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A combined fuzzy PCA approach for location optimization and capacity planning in Glycyrrhizae green supply network design

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ABSTRACT

Selecting proper location for *Glycyrrhiza* farms is very important in obtaining the best quality in *Glycyrrhiza* cultivation and at the other hand, optimized capacity planning can cause significant reduction in cultivation costs. In this paper, we consider economic factors, social effects, cultivation conditions, and environmental issues for Location Optimization and Capacity Planning (LOCP) of *Glycyrrhiza*. Fuzzy principal component analysis (PCA) is used to address the problem complexity. Next, we develop a multiple objective mathematical model to calculate the amount of land assigned for *Glycyrrhiza* cultivation in each area. Then, we use epsilon-constraint method for solving the model. Finally, the proposed approach is applied in the country of Iran. Results illustrate which provinces are the best for Glycyrrhizae cultivation. Moreover, the optimized amount of Glycyrrhizae cultivation in each area is identified, using the mathematical model suggested here.

Keywords: Location optimization; capacity planning; principal component analyze; Radix *Glycyrrhiza*.

INTRODUCTION

Licorice (Radix *Glycyrrhiza*) is mainly cultivated in countries with semi-Mediterranean climate, especially in Italy, Turkey, Iran, Uzbekistan, China, Iraq, Azerbaijan, and Russia (Henry et al., 1991). Licorice root is used in many industries, like traditional medicine, pharmaceutical industry, food industry, cosmetics industries, etc. Several researchers have studied Licorice cultivation from various perspectives (Messier et al., 2012), like climatic conditions (Andersen & Nelson, 2014), microbiological properties of licorice root (Al-Bachir & Al-Adawi, 2014), bioactivity, and potential health benefits of licorice (Kao et al., 2014), evaluation of licorice cream as treatment for Melasma (Alobaidi et al., 2015), medicinal importance of licorice (Parvaiz et al., 2014), risk and safety assessment on the consumption of licorice root (Isbrucker & Burdock, 2006), etc. Furthermore, the impact of licorice root and its pharmacological effects on several diseases like gastric ulcers, cancer, hepatitis, and bacterial infections are investigated in reviews (Shen et al., 2007, Asl & Hosseinzadeh, 2008, Wang et al., 2013, Raut & Karuppayil, 2014).

Location Optimization and Capacity Planning are the two very important strategies in determining land-use policies (Bui et al., 2013, Colantoni et al., 2016). Location optimization problem is to determine an appropriate location among alternative sites in order to optimize one or several objective functions (Phan et al., 2014, Nasrollahi & Razmi, 2019). Capacity planning is the procedure of determining the production capacity required in the candidate areas to satisfy all demands of Licorice root (Chinguwa et al., 2013). Location optimization problem was studied in many papers and many researchers propose several mathematical models for location optimization (Liu et al., 2015, Babazadeh et al., 2015). Due to the complexity degree of mathematical modeling, considering all the judgments of decision makers and several qualitative factors in mathematical models is impossible; so in this research the Multi-Criteria Decision Making (MADM) method is employed in order to tackle these drawbacks (Tzeng & Huang, 2011, Nasrollahi et al., 2016).

Many scholars used MADM methods in various fields of location optimization (Guneri et al., 2009, Zhou et al., 2012, Mina et al., 2014, Jelokhani-Niaraki & Malczewski, 2015, Koç & Burhan, 2015). For instance, Ho et al. (2013) integrated analytic hierarchy process (AHP) and multi-choice goal programming (MCGP) methods for determining the appropriate house among alternatives. Moreover, an integrated approach for transshipment site selection is presented by Önüt & Soner (2008). They combined fuzzy TOPSIS and AHP method to select the best locations for transshipment sites. Also, Devi & Yadav (2013) implemented fuzzy elimination and ELECTRE method for optimizing plant location.

Especially, many researchers focused on location problem in agricultural fields (Soltanmohammadi et al., 2010, Rezaeiniya et al., 2014, Jeong et al., 2015). For instance, Rezaeiniya et al. (2014) used Fuzzy Analytic Network Process (FANP) to develop a model for optimizing greenhouse location problem in Iran. Meanwhile, Kouchaksaraei et al. (2015) determined the appropriate alternative among candidate sites for glasshouse location, using SWARA-COPRAS approach. They ranked candidate locations for glasshouses using complex proportional assessment. In their research, in order to calculate criteria weights, they implemented Stepwise Weight Assessment Ratio Analysis. In another paper, Rajabi & Mousavizadeh (2015) used TOPSIS method for ranking candidate locations for agricultural industries in Iran. They claimed that their methodology is the proper approach for location optimization in real-world problems. Kawa & Maryniak (2015) implemented data envelopment analysis and TOPSIS method for optimizing the location of agricultural sites. They conclude that optimizing the location of these sites has a large impact on the total efficiency of the supply chain.

Some other researchers, who work on mathematical modeling for location problems, consider only considering cost as the essential factor in agricultural LOCP. However, considering cost as the only important factor in farms location problem cannot ensure sustainable yields of the plants. So it is very important to consider other criteria as environmental issues, social effects, labor availability, cultivation condition, etc. In decision-making process, Babazadeh et al. (2015) considered climate conditions, social effects, and economic factors for location optimization of Jatropha curcas L. (JCL) cultivation in Iran. They identified the best locations for Glycyrrhizae cultivation through considering these factors.

To the best of our knowledge, there is no other research in the literature for simultaneous capacity planning and location optimization of Licorice cultivation. Moreover no other paper addresses location optimization of Licorice cultivation conceding economic factors, social effects, environmental, and cultivation condition criteria simultaneously. The remainder of this paper is organized as follows: in Section 2, the literature review is presented; PCA method is introduced in Section 3; Proposed Fuzzy-PCA approach for LOCP of Licorice farms is given in Section 4; and Section 5 describes the studied case and acquired results. Conclusion and suggestions are given in the final section.

MATERIAL AND METHODS

In this paper, we propose a methodology for obtaining the best quality of produced Licorice root and minimum cost of cultivation by location optimization of Licorice farms and proper capacity planning in each area. At the first step, we consider the areas with suitable climate conditions and well-drained soils for Licorice cultivation as the candidate sites for Licorice farms. The efficiency of these candidate sites for cultivation is measured based on 4 essential factors including economic, environmental, social effects, and cultivation condition of candidate sites. To reduce the calculations, we use fuzzy principle component analysis (FPCA) to summarize sub-criteria. For simultaneous location optimization and proper capacity planning of Licorice farms, we develop a multi-objective mathematical programming model.

After a large investigation in the literature, we define four categories of criteria to evaluate the efficiency of the potential areas for Licorice cultivation. Economic factors, social effects, cultivation condition, and environmental issues are considered in this research. List of criteria and sub-criteria are presented in Table 1. These criteria are defined as follows:

Economic Factors

In decision-making process, the economic factors of LOCP problem are very important (Godin, 2006). In this regard, we consider 5 economic criteria: investment cost, irrigation cost, cultivation cost per hectare, land cost, and payback period.

Social Effects

In this paper, we consider social aspects of Glycyrrhizae cultivation as an important issue in LOCP problem (Azadnia et al., 2014). As a result, we consider 5 social factors: social acceptability, job creation, social benefits, human development index (HDI), and labor availability.

Cultivation Condition of Licorice

It is obvious that cultivation condition of potential areas has a large impact on productivity (Godin, 2006). Cultivation condition consisted of annual average of mean daily temperature, humidity and solar radiation, annual precipitation, the area of arid and semi-arid lands, the amount of water resources, the cultivated region of different gardens, availability of manures and fertilizers, and the average harvest per hectare.

Environmental issues

In recent century, many societies and governments are now considering environmental issues and trying to minimize the environmental hazards of their performance (Babazadeh et al., 2015). Hence, environmental factors were taken into account in this research. We consider the impact of environmental factors on natural ecosystems, soil erosion, land degradation, and environmental risk as environmental factors in LOCP problem.

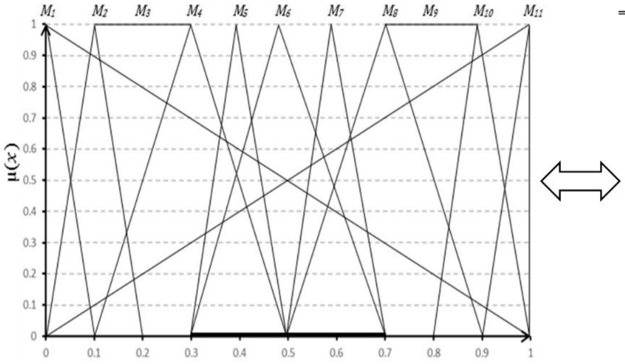
Table 1. Criteria and sub-criteria for evaluating the efficiency of potential areas.

Criteria	Sub-Criteria	References
C1: Economic	Cr1-1: Investment cost	(Sfeir et al., 2014, Rasutis et al., 2015)
	Cr1-2: Irrigation cost	(Khan, 2010, Sfeir et al., 2014)
	Cr1-3: Cultivation cost per hectare	(Iraizoz et al., 2003, Babazadeh et al., 2015)
	Cr1-4: Land cost	(Azadeh et al., 2011, Makovskis et al., 2012)
	Cr1-5: Payback Period	(Sfeir et al., 2014, Rasutis et al., 2015)
C2: Social	Cr2-1: Social acceptability	(Cavallaro & Ciraolo, 2005, Lipošćak et al., 2006)
	Cr2-2: Job creation	(Doukas et al., 2007, Animashaun & Toye, 2014)
	Cr2-3: Social benefits	(Cavallaro & Ciraolo, 2005, Rodrigues et al., 2008)
	Cr2-4: Human development index (HDI)	(Rodrigues et al., 2008, Babazadeh et al., 2015)
	Cr2-5: Labor availability	(John & Nair, 1999, Khan, 2010, Azadeh et al., 2011)
C3: Cultivation condition	Cr3-1: Annual average of mean daily temperature	(Bowen & Hollinger, 2004, Cavallaro & Ciraolo, 2005, Khan, 2010, Babazadeh et al., 2015)
	Cr3-2: Humidity and solar radiation	(Bowen & Hollinger, 2004, Khan, 2010)
	Cr3-3: Annual precipitation	(Bowen & Hollinger, 2004, Mandal & Sharda, 2013)
	Cr3-4: Area of arid and semi-arid lands	(Babazadeh et al., 2015)
	Cr3-5: Amount of water resources	(Al-Qura'n, 2011, Babazadeh et al., 2015)
	Cr3-6: Cultivated region of different gardens	(Babazadeh et al., 2015)
	Cr3-7: Availability of manures and fertilizers	(John & Nair, 1999, Khan, 2010)
	Cr3-8: The average harvest per hectare	(Lemeshev, 1986, Axtell et al., 2002)
C4: Environmental issues	Cr4-1: Impact on natural ecosystems	(Fei et al., 2014)
	Cr4-2: Soil erosion	(Brown, 1986, Mandal & Sharda, 2013, Hatfield, 2014)
	Cr4-3: land degradation	(Brown, 1986, Mandal & Sharda, 2013)
	Cr4-4: Environmental risk	(Gutsche & Rossberg, 1997, Moll & Schoot Uiterkamp, 1997, Nair & Harris, 2014)

Proposed fuzzy PCA approach

Step 1. Identify the list of candidate locations for Licorice cultivation.

Step 2. Determine the relative importance between sub-criteria and the scores of potential areas. The scores of potential areas can be obtained from linguistic terms. In this paper, we adopt the method proposed by Chen and Hwang (1992) in eleven-point scale for converting fuzzy scores into crisp scores (CHEN, L.Y., 2009). For this purpose, Figure 1 is used.



Linguistic term	Crisp score
Exceptionally low (M_1)	0.045
Extremely low (M_2)	0.135
Very low (M_3)	0.255
Low (M_4)	0.335
Below average (M_5)	0.420
Average (M_6)	0.500
Above average (M_7)	0.590
High (M_8)	0.665
Very high (M_9)	0.745
Extremely high (M_{10})	0.865
Exceptionally high (M_{11})	0.955

Figure 1. Linguistic terms for fuzzy number conversation to evaluate candidate locations scores in each criterion (Baykasoglu, 2012).

Step 3. Apply principle component analysis to increase the problem complexity. PCA aims to summarize data set by extracting a few Principal Components (PC) that describe data set with maximum possible information (Sarbu & Pop, 2005, Sayadi et al., 2012).

For extracting PCs, if we have p variables, p linear combinations of variables are obtained using Equations (1):

$$\xi_1 = w_{11}x_1 + w_{12}x_2 + \cdots + w_{1p}x_p$$

$$\xi_2 = w_{21}x_1 + w_{22}x_2 + \cdots + w_{2p}x_p \qquad (1)$$

$$\xi_p = w_{p1}x_1 + w_{p2}x_2 + \cdots + w_{pp}x_p$$

where $\xi_1, \xi_2, \dots, \xi_p$ are the p PCs and w_{ij} is the weight of the jth variable in the ith PC. The first PC (ξ_1) accounts for the maximum variance in the data set, the second PC (ξ_2) accounts for the maximum variance, which is not accounted by the first principal component, and so on (Sarbu and Pop, 2005). The weights, w_{ij} are calculated as follows:

$$w_{i1}^2 + w_{i2}^2 + \cdots + w_{ip}^2 = 1 \quad i = 1, 2, \dots, p \qquad (2)$$

$$w_{i1}w_{j1} + w_{i2}w_{j2} + \cdots + w_{ip}w_{jp} = 0 \quad \forall\, i \neq j \qquad (3)$$

Equation (2) is used to rescale the new variables in order to fix the effect of increasing the variance of linear combination given in Equations (1) as a result of changing the scale of the weights. As the axes rotate, new axes must be orthogonal to each other. Equation (3) is implemented to satisfy this condition (Sharma, 1996). Therefore, PCA summarizes the criteria and sub-criteria identified for evaluating the efficiency of potential areas by extracting a few principal components.

Step 4. Identify the weights of principle components (w_j) by fuzzy AHP pairwise comparison matrix (Kahraman, 2008).

Step 5. Allocate the demand to the potential lands. A multiple objective mathematical programming approach is proposed for demand allocation and capacity planning. In this model, minimization of total costs and maximization of preference of selected area for cultivation are the objective functions. The preference of each area is the score if x_i hectare of that potential area used for *Glycyrrhiza* cultivation subject to criteria and sub-criteria identified for evaluating the efficiency of potential areas. The proposed model is as follows:

Sets:

i: Potential areas Index, $i = 1, 2, \ldots, k$ where k is the number of potential land

j: Principle components Index, $j = 1, 2, \ldots, P$ where P is the number of principle components

Parameters:

D: Total Demand

ξ_i: Maximum cultivation capacity of i^{th} potential area

ζ_i: Minimum cultivation capacity of i^{th} potential area if it is selected

φ_i: The average harvest per hectare in i^{th} potential area

ϖ_{ij}: Relative importance between j^{th} principle component and the scores of i^{th} potential area

ψ_i: Average cultivation cost per hectare in i^{th} potential area

ϱ_i: The average harvest cost per hectare in i^{th} potential area

w_j: Weight of j^{th} principle component identified in step 4

Decision variables:

x_i: Land under cultivation in i^{th} potential area

$$y_i = \begin{cases} 1, & if\ i^{th} \text{ potential area is selected} \\ 0, & O.W \end{cases}$$

$$\max Z_1 = \sum_{j=1}^{P} w_j \left(\sum_{i=1}^{k} \varpi_{ij} \varphi_i x_i \right) \tag{4}$$

$$\text{Min}\, Z_2 = \sum_{i=1}^{k} (\psi_i + \varrho_i) x_i \tag{5}$$

St:

$$\sum_{\forall i} x_i \varphi_i \geq D \tag{6}$$

$$x_i \geq \zeta_i y_i \quad \forall i \tag{7}$$

$$x_i \leq \xi_i y_i \quad \forall i \tag{8}$$

$$y_i \in \{0, 1\} \tag{9}$$

$$x_i \geq 0 \tag{10}$$

The objective function (4) presents maximization of preference of selected area for cultivation. In this objective function, relative importance between j^{th} principle component and the scores of i^{th} potential area is shown by ϖ_{ij} and φ_i is the average harvest per hectare in that area. In addition, decision variable is x_i which identifies the amount of land under cultivation in i^{th} area. Therefore $\varpi_{ij}\varphi_i x_i$ shows the score if x_i hectare of i^{th} potential area used for *Glycyrrhiza* cultivation and $\sum_{i=1}^{k} \varpi_{ij}\varphi_i x_i$ shows the total score for all potential areas. Since w_j is the weight of j^{th} principle component, Equation (4) calculates the preference of selected area for *Glycyrrhiza* cultivation, which is the weighted sum of the score for all land used for cultivation subject to all principle components, which are the summarized form of the criteria and sub-criteria identified for evaluating the efficiency of potential areas.

In the objective function (5) ψ_i and ϱ_i are, respectively, the average cultivation and harvest cost per hectare in i^{th} potential area and x_i identify the amount of land under cultivation in that area. It is clear that $(\psi_i + \varrho_i)x_i$ calculate the cultivation and harvesting cost the in the i^{th} area. Therefore $\sum_{i=1}^{k}(\psi_i + \varrho_i)x_i$ is the total cost for cultivation and harvest for satisfying all of the demands.

Since sum of the *Glycyrrhiza* production in all potential areas can be calculated as $\sum_{\forall i} x_i\varphi_i$, constraint (6) assures that all demands will be satisfied. ζ_i is the minimum cultivation capacity of i^{th} potential area if it is selected. Therefore constraint (7) guarantees that the minimum cultivation capacity of potential areas is considered. Maximum cultivation capacity of i^{th} potential area is ξ_i. So, constraint (8) assures that cultivation area does not exceed maximum cultivation capacity of potential areas. The binary variable is defined in constraint (9). Finally, decision variable taking positive values is declared in constraint (10).

Step 6. Solve the model by applying the epsilon-constraint method to find the Pareto solutions. Epsilon-constraint method is proposed by Haimes (1971) and is one of the best known approaches for multi-objective optimization. This method has been applied in many researches in the literature to generate optimal Pareto-front in various problems (Yang et al., 2014, Nasrollahi et al., 2018, Xing et al., 2019). In this approach one of the objective functions is optimized and the others are converted to constraints bounded by some allowable levels ε_k. In the proposed model the modified objective function (5) can be represented as constraint (8).

$$\sum_{i=1}^{k}(\psi_i + \varrho_i)x_i \leq \varepsilon_k \tag{11}$$

The proposed multiple objective mathematical programming model is solved by GAMS 24.1.2/Cplex software, on Surface Book - N2, Core i7 2.6 GHz up to 3.4 GHz, with 16 GB of Ram.

Step 7. Identify the best solution from Pareto front obtained in step 5 by PROMETHEE-II. PROMETHEE method was first developed by Brans and Vincke in 1985 (Kilic et al., 2015). PROMETHEE-I can only provide a partial ranking, while PROMETHEE-II can drive the total ranking of the solutions. In this paper, we use PROMETHEE-II.

I) Determine the deviations based on pair-wise comparisons by Equation (1):

$$d_j(a, b) = g_j(a) - g_j(b) \tag{12}$$

where $d_j(a, b)$ shows the difference between the evaluation of a and b in criterion j.

II) Apply the preference function as it presented in Equation (1):

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \qquad j = 1,\dots,k \tag{13}$$

where $P_j(a,b)$ shows the preference of alternative a with regard to alternative b in criterion j and k is the number of criteria.

III) Calculate the global preference index by Equation (1):

$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b)w_j \qquad \forall a,b \in A \tag{14}$$

where $\pi(a,b)$ is defined as the weighted sum of $P_j(a,b)$ for each criterion and w_j is the weight of criterion j.

IV) Calculate the positive and negative outranking flows by Equations (1) & (16).

$$\phi^+(a) = \frac{1}{n-1}\sum_{x\in A}^{k} \pi(a,x) \tag{15}$$

$$\phi^-(a) = \frac{1}{n-1}\sum_{x\in A}^{k} \pi(x,a) \tag{16}$$

where $\phi^+(a)$ and $\phi^-(a)$, respectively, are the positive and negative outranking flow for each alternative.

V) Calculate the net outranking flow by Equation (1), which shows the PROMETHEE-II complete ranking.

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{17}$$

where $\phi(a)$ shows the net outranking flow for each alternative (Behzadian et al., 2010).

RESULTS AND DISCUSSION

Almost 30000 tons of Licorice root is needed annually in Iran. The problem is to determine the best locations for Licorice cultivation and capacity planning for available land in such a way that all the demands are satisfied. In addition, cost and quality of the product must be considered. To accomplish these objectives, the efficiency of potential areas for Licorice cultivation should be considered. Candidate locations and area of available lands are listed in Table 2. Also, the candidate locations are illustrated in Figure 2.

Table 3 shows some of the relative importance between sub-criteria, given in Table 1, and the scores of potential areas, illustrated in Figure 2. The next step is to identify the PCs. In this research, we use IBM SPSS Statistics 23 to calculate principle components. As illustrated in Figure 3, there are 3 principle components in this problem. Component 1 shows cultivation conditions of potential locations; component 2 represents the sustainability factors and; component 3 is related to economic aspects.

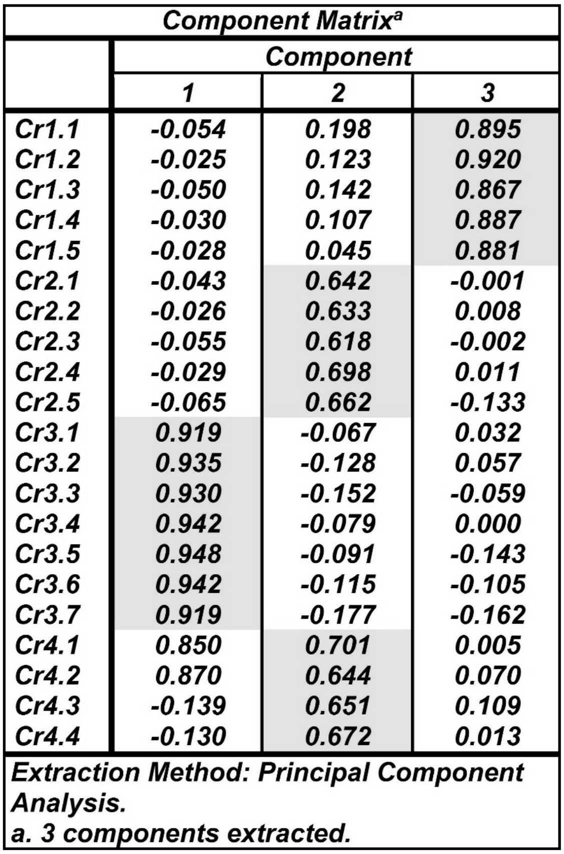
Table 2. Candidate locations and area of available lands.

Candidate Locations	Available Lands (1000 Hectare)	Candidate Locations	Available Lands (1000 Hectare)
Alborz	27	Khorasan Razavi	175
Ardabil	588	Khorasan Jonoubi	85
Azerbaijan Sharqi	807	Khuzestan	994
Azerbaijan Gharbi	764	Kohgiluyeh o Boyer-Ahmad	200
Bushehr	180	Kurdistan	666
Chahar Mahaal o Bakhtiari	184	Lorestan	708
Fars	1214	Markazi	373
Gilan	335	Mazandaran	509
Golestan	651	Qazvin	318
Hamadan	650	Qom	79
Hormozgan	140	Semnan	168
Ilam	235	Sistan o Baluchestan	330
Isfahan	468	Tehran	205
Kerman	688	Yazd	127
Kermanshah	762	Zanjan	680
Khorasan Shomali	300		

Figure 2. Candidate locations for Licorice cultivation in Iran.

Table 3. Some of the relative importance between criteria and the scores of potential areas.

	C1: Economic					C2: Social				
	Cr1-1	Cr1-2	Cr1-3	Cr1-4	Cr1-5	Cr2-1	Cr2-2	Cr2-3	Cr2-4	Cr2-5
Alborz	0.335	0.335	0.335	0.335	0.335	0.500	0.500	0.500	0.420	0.500
Ardabil	0.335	0.335	0.335	0.335	0.335	0.135	0.135	0.255	0.255	0.335
Azerbaijan Sharqi	0.420	0.335	0.420	0.335	0.420	0.135	0.135	0.255	0.135	0.255
Azerbaijan Gharbi	0.420	0.335	0.420	0.335	0.420	0.135	0.135	0.135	0.255	0.335
Bushehr	0.590	0.665	0.665	0.590	0.590	0.500	0.590	0.590	0.590	0.590
Chahar Mahaal o Bakhtiari	0.420	0.420	0.420	0.420	0.420	0.590	0.590	0.500	0.500	0.500
Fars	0.665	0.665	0.665	0.665	0.745	0.955	0.955	0.865	0.865	0.955



Component Matrix^a

	Component		
	1	2	3
Cr1.1	-0.054	0.198	0.895
Cr1.2	-0.025	0.123	0.920
Cr1.3	-0.050	0.142	0.867
Cr1.4	-0.030	0.107	0.887
Cr1.5	-0.028	0.045	0.881
Cr2.1	-0.043	0.642	-0.001
Cr2.2	-0.026	0.633	0.008
Cr2.3	-0.055	0.618	-0.002
Cr2.4	-0.029	0.698	0.011
Cr2.5	-0.065	0.662	-0.133
Cr3.1	0.919	-0.067	0.032
Cr3.2	0.935	-0.128	0.057
Cr3.3	0.930	-0.152	-0.059
Cr3.4	0.942	-0.079	0.000
Cr3.5	0.948	-0.091	-0.143
Cr3.6	0.942	-0.115	-0.105
Cr3.7	0.919	-0.177	-0.162
Cr4.1	0.850	0.701	0.005
Cr4.2	0.870	0.644	0.070
Cr4.3	-0.139	0.651	0.109
Cr4.4	-0.130	0.672	0.013

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

Figure 3. Result of principle component analysis.

According to step 4 of the proposed algorithm, we applied FAHP pairwise comparison matrix for calculating the weights. The weight of component 1 is 0.486; component 2 is 0.393; and component 3 is 0.121. The proposed multiple objective mathematical programming model is solved by GAMS 24.1.2/Cplex software, on Surface Book - N2, Core i7 2.6 GHz up to 3.4 GHz, with 16 GB of Ram. The Pareto front for the proposed LOCP model is illustrated in Figure 4. The best solution in this front is identified by PROMETHEE-II. The best solution is illustrated in Table 4. For this solution, average cost per 1000 Kilograms product is 373.26 $ and preference of selected areas for cultivation is 29,435.76. Accordingly, for this solution, the total cost will be 11,198,110 $.

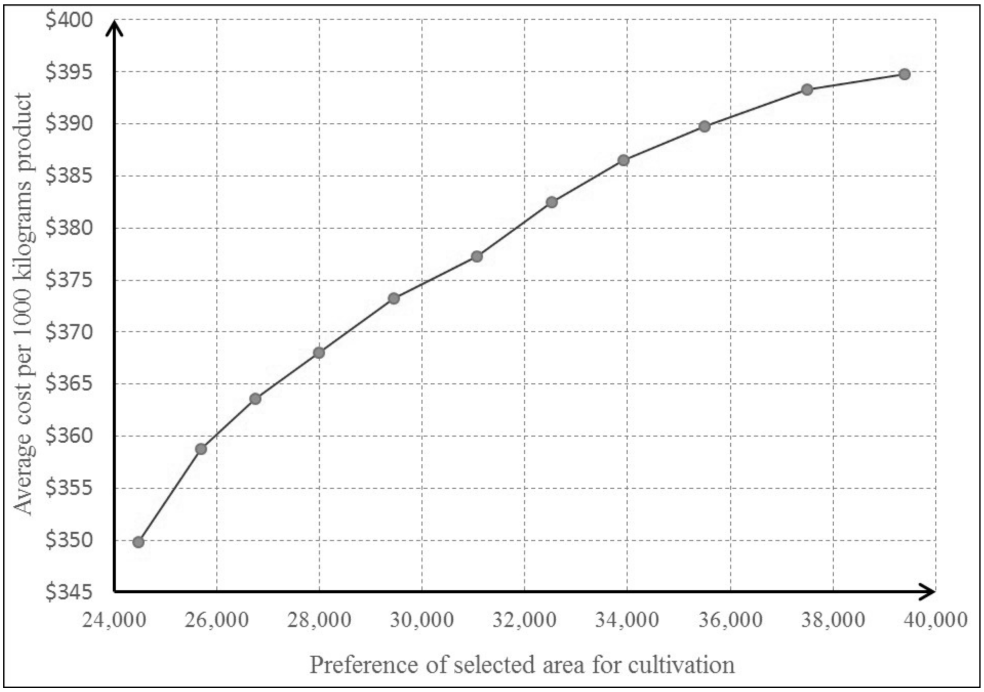


Figure 4. Solution results by epsilon constraint method.

Table 4. Best solution for the LOCP problem.

Candidate Locations	Land assigned for cultivation (Hectare)	Amount of Product (1000 Kilograms)
Fars	3634	13755
Kerman	1563	5858
Kermanshah	976	3221
Kohgiluyeh o Boyer-Ahmad	212	638
Khuzestan	1747	5807
Bushehr	219	722
Total	8351	30001

As shown in Table 4, 3634 hectares is assigned to Licorice cultivation in Fars. Moreover, Licorice cultivation is conducted in 1563 hectares in Kerman, 926 hectares in Kermanshah, 212 hectares in Kohgiluyeh o Boyer-Ahmad, 1747 hectares in Khuzestan, and 219 hectares in Bushehr assigned. As presented in Table 4, the total demand of 30000 tons is satisfied.

CONCLUSION

LOCP of Glycyrrhizae cultivation regions are among the most important decision-making challenges in obtaining the best quality of licorice root. In this paper, we present a combined fuzzy PCA approach for LOCP of Glycyrrhizae cultivation regions in Iran. At first candidate locations and decision-making factors were identified. Subsequently, PCA method was applied for problem dimension reduction. This approach is very helpful for decision makers to make a clear decision in such high-dimensional problems. In the next step, a multi-objective mathematical programming model was proposed for LOCP problem. Finally, the proposed approach was applied to the case under study, i.e., Iran.

Results showed that the demand should be assigned to Fars, Kerman, Kermanshah, Kohgiluyeh o Boyer-Ahmad, Khuzestan, and Bushehr.

CONFLICTS OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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نهج لتحليل المكون الرئيسي لتحسين الموقع الأمثل والتخطيط للحصول على الإنتاجية القصوى عند زراعة نبات العرقسوس

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الخلاصة

يعد اختيار الموقع المناسب لمزارع العرقسوس (Glycyrrhiza) أمراً هاماً للغاية للحصول على أفضل جودة عند زراعتة؛ ومن ناحية أخرى، يمكن أن يؤدي التخطيط الأمثل للإنتاجية القصوى إلى انخفاض كبير في تكاليف الزراعة. في هذا البحث، نضع في الاعتبار العوامل الاقتصادية والتأثيرات الاجتماعية وظروف الزراعة والأمور البيئية الأخرى للحصول على الموقع الأمثل وتخطيط الإنتاجية القصوى (LOCP) عند زراعة العرقسوس. تم استخدام تحليل المكون الرئيسي (PCA) الغامض لمعالجة المشكلة. وبعد ذلك، قمنا بتطوير نموذج رياضي موضوعي متعدد لحساب مساحة الأرض المخصصة لزراعة العرقسوس في كل منطقة. ومن ثم، قمنا باستخدام طريقة epsilon-constraint لحل النموذج. وأخيراً، تم تطبيق النهج المُقترح في دولة إيران. وأظهرت النتائج أفضل المحافظات لزراعة العرقسوس. علاوة على ذلك، تم تحديد الكمية الأمثل لزراعة العرقسوس في كل منطقة باستخدام النموذج الرياضي المُقترح في هذا البحث.