG^{3,*}

LONG RUIJUN^{4,1}

JIANG WENLAN¹

¹College of Grassland Science of Gansu
Agricultural University
Gansu, Lanzhou City
730070, PR China

²Animal Science College of South-west
Agricultural University
Chongqing City
400716, PR China

³College of Pastoral Agricultural Science
and Technology of Lanzhou University
Lanzhou City
730020, PR of China

⁴Northwest Institute of Plateau Biology
Chinese Academy of Sciences
Xining City, 810008, PR of China

Abstract Forage selection plays a prominent role in the process of returning cultivated lands back into grasslands. The conventional method of selecting forage species can only provide attempts for problem-solving without considering the relationships among the decision factors globally. Therefore, this study is dedicated to developing a decision support system to help farmers correctly select suitable forage species for the target sites. After collecting data through a field study, we developed this decision support system. It consists of three steps: (1) the analytic hierarchy process (AHP), (2) weights determination, and (3) decision making. In the first step,

six factors influencing forage growth were selected by reviewing the related references and by interviewing experts. Then a fuzzy matrix was devised to determine the weight of each factor in the second step. Finally, a gradual alternative decision support system was created to help farmers choose suitable forage species for their lands in the third step. The results showed that the AHP and fuzzy logic are useful for forage selection decision making, and the proposed system can provide accurate results in a certain area (Gansu Province) of China.

Keywords forage selection; decision support system; analytic hierarchy process; fuzzy logic

INTRODUCTION

Western China is the source of major Chinese rivers, occupies 56% of China's total land area, and 20% of Chinese people live there, most of whom are minorities depending on expansive grassland farming for survival. The area serves as a natural barrier of ecological protection to eastern China. However, the environment is deteriorating severely due to unwise human activities, overgrazing, and soil degradation. Thus, desertification is accelerating. Therefore, returning cropland to forests and grasslands to improve the ecological environment is the foremost task for local and central governments.

Having such different ecological zones in western China requires different kinds of forage species to match their individual environments. Most of the forage species which suit these environments, either for establishing improved pastures or rehabilitating degraded native grasslands, are introduced from outside the regions. However, the users have found that some introduced species have not adapted well to the local environments, even leading to some economic loss by failed introduction in some areas. Thus, an integrated approach is urgently needed for the evaluation of ecological adaptability of introduced forage species in order to reduce the risks for users and to biodiversity.

*Author for correspondence. Email: chenqg@lzu.edu.cn
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The conventional approaches of selecting forage species in the regions do not consider the impact of existing environmental factors and decision factors on those exotic forage species in the long term.

The analytic hierarchy process (AHP) is one of the extensively used multi-criteria decision-making (MCDM) methods (Braganoff 1989; Arbel & Orgler 1990; Moutinho 1993). Previous studies showed that AHP can be used to select convenience store location (Kuo et al. 2002), analyse journal quality (Forgionne et al. 2002), choose the best flexible manufacturing systems design (Chan et al. 2000), and choose the most favourable equipment type for material handling (Chan et al. 2001). It is clear that none of the above systems combine AHP in forage selection. On the other hand, in forage selection, particularly where ecological data are included, fuzzy sets permit the representation and processing of "soft" ecological knowledge in terms of natural language. This is done by sets of IF-THEN rules that relate the variables (expressed in the form of fuzzy sets such as "rather cold", "comparably few species", etc.) to each other (Kampichler et al. 2000). Hence, this paper proposes a solution to this problem through fuzzy AHP, implemented in a decision support system.

METHODOLOGY

The proposed system consists of three main components: (1) the analytic hierarchy process (AHP), (2) weights determination, and (3) decision making.

Analytic hierarchy process

The AHP is one of the extensively used MCDM methods (Braganoff 1989; Arbel & Orgler 1990; Moutinho 1993). AHP aims to settle the conflict between practical demand and scientific decision making, and aims to find a way to blend process qualitative analysis and quantitative analysis (Mu 1997, pp. 326–327). However, applications of AHP still need human judgments and this relies on experienced technical operators (Chan et al. 2000). The first step of fuzzy AHP, as for the conventional AHP, is to review the related papers and interview the domain experts about the specific domain in order to break down the problem hierarchically (Kuo et al. 1999). The first level represents the overall objective/focus of the problem. The second level includes the criteria used for evaluating the alternatives, while the sub-criteria are listed in the following level.

Weights determination

A common form of fuzzy produced rule in weight fuzzy logic is: $P \rightarrow Q$, CF, τ , where the right-hand shows a set of presupposition or condition, while the left-hand shows some conclusion or action. The precondition Q and conclusion P both may be logic, $CF(0 < CF \leq 1)$ called confidence, τ is the threshold value of accordant rule. The rule can be explained as follows: if precondition Q is fulfilled in some degree, then conclusion P can be reached through confidence (Zhao et al. 2000). The computation of confidence is mainly founded on the fuzzy logic work of Aquila et al. (2002). Then, compute the truth value T of precondition, $T = \sum(\text{Weight}_i) * (\text{Confidence}_i)$, and confirm threshold value τ , then elicit a decision making through comparing total truth value T with threshold value τ to tell the user whether a forage species can grow there or not. Triantaphyllou & Shu (2001) considered that in many real-world decision-making problems, it is even more difficult for decision maker(s) to determine the criteria weights than the performance values. Here, the AHP is used to ascertain weights of factors, in the AHP paired comparison judgments are entered in a reciprocal matrix. Absolute numbers from a fundamental scale are used to represent these judgments: 1 = equal, 3 = moderately dominant, 5 = strongly dominant, 7 = very strongly dominant, and 9 = extremely dominant (Saaty & Vargas 1993). For simplicity, this study only used the three-point scale, 1 = equal, 3 = moderately dominant, 5 = strongly dominant; and it was proved that the eigenvalue method (EM) is the only valid method for deriving the priority vector from a pairwise comparison matrix, particularly when the matrix is inconsistent (Saaty & Hu 1998). Mainly based on Saaty's AHP theory and integration of different experts' opinions, the following formulas were applied:

$$A = (a_{ij})$$

$$a_{ji} = 1/a_{ij}, a_{ij} > 0, i, j = 1, 2, \dots, n$$

where A is judgment matrix.

$$W = (W_1, W_2, \dots, W_n)^T$$

$AW = \lambda_{\max} W$, where λ_{\max} is the principal eigenvalue of A; and W is the priority vector, here, W_i is weights of factors affecting forage growth, its defuzzified value is as follows:

$$u_i = \prod_{j=1}^n c_{ij}$$

$$i = 1, 2, \dots, n, \text{ and}$$

$$w_i = \sqrt[n]{u_i}$$

$$W_i = u_i / \left(\sum_{j=1}^n u_j \right)$$

These weights can be treated as the criteria for selecting the more important factors as time and cost are limited.

$$\lambda_{\max} = \sum_{i=1}^n [(AW)_{ii} / nW_i]$$

$$CI = (\lambda_{\max} - n) / (n - 1)$$

$$CR = CI/RI$$

Coherence ratio (CR) and coincidence indicator (CI) were used to check out the coherence of judge matrix in order to check the veracity of weights.

Decision making

The weights and confidence (calculated from corresponding data) are multiplied in order to get the final result. Basically, the larger $T = \Sigma(\text{Weight}_i) * (\text{Confidence}_i)$ value indicates that the proposed forage could grow there better, if $T > \tau = 0.7$, then this forage species will be put on the short-list for selection by users.

MODEL EVALUATION RESULTS AND DISCUSSION

Founded on the system structure discussed previously, this section investigated Gansu Province. It is obvious that the number of factors affecting forage growth is quite large. After discussion with the related experts, this study uses six factors: (1) annual maximal temperature (named a_1 in following judge matrix), (2) annual rainfall (a_2), (3) frost-free days (a_3), (4) elevation (a_4), (5) annual accumulative temperature ($\geq 0^\circ\text{C}$) (a_5), and (6) minimal temperature (a_6).

This study employs the fuzzy AHP procedures as mentioned above to calculate the weight for each evaluation factor. There are three different degrees of evaluation used in this study, and they are: (1) important, (2) a little important, and (3) equally important—in the judge matrix, 1 means equally important, 3 means a little important, 5 means important. So the judge matrix was built as follows (Table 1):

Now, we calculate latent root λ_{\max} and eigenvector W .

1) Product (u_i) of element of each line in Table 1:

Table 1 The judge matrix of weights between six indices.

A_k	a_1	a_2	a_3	a_4	a_5	a_6
a_1	1	1/3	1/3	3	1/3	3
a_2	3	1	1/3	3	1/3	3
a_3	3	3	1	3	1/5	5
a_4	1/3	1/3	1/3	1	1/3	3
a_5	3	3	3	3	1	3
a_6	1/3	1/3	1/5	1/3	1/3	1

$$u_1 = a_{11} \times a_{12} \times a_{13} \times a_{14} \times a_{15} \times a_{16} = 1 \times 1/3 \times 1/3 \times 3 \times 1/3 \times 3 = 1/3$$

$$u_2 = a_{21} \times a_{22} \times a_{23} \times a_{24} \times a_{25} \times a_{26} = 3$$

$$u_3 = a_{31} \times a_{32} \times a_{33} \times a_{34} \times a_{35} \times a_{36} = 27$$

$$u_4 = a_{41} \times a_{42} \times a_{43} \times a_{44} \times a_{45} \times a_{46} = 1/27$$

$$u_5 = a_{51} \times a_{52} \times a_{53} \times a_{54} \times a_{55} \times a_{56} = 243$$

$$u_6 = a_{61} \times a_{62} \times a_{63} \times a_{64} \times a_{65} \times a_{66} = 1/405$$

2) Result of $\sqrt[n]{u_i}$ respectively:

$$0.8327, 1.2009, 1.7321, 0.5774, 2.4981, 0.3676$$

3) Normalisations of vectors of 2):

$$W_1 = 0.8327 / (0.8327 + 1.2009 + 1.7321 + 0.5774 + 2.4981 + 0.3676) = 0.1155$$

$$W_2 = 1.2009 / (0.8327 + 1.2009 + 1.7321 + 0.5774 + 2.4981 + 0.3676) = 0.1666$$

$$W_3 = 1.7321 / (0.8327 + 1.2009 + 1.7321 + 0.5774 + 2.4981 + 0.3676) = 0.2403$$

$$W_4 = 0.5774 / (0.8327 + 1.2009 + 1.7321 + 0.5774 + 2.4981 + 0.3676) = 0.0801$$

$$W_5 = 2.4981 / (0.8327 + 1.2009 + 1.7321 + 0.5774 + 2.4981 + 0.3676) = 0.3465$$

$$W_6 = 0.3676 / (0.8327 + 1.2009 + 1.7321 + 0.5774 + 2.4981 + 0.3676) = 0.0510$$

Then, the eigenvector is:

$$W = [0.1155, 0.1666, 0.2403, 0.0801, 0.3465, 0.0510]^T$$

4) Calculation of maximal latent root λ_{\max} :

$$AW = \begin{pmatrix} 1 & 1/3 & 1/3 & 3 & 1/3 & 3 \\ 3 & 1 & 1/3 & 3 & 1/3 & 3 \\ 3 & 3 & 1 & 3 & 1/5 & 5 \\ 1/3 & 1/3 & 1/3 & 1 & 1/3 & 3 \\ 3 & 3 & 3 & 3 & 1 & 3 \\ 1/3 & 1/3 & 1/3 & 1/5 & 1/3 & 1 \end{pmatrix} \begin{pmatrix} 0.1155 \\ 0.1666 \\ 0.2403 \\ 0.0801 \\ 0.3465 \\ 0.0510 \end{pmatrix}$$

$$(AW)_1 = 1 \times 0.1155 + 1/3 \times 0.1666 + 1/3 \times 0.2403 + 3 \times 0.0801 + 1/3 \times 0.3465 + 3 \times 0.0510 = 0.7599, \text{ and } (AW)_2 = 1.1100, (AW)_3 = 1.6512, (AW)_4 = 0.5227, (AW)_5 = 2.3069, (AW)_6 = 0.3353.$$

Table 2 Ranking of sampled sites in Gansu Province.

Site no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Actual ranking	9	8	3	6	9	8	7	6	7	11	8	8	10	11
Forecast ranking	13	10	4	7	9	11	9	4	9	13	7	10	13	13

Maximal latent root λ_{max}

$$\begin{aligned} \lambda_{max} &= (AW)_1/6W_1 + (AW)_2/6W_2 + (AW)_3/6W_3 + \\ & (AW)_4/6W_4 \\ &+ (AW)_5/6W_5 + (AW)_6/6W_6 \\ &= 0.7599/(6 \times 0.1155) + 1.1100/(6 \times 0.1666) + \\ & 1.6512/(6 \times 0.2403) \\ &+ 0.5227/(6 \times 0.0801) + 2.3069/(6 \times 0.3465) + \\ & 0.3353/(6 \times 0.0510) \\ &= 6.6373 \end{aligned}$$

5) Check the coherence of Table 1:

It is necessary to check out the coherence after product of λ_{max} in order to guarantee the credibility of the conclusion, steps as follows:

5.1) Calculation of coincidence indicator (CI)

$$CI = (\lambda_{max} - n)/(n - 1) = (6.6373 - 6)/(6 - 1) = 0.1275$$

Use the average random coincidence indicator (RI) table (Mu 1997, p. 330), then, RI = 1.26 when index number (n) of the judge matrix is 6.

5.2) Calculation of coherence ratio (CR)

$$CR = CI/RI = 0.1275/1.26 = 0.1011$$

CR near 0.1 is acceptable; as a result, weights of six factors, annual accumulative temperature above 0°C, annual rainfall, frost-free days, elevation, annual maximal temperature, and minimal temperature are Weight_{a5} = 0.3, Weight_{a2} = 0.2, Weight_{a3} = 0.2, Weight_{a4} = 0.1, Weight_{a1} = 0.1, Weight_{a6} = 0.1, respectively. The results showed that annual accumulative temperature above 0°C is the most important factor followed by annual rainfall and frost-free days. Thus, annual accumulative temperature above 0°C is the major consideration. Meanwhile, these weights can be used as the criteria for selecting the important factors if time or cost is limited.

We concluded from previous steps that the total confidence of six factors is:

$$T = 0.3T_{a5} + 0.2T_{a2} + 0.2T_{a3} + 0.1T_{a4} + 0.1T_{a1} + 0.1T_{a6}$$

and we developed the fuzzy model according to Aquila et al. (2002), to calculate the truth value T_{a1} , T_{a2} , T_{a3} , T_{a4} , T_{a5} , and T_{a6} for the six factors, respectively.

According to the related experts' advice, the threshold value (λ) of T is assumed to be 0.7. The system can analyse whether forage can grow at the location or not through comparing T and τ , that is to say, if $T > \tau = 0.7$, then the system believes that this kind of forage can grow there, otherwise it will be denied. Thus, this decision support system can predict whether the forage species can grow at a target site or not only if the six factors of the site are put into the system.

An intelligent forage selection decision support system is built on learning historical data, and predicts whether a new forage species can grow in a target site or not. This study focuses on returned land in Gansu Province, and 14 sites were selected randomly. Table 2 shows the results of the actual ranking and the forecast ranking. It is obvious that the proposed system is able to provide a good solution both in speed and accuracy.

CONCLUSION

This research proposes a decision support system for forage selection. This system can predict suitable forage species or variety for a target site in western China. It is confirmed that the evaluation weights provided by fuzzy AHP can be applied as the criteria for selecting the important factors. This will significantly increase the incentive of using the proposed system since the user can have a selection criterion based on different situations to evaluate other factors. Moreover, the system has been computerised. It can provide the users with a very friendly environment that can improve the usability as well. In the future, we can combine the proposed system with a geographic information system (GIS) in order to make the system become more convenient.

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