ANALYSING SUPPLIER SELECTION CRITERIA IN FERTIGATION SYSTEM USING FUZZY DEMATEL METHOD

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Abstract

In the agricultural field, the fertigation system helps improve root activity, nutrient mobility and uptake, besides decreased pollution of groundwater. A well-designed fertigation system should be combined with a suitable selection of materials and equipment. Various criteria should be considered throughout the process of making decision on selecting the right suppliers. Thus, the purpose of the study is to analyse the selection criteria of the supplier in fertigation system using fuzzy DEMATEL method. The present study focuses on six criteria of supplier selection; price, quality, delivery, public procurement policy, technical and managerial which are relevant for fertigation system. This study incorporates questionnaires from expert interviews to evaluate the significance of criteria involved in supplier selection. Data collected from experts in the field of fertigation system were analysed using fuzzy DEMATEL method. The findings show that public procurement policy is the most influential criteria for supplier selection in fertigation system.

Keyword: Causal relationships, Decision making, Fertigation system, Fuzzy DEMATEL method, Selection of Supplier

Introduction

One of the features of precision farming is that it is possible to make the most efficient use of applied inputs, especially water and fertilizers. Fertilizers are dissolved at appropriate concentrations in water and are distributed evenly through irrigation water by micro irrigation systems. This practice is known as fertigation, where the nutrients and water in necessary quantity at right time are deposited in the root zone so that maximum absorption of applied nutrients and water is guaranteed to achieve more harvest per drop of water (Bar-Yosef, 1999). Fertigation encourages overall root activity, increases nutrient availability and absorption, and decreases groundwater contamination (Magen, 1995; Kafkafi & Tarchitzky, 2011). The efficient use of water and fertilizers for more harvest per unit are necessary for crop safety and for keeping the soil and water in a pollution-free environment. This is required to harvest more quantity produced with a competitive price which can be planned for growing seasons under protected agriculture system (Haynes, 1985). The best way to realize the potential harvest with maximum efficiency of fertilizer and water but with minimum pollution can be achieved through fertigation (Hagin & Lowengart, 1995).

A study by Elasbah et al. (2019) reported that a proper fertilization strategy compatible with modern irrigation technology should be introduced in order to achieve maximum efficiency in the use of fertilizers. Drip irrigation is considered to be a modern irrigation system that offers a high degree of control for both irrigation and fermentation, enabling precise application in compliance with the requirements of crop water and thus reducing fertilizer leaching. In addition, it allows for regulated placement of nutrients near plant roots, decreases fertilizer losses and eliminates fertilizer leaching to groundwater. Therefore, a fully understanding of the patterns of distribution of water and fertilizer in the root zone and of fertilizer leaching below the root zone is needed for the proper design of the drip fertigation systems (Hanson et al., 1996). The choice of fertigation equipment must consider both crop requirement and irrigation system capacity. Agronomists that use fertigation systems must ensure that they choose a well-designed system combined with an adequate selection of materials and equipment. Both designs and materials used are critical to achieve good standards of fertigation systems.

Supplier selection is the most important aspect in an organization that will determine the performance of production and management of the organization (Gharakhani, 2012). An organization must find the best suppliers who can meet their needs to provide the raw materials and parts with a reasonable price, perfect time and with the best quality. Due to the rapid evolution of technology nowadays, it is important to have a well-designed supply chain management system in an organization to optimize their profit. However, making decision on selecting the right suppliers is tough since various factors and criteria should be considered throughout the process. Thus, it is important to identify the criteria that might affect the organizational performance and further, determine the most influential criteria on supplier selection problem (Chang et al., 2011).

Although traditional quantification approaches provide reliable solutions, they are not fully capable of solving human-centered problems due to the nature of human factors (Tsai et. al., 2015). The principle of fuzzy set theory proposed by Zadeh (1965) is appropriate to be used to solve real-world problems where complexity and fuzziness are involved in human judgement. Decision-making issues in real-world systems need to be carried out under ambiguity, because goals, limitations and future actions are imprecise (Tsai et. al., 2015). Many studies have been done on the multi-criteria supplier selection problems using multi-criteria decision analysis such as the Entropy method, the Simos method, the Analytic Hierarchical Process (AHP) and the Analytic Network Process (ANP) method, the Step-wise Weight Assessment Ratio Analysis (SWARA), Subjective and Objective Weight Integrated Approach (SOWIA) method and many others (Kobryń, 2017; Zaher et al., 2018). All these methods are used to determine the weights of the criteria and to identify the significance of all the criteria involved. However, in order to identify which criteria to be the most influential criteria in making decision to choose the best supplier, the causal relationships among all the criteria involved should be analysed.

One of the methods that has been commonly used since the 1970s to solve decision-making problems is the fuzzy Decision-Making Trial and Test Laboratory (DEMATEL) method. Fuzzy DEMATEL is a method which can identify the direct and indirect influence among criteria, determine the cause and effect relationships as well as strength of the criteria (Chang et al., 2011; Kobryń, 2017). This approach is more superior to other methods such as fuzzy AHP because it is known to be interdependence between the factors of the system by means of a causal diagram (Mentes et al., 2014). Many scholars had studied the usage of the DEMATEL method to determine the significance of the criteria and the causal relationship among the criteria involved in different cases. For examples, Chang et al. (2011) applies fuzzy DEMATEL method to identify the influential factor for supplier selection in electronic industry, Gharakhani (2012) used DEMATEL method to determine the influence of supplier selection criteria in automobile industry in Iran while Etraj and Jayaprakash (2017) applied DEMATEL in green supply chain management in India. Most studies on fertigation systems are only focused on designing the system but not the supplier selection. Researchers should focus on the strategy in selecting the best supplier to reduce the issues such as price, delivery, technical, supplier management and others that can affect the selection of suppliers for fertigation system (Suárez-Rey et al., 2018). In this paper, the fuzzy DEMATEL method is employed in identifying the influence of criteria involved in the process of making decision for selecting the supplier in fertigation system.

Fuzzy DEMATEL Method

The Fuzzy DEMATEL method is a well-known and detailed tool for obtaining a structural model that offers a causal relationship between complex real-factors. The basis of the fuzzy DEMATEL method consists of the following steps (Tsai et al., 2015; Mentes et al., 2014):

Step 1: Defining the assessment criteria, A_1, A_2, … A_n where A_i is the i-th criteria and n is the number of criteria.

Step 2: Choosing a group of k experts with expertise and information on issues related to the evaluation of the impact between criteria using pairwise comparison.

Step 3: Defining the fuzzy linguistic scale for dealing with the ambiguity of human judgement, the five-level linguistic term "influence" is used in the group decision-making process suggested by Li (1999): No influence, Very low influence, Low influence, High influence, and Very high influence. The fuzzy numbers for these linguistic terms are shown in **Table 1**.

Table 1 The fuzzy linguistic scale of the evaluations of respondents (Li, 1999)

Linguistic Terms	Triangular fuzzy numbers
No influence (NO)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (VH)	(0.75, 1, 1)

Step 4: Setting up the linguistic scale direct relation matrix based on Table 1 for each expert. Each expert is given an n x n fuzzy linguistic scale direct relation matrix for pairwise comparison of criteria.

Step 5: Obtaining the initial direct relation matrix for pairwise comparison by using Converting Fuzzy data into Crisp Scores (CFCS) deffuzication technique from Oprovic and Tzeng (2003). Let $t_{ij}^n = \left(f_{ij}^n, m_{ij}^n, l_{ij}^n\right)$ whereby t_{ij}^n denotes the influence degree of i^{th} criterion which affects j^{th} criterion evaluated by the n^{th} expert and $n = 1, 2, \ldots, k$. The CFCS algorithm consists of five steps as follows:

Normalization:

$$\Delta_{\min}^{\max} = \max l_{ij}^n - \min_{ij}^n \tag{1}$$

$$yl_{ij}^n = \frac{l_{ij}^n - \min f_{ij}^n}{\Delta_{\min}^{\max}} \tag{2}$$

$$ym_{ij}^n = \frac{m_{ij}^n - \min f_{ij}^n}{\Delta_{\min}^{\max}} \tag{3}$$

$$yf_{ij}^n = \frac{f_{ij}^n - \min f_{ij}^n}{\Delta_{\min}^{\max}} \tag{4}$$

Computing left (fa) and right (la) normalized values:

$$yfa_{ij}^{n} = \frac{ym_{ij}^{n}}{1 + ym_{ij}^{n} - yf_{ij}^{n}} \quad (5)$$

$$yla_{ij}^{n} = \frac{yl_{ij}^{n}}{1 + yl_{ij}^{n} - ym_{ij}^{n}} \quad (6)$$

Computing total normalized crisp values:

$$y_{ij}^{n} = \frac{yfa_{ij}^{n}\left(1 - yfa_{ij}^{n}\right) + yla_{ij}^{n} \times yla_{ij}^{n}}{1 - yfa_{ij}^{n} + yla_{ij}^{n}} \quad (7)$$

Computing crisp values:

$$p_{ij}^{n} = \min f_{ij}^{n} + y_{ij}^{n} \times \Delta_{\min}^{\max} \quad (8)$$

Integrating crisp values (for all experts):

$$p_{ij} = \frac{1}{k}\left(p_{ij}^{1} + p_{ij}^{2} + \ldots + p_{ij}^{k}\right) \quad (9)$$

Step 6: Computing the normalized fuzzy direct-relation matrix *G* using Eq.(10) related to the overall fuzzy direct-relation matrix $P = \left(p_{ij}\right)$.

$$G = \frac{p_{ij}}{\max_{1 \le i \le n} \Sigma_{j=1}^{n} p_{ij}} \quad \text{, where } i, j = 1,2,\ldots,n \quad (10)$$

Step 7: Computing the total-relation matrix *S* using Eq. (11) as follows:

$$S = G(1 - G)^{-1} \quad (11)$$

whereby *I* is the matrix identity *n* x *n*.

Step 8: Calculating the sum of rows (r_i) and the sum of columns (c_j) for each row *i* and column *j* from matrix $S = \left[s_{ij}\right]_{n \times n}$ respectively.

$$r_i = \Sigma_{1 \le j \le n}^{n} s_{ij}, \forall i \quad (12)$$

$$c_j = \Sigma_{1 \le i \le n}^{n} s_{ij}, \forall j \quad (13)$$

Step 9: Calculating the values of $r_i + c_j$ and $r_i - c_j$ and build the causal diagram with the horizontal axis $r_i + c_j$ and the vertical axis $r_i - c_j$. The degree of influence $r_i + c_j$ in DEMATEL represents the strength of influences both cause and effect (Gharakhani, 2012). From the causal diagram, the horizontal axis represents the importance degree of the criterion, while the vertical axis indicates the extent of the influence. If the axis of the $r_i - c_j$ is positive, the element is in the category of causes. Otherwise, if the axis of the $r_i - c_j$ is negative, the element is in the impact group.

Analysing the Criteria of Supplier Selection in Fertigation System using Fuzzy DEMATEL Method

This section focuses on analysing the criteria of supplier selection in the fertigation system by using fuzzy DEMATEL method. The procedures of fuzzy DEMATEL method are given as follows:

Step 1: Based on Etraj and Jayaprakash's study (2017), six criteria of supplier selection were chosen which are price (A_1), quality (A_2), delivery (A_3), public procurement policy (A_4), technical (A_5) and managerial (A_6). Table 2 shows the definition of each criteria and the dimension of each criteria.

Table 2 Definition of criteria and its dimension (Etraj & Jayaprakash, 2017)

Criteria	Definition	Dimension
Price (A_1)	Suppliers' ability to offer goods and services at an optimal quality and expense	Price competitiveness Price fluctuation Payment terms
Quality (A_2)	Suppliers' capability to meet the buyers' quality specifications	Compliance to quality Corrective and preventive action Reliability of Quality
Delivery (A_3)	Suppliers' capability to supply goods and services in time	Compliance to delivery Geographical location Delivery Reliability
Public Procurement Policy (A_4)	Compliance to governmental laid down purchase procedures and to follow guidelines	Corporate Social Responsibility Local order (LO) Cash on delivery (COD)
Technical (A_5)	Technical capacity established at suppliers' organization	Process Control Capability Production control Capability ISO-QMS Compliance
Managerial (A_6)	Supplier's management control and caliber	Organization Capability Customer Focus Purchase Order Reactiveness

Step 2: Six experts in the field of fertigation system were interviewed. All the experts have many experiences in managing the fertigation system and have their own fertigation farm. The interview was carried out at the Rubber Industry Smallholders Development Authority (RISDA) office in Chenor, Temerloh Pahang. RISDA is a Malaysian federal government agency under the Ministry of Economic Affairs, which is responsible for coordinating the smallholder sector as an important development field in the national economy.

Step 3: This study used five fuzzy linguistic terms; no influence, very low influence, low influence, high influence and very high influence as shown in **Table 1**.

Step 4: Data from each expert were presented in a 6x6 linguistic fuzzy scale direct-relation matrix for comparison of supplier selection criteria. **Table 3** shows the linguistic scale direct relation matrix given by expert 1.

Table 3 The linguistic scale direct-relation matrix by expert 1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0.25, 0.50)
A_2	(0.50, 0.75, 1.00)	0	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0.25, 0.50)	(0, 0.25, 0.50)
A_3	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	0	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)
A_4	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0.25, 0.50)	0	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)
A_5	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	0	(0.75, 1.00, 1.00)
A_6	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	0

Step 5: To get the initial direct relation matrix, the five-step algorithm of CFCS defuzzification method which involves Eq.(1) to Eq.(9) is applied. Based on the linguistic scale matrix by expert 1 in Table 3, the comparison of criterion A_1 to A_2 by expert 1 found $t_{12}^{1} = (0.75, 1.00, 1.00)$.

Applying Eq. (1), to Eq. (4),
$\Delta_{\min}^{\max} = 0.25$, $yf_{12}^{1} = 0.75$, $ym_{12}^{1} = 1$ and $yl_{12}^{1} = 1$.

Applying Eq. (5) and Eq. (6),
$yfa_{12}^{1} = 0.8$ and $yla_{12}^{1} = 1$.

Based on Eq. (7), the total normalized crisp value found is $y_{12}^{1} = 0.967$.

Then, from Eq. (8), $p_{12}^{1} = 0 + 0.967(1) = 0.967$.

In similar manner, the crisp values for all experts were obtained as follows:

$p_{12}^{2} = 0.967$, $p_{12}^{3} = 0.733$, $p_{12}^{4} = 0.733$, $p_{12}^{5} = 0.733$ and $p_{12}^{6} = 0.733$.

Applying Eq. (9), the average value of influence of criterion A_1 on criterion A_2 is given as $p_{12} = \dfrac{0.967 + 0.967 + 0.733 + 0.733 + 0.733 + 0.733}{6} = 0.811$.

Table 4 The initial direct-relation matrix *P*

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0.000	0.811	0.539	0.653	0.539	0.539
A_2	0.811	0.000	0.461	0.617	0.617	0.694
A_3	0.500	0.539	0.000	0.498	0.578	0.578
A_4	0.656	0.694	0.694	0.000	0.694	0.694
A_5	0.772	0.811	0.694	0.577	0.000	0.772
A_6	0.733	0.617	0.617	0.383	0.656	0.000

By repeating Step 1 to Step 5, the results of comparison between other criteria were obtained. **Table 4** shows the initial direct-relation matrix *P* for the influence relationship between all six supplier selection criteria.

Step 6: Based on Eq. (10) and by dividing with maximum sum of the rows (3.627), the normalized fuzzy direct-relation matrix *G* was obtained as in **Table 5**.

Table 5 Normalized fuzzy direct-relation matrix G

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0.000	0.224	0.149	0.180	0.149	0.149
A_2	0.224	0.000	0.127	0.170	0.170	0.191
A_3	0.138	0.149	0.000	0.137	0.159	0.159
A_4	0.181	0.191	0.191	0.000	0.191	0.191
A_5	0.213	0.224	0.191	0.159	0.000	0.213
A_6	0.202	0.170	0.170	0.105	0.181	0.000

Step 7: From Eq. (11), the total-relation matrix *S* was obtained as shown in **Table 6**.

Table 6 The total-relation matrix *S*

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1.096	1.277	1.084	1.042	1.111	1.164
A_2	1.315	1.129	1.099	1.062	1.157	1.226
A_3	1.092	1.098	0.847	0.907	1.007	1.054
A_4	1.347	1.351	1.202	0.968	1.230	1.288
A_5	1.426	1.431	1.249	1.150	1.119	1.356
A_6	1.232	1.207	1.072	0.960	1.105	1.003

Step 8: Based on Eq. (12) and (13), the following values were obtained:

Sum of rows, $r_i = 6.774, 6.988, 6.005, 7.386, 7.731, 6.579$

Sum of columns, $c_j = 7.508, 7.493, 6.553, 6.089, 6.729, 7.091$

Step 9: The degree of influence for each criterion are ranked based on the values of $r_i + c_j$ as presented in **Table 7**. The importance of criteria in this study was ranked as $A_2 \succ A_5 \succ A_1 \succ A_6 \succ A_4 \succ A_3$. The 'quality' criterion (A_2) with highest $r_i + c_j$ is the most important criterion for selection of supplier.

Table 7 Degree of influence for each criterion

	A_1	A_2	A_3	A_4	A_5	A_6
r_i	6.774	6.988	6.005	7.386	7.731	6.579
c_j	7.508	7.493	6.553	6.089	6.729	7.091
$r_i + c_j$	14.282	14.481	12.558	13.475	14.460	13.670
$r_i - c_j$	-0.734	-0.505	-0.548	1.297	1.002	-0.512

Furthermore, a causal diagram was built with $r_i + c_j$ and $r_i - c_j$ be the horizontal and the vertical axis respectively as shown in **Figure 1**. Based on the causal diagram in **Figure 1**, it shows that criteria public procurement policy (A_4) and technical (A_5) are categorised into the causal group, while the effect group consists of criteria price (A_1), quality (A_2), delivery (A_3) and managerial (A_6). The most significant causal criteria of supplier selection of this study are public procurement policy (A_4) and followed by technical (A_5). These two criteria need to be given more consideration than other criteria since the causal group is related to its influence on the effect group criteria and by improving the cause criteria, the effect criteria are enhanced concurrently (Seker & Zavadskas, 2017). The public procurement policy (A_4) and technical (A_5) criteria can directly or indirectly influence the other criteria. The results can be used as a guidance in improving the selection of supplier in fertigation system by focusing on the critical criteria.

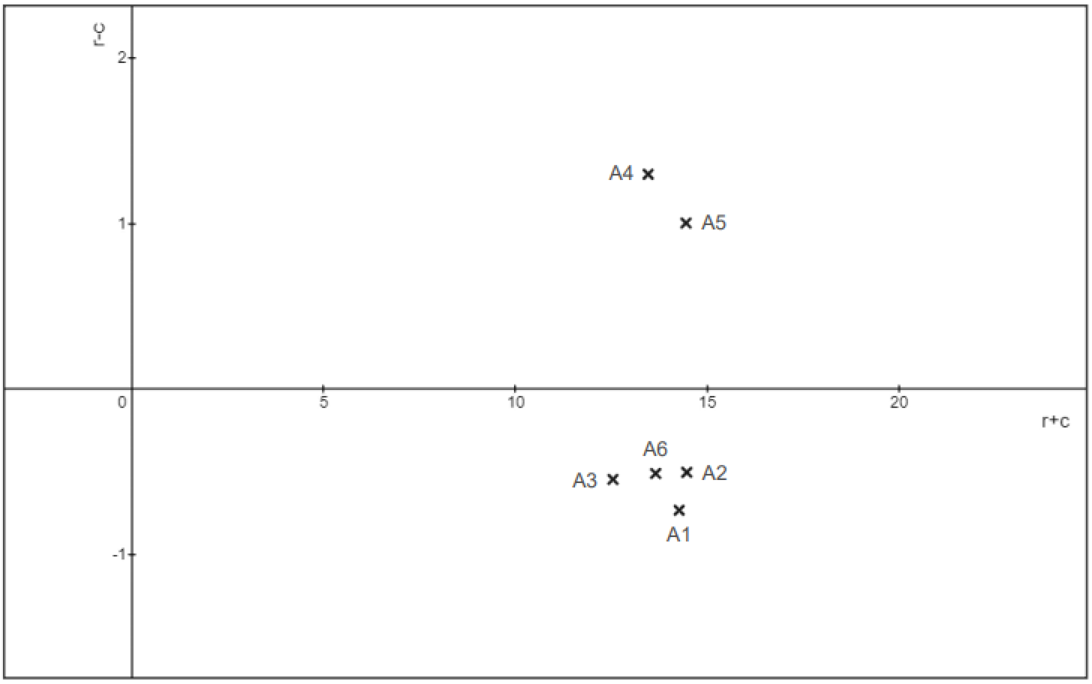

Figure 1 Causal diagram

Conclusion

The fuzzy DEMATEL method is widely used in solving problems involving multi criteria decision making of supplier selection. In this paper, the fuzzy DEMATEL method is applied in analysing the supplier selection in fertigation system. Supplier selection decision has become an important aspect that determines the production of the fertigation system. A good standard of fertigation system must come up with a well-designed system combined with an adequate selection of materials and equipment. From the results, we found that criteria of public procurement policy (A_4) and technical (A_5) can be classified into the causal group. Public procurement policy (A_4) is the most significant causal criteria among other supplier selection criteria and followed by technical (A_5). The 'quality' criterion (A_2) was ranked as the most important criterion for selection of supplier in fertigation system followed by technical (A_5), price (A_1), managerial (A_6), public procurement policy (A_4) and delivery (A_3). It shows that although public procurement policy (A_4) is not the highest value ranked in the importance criteria, it is the most influential criteria that could lead directly or indirectly to other criteria. The findings of this study will hopefully allow the agriculture sector to concentrate on essential requirements for the selection of suppliers. In future research, the DEMATEL method can be integrated with other methods which could yield to a better result that can help in selecting the best suppliers.

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Conflict of interests

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