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Fuzzy Entropy based MOORA Model for Selecting Material for Mushroom in Viet Nam

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Abstract—The role of materials in the proper design and operation of products has been acknowledged. An incorrectly selected material for a certain product may cause premature failure of the final product. The right choice of available materials is very important to the success and competitiveness of manufacturing organizations. In Vietnam, tropical monsoon climate conditions greatly affect mushroom cultivation. The raw materials, additives and the ratio between them will also affect the quality and yield of mushrooms. Therefore, selecting the options for growing mushrooms or choosing good materials to grow mushrooms effectively is also a matter of concern. This is a problem of many decision-making problems. In this paper we multi-objective optimization on the basis of ratio analysis (MOORA) method to evaluate mushroom cultivation options in Vietnam.

Index Terms—MOORA method, Mushroom, FMCDM, entropy.

I. INTRODUCTION

King oyster mushrooms and Pleurotus sajor-caju are delicious, nutritious foods and bring great value to tropical countries. Materials for growing mushrooms in tropical countries are diverse such as sawdust, rice husk, rice bran, bagasse, straw, etc… By 2013, Sharma et al. [5] also confirmed that rice straw is a substrate for abalone mushroom production with higher yield than wheat straw and sawdust. In 2015, Le et al. [3] studied and pointed out that although the productivity of Pleurotus sajor-caju grown on rice husk is not the highest, the mushroom grows fast, giving the early harvest. In 2016, Nguyen et al. [1] studied the mixing formula of the proportions of raw materials including rice straw, corn cob, sawdust, rice bran and $CaCO_3$. They show that the formula mixed with 40% rice straw + 20% corn cob + 19% sawdust + 20% rice bran + 1% $CaCO_3$ will result in the biological performance of King oyster mushroom originating from Japan growing in Vietnam is the highest. Studies also analyze the characteristic properties of mushroom, such as the diameter of mushroom caps, fungal stem height and biological efficiency. Experimental studies also analyze the characteristic properties of mushroom, such as diameter of mushroom caps, fungal stem height and biological efficiency. From there, conclude the mixing formula, or mushroom planting materials for the best results. These studies also indicate infection rates when using fungal growing materials, or different mixing formulations. But the incidence of this disease should be studied in parallel with the characteristics of the fungus or biological performance as mentioned above so that there is an evaluation of the best ingredients or mixing formula for mushroom cultivation. Then we will have the multi-criteria decision making (MCDM) problem, i.e. selecting the best options on the set of alternatives based on the set of criteria. In the study of growing mushrooms, selecting the right materials will give the best results while taking advantage of the diverse available local materials. There are many different optimization techniques that have been used to select the most suitable material source for design or farming. For instance, Analytical Hierarchy Process (AHP) [6], TOPSIS [7, 14], Gray relational analysis (GRA) [8], VIKOR method [9], MOORA method [2, 4, 10] and MCDM method [11, 13, 19-21,24], etc. Because in evaluating the selection of ingredients or mixing formulations used for mushroom cultivation, the above analysis has the infection rates of fungi brought by the ingredients. We consider the incidence of this disease to be a non-profit criterion, in addition to other criteria such as biological productivity as a benefit criterion. That is, decision making here has both benefits and non-benefit criteria, they can conflict with each other.

At the same time, the obtained data may be inaccurate due to the measurement, or the recorded report. Fuzzy logic [12] is an effective tool for solving inaccurate, uncertain data problems. Therefore, in this paper, we propose the use of fuzzy MOORA (FMOORA) and fuzzy MCDM (FMCDM) methods to select the most effective mushroom growing ingredients or the most effective mushroom mixing recipes. In this paper, we use the fuzzy method Left-Right to construct the membership function for fuzzy sets from the set of real numbers as shown in Fig.1 and Fig.2. The weights are also built based on the entropy function, because the entropy function is verified to evaluate information as well. In this paper, we also used fuzzy MCDM model with Euclidean distance measurement to evaluate mushroom selection. We then compared the results to the experimental results. The results of the article also contribute to reinforce the conclusion of experimental results. Moreover, the experimental results independently consider the criteria of benefit and non-benefit criterion, they attach importance to the benefit criteria first, then consider the criteria of no benefit. In our proposed models using theoretic of fuzzy set, we combined to use both consider group of benefits and group of non-benefit criteria simultaneously. That is the outstanding contribution of this article to select mushroom planting materials. The rest of the article is organized as follows: Section 2, we reiterate the methodology of FMCDM, FMOORA methods. Section 3, we apply the methods mentioned in section 2 to the numerical examples already in references [1, 3]. The conclusion is shown in section 4.

II. Methodology

Fuzzy multi criteria decision making method (FMCDM) provides the ranking solution to find out the best quantitative solution from a set of alternatives $A=\{A_1, A_2,..., A_m\}$ based on the set of criteria $C=\{C_1, C_2,..., C_n\}$. In which each criterion C_j has a weight $w_j (j=1,2,...,n)$ such that $\sum_{j=1}^{n} w_j = 1$. In this paper, we applied entropy method for the FMCDM because it provides high accuracy in determination of weight of the criteria in the model. A FMCDM problem can be expressed in fuzzy decision matrix $D=\left[d_{ij}\right]_{m\times n}$ as follows

$$\begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \cdots & C_n \end{array} \\ \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \end{array}$$

In which $d_{ij} \in [0,1]$ for all $i=1,2,...,m$ and $j=1,2,...,n.$

2.1 The FMOORA method

Fuzzy Multi Objective Optimization on the Basis of Ratio Analysis (FMOORA) method [2] is presented with these following steps.

Step 1. Normalization decision matrix

In this step, we construct the fuzzy decision making matrix using eq.(1) or eq. (2)

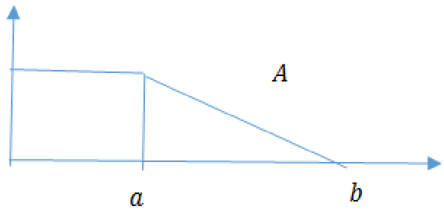

Fig.1. The membership function of fuzzy set A

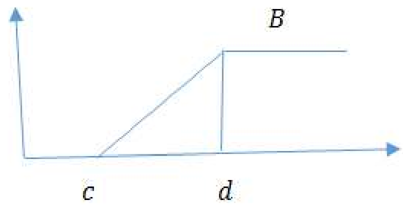

Fig.2. The membership function of fuzzy set B

The membership function [12] of A or B as

$$\mu_A(x)=\begin{cases} 1 & if\ x\le a \\ \dfrac{b-x}{b-a} & if\ a\le x\le b \\ 0 & if\ x\ge b \end{cases} \quad (1)$$

or

$$\mu_B(x)=\begin{cases} 0 & if\ x\le c \\ \dfrac{x-c}{d-c} & if\ c\le x\le d \\ 1 & if\ x\ge d \end{cases} \quad (2)$$

This step can be ignored if D is the fuzzy decision matrix.

Step 2. Calculate the fuzzy entropy [15] e_j of each criteria C_j for all $j=1,2,...,n.$

$$e_j = \frac{-1}{m\ln(2)}\sum_{i=1}^{m}\left[d_{ij}\ln(d_{ij})+(1-d_{ij})\ln(1-d_{ij})\right] \quad (3)$$

Step 3. Calculate the weight w_j of each criteria C_j for all $j=1,2,...,n.$

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \quad (4)$$

Step 4. Calculate the weighed normalized decision matrix $W = \left[W_{ij}\right]_{m\times n}$

$$W_{ij} = w_j \times d_{ij} \quad (5)$$

Step 5. Compute

$$P_i = \frac{1}{|B|}\sum_{j\in B} W_{ij} \quad (6)$$

and

$$R_i = \frac{1}{|NB|}\sum_{j\in NB} W_{ij} \quad (7)$$

where B is the set of benefit criteria and NB is the set of all non-benefit criteria, for all $i = 1, 2, ..., m.$

Step 6. Compute the relative weight of each alternative

$$Q_i = P_i - R_i \quad (8)$$

for all $i = 1, 2, ..., m.$

Step 7. Ranking the alternatives $A_k \succ A_i$ if $Q_k > Q_i$ for all $i, k = 1, 2, ..., m.$

2.2. The FMCDM method based on the distance of fuzzy sets

The fuzzy multi criteria decision making (FMCDM) based on distance of fuzzy sets is presented with these following steps.

Step 1. Normalization decision matrix

In this step, we construct the fuzzy decision making matrix using eq.(1) or eq. (2).

This step can be ignored if D is the fuzzy decision matrix.

Step 2. Chose the perfect option $P^* = (p_1, p_2, ..., p_n)$ where $p_j = 1$ if C_j is the benefit criterion and $p_j = 0$ if C_j is the non-benefit criterion, for all $j = 1, 2, ..., n.$

Step 3. Compute the distance of each alternative to the perfect option P^* as follows

$$d(A_i, A^*) = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(d_{ij} - p_j)^2} \quad (9)$$

Step 4. Ranking the alternatives $A_k \succ A_i$ if $d(A_k, A^*) \le d(A_i, A^*)$ for all $i, k = 1, 2, ..., m.$

III. Case Studies

In order to demonstrate the effectiveness of the proposed methods (in section 2), we consider numerical examples in the selection of mushroom cultivation options in Vietnam and compare them with experimental results.

Example 1 [1]. To grow King oyster mushroom, we often use straw, corn cob, sawdust, rice bran, $CaCO_3$. They are blended according to certain ratios, Nguyen et al. [1] consider each mixing formula as an alternative.

Alternative A_1: 40% straw + 30% corn cob + 29% sawdust + 0% rice bran+ 1% $CaCO_3$

Alternative A_2: 40% straw + 27% corn cob + 27% sawdust + 5% rice bran+ 1% $CaCO_3$

Alternative A_3: 40% straw + 25% corn cob + 24% sawdust + 10% rice bran+ 1% $CaCO_3$

Alternative A_4: 40% straw + 22% corn cob + 22% sawdust + 15% rice bran+ 1% $CaCO_3$

Alternative A_5: 40% straw + 20% corn cob + 19% sawdust + 20% rice bran+ 1% $CaCO_3$

Alternative A_6: 40% straw + 17% corn cob + 17% sawdust + 25% rice bran+ 1% $CaCO_3$

Evaluate the impact of growing raw materials on the growth and productivity of king oyster mushrooms. We consider the criteria (C_1) the diameter of the mushroom caps (mm), (C_2) the diameter of the mushroom stalks (mm), (C_3) the length of the mushroom stalks (mm), (C_4) Biological productivity (%) and (C_5) the infection rate (%). In there, Criteria C_1, C_2, C_3, C_4 are criteria for benefits, and the C_5 criterion is a non-benefit criterion. Data of the impact of growing raw materials on the growth and productivity of king oyster mushrooms [1] indicates the table 1.

Table 1. Effect of mixing formula on fruit size, biological productivity and infection rate of king oyster mushroom [1]

	C_1	C_2	C_3	C_4	C_5
A_1	27.7	20.1	96.5	33.5	6.6
A_2	35.2	24.3	102.6	41.7	7.1
A_3	40.4	27.9	120.1	46.8	8.3
A_4	46.8	30.4	132.4	51.4	9.4
A_5	50.4	32.6	146.2	59.4	9.9
A_6	50.3	32.5	143.4	59.1	10.8

- **Using the FMOORA method**

Now, we present the process of the proposed method for evaluating the impact of growing raw materials on the growth and productivity of king oyster mushrooms.

Step 1. Because of the C_1, C_2, C_3 criteria are not normalized, we need to bring it to the normalized fuzzy form by using the eq.(2). Specially, criterion C_1 we using the eq.(2) with $c = 20, d = 60$; criterion C_2 we using the eq.(2) with $c = 20, d = 40$ and criterion C_3 we using the eq.(2) with $c = 50, d = 150$ Then, we get the fuzzy decision matrix of effecting of mixing formula on fruit size, biological productivity and infection rate of king oyster mushroom as see in Table 2.

Step 2: Using the eq.(3) we get the entropy of each criteria (Table 3)

Steep 3. Using the eq.(4) we get the weight of each criteria (Table 3)

Step 4. Calculate the weighed normalized decision matrix $W = \left[W_{ij}\right]_{m\times n}$ by using the eq.(5) as see in Table 4.

Step 5. Compute P_i and R_j for all $i = 1, 2, ..., 6$, see in Table 5.

Step 6. Compute Q_i for all $i = 1, 2, ..., 6$, see in Table 5

Step 7. Ranking alternatives, see in Table 5.

Table 2. The fuzzy decision matrix king oyster mushrooms

	C_1	C_2	C_3	C_4	C_5
A_1	0.7925	0.005	0.465	0.335	0.066
A_2	0.38	0.215	0.526	0.417	0.071
A_3	0.51	0.395	0.701	0.468	0.083
A_4	0.67	0.52	0.824	0.514	0.094
A_5	0.76	0.63	0.962	0.594	0.099
A_6	0.7575	0.625	0.934	0.591	0.108

Table 3. The weight of criteria in Example 1

	C_1	C_2	C_3	C_4	C_5
Entropies	0.5977	0.5393	0.4771	0.6754	0.2937
Weights	0.1665	0.1906	0.2164	0.1343	0.2922

Table 4. The fuzzy weighed normalized decision matrix king oyster mushrooms

	C_1	C_2	C_3	C_4	C_5
A_1	0.0321	0.0010	0.1006	0.0450	0.0193
A_2	0.0633	0.0410	0.1138	0.0560	0.0207
A_3	0.0849	0.0753	0.1517	0.0629	0.0243
A_4	0.1116	0.0991	0.1783	0.0690	0.0275
A_5	0.1265	0.1201	0.2082	0.0798	0.0289
A_6	0.1261	0.1191	0.2021	0.0794	0.0316

Table 5. The results of P_i, R_i and Q_i for ranking of alternatives

	P_i	R_i	Q_i	$100\times\frac{Q_i}{\max Q_i}$	Ranking
A_1	0.1786	0.0193	0.1593	31.51	6
A_2	0.2741	0.0208	0.2533	50.1	5
A_3	0.3748	0.0243	0.3505	69.32	4
A_4	0.4580	0.0275	0.4305	85015	3
A_5	0.5345	0.0289	0.5056	100	1
A_6	0.5267	0.0315	0.4952	97.93	2

This result indicates that A_5 is the best option. It is also consistent with the experimental results shown in [1]. But in [1], the authors ranked mainly based on the four original criteria which are only criteria of benefit, without considering the non-benefit criteria C_5 . In many cases, infection rates can affect the final profit of mushroom cultivation. Therefore, the use of the FMOORA decision-making model in assessing the selection of options on which there are conflicting attributes is meaningful.

- **Using the FMCDM method based on the distance of fuzzy sets**

Step 1. The normalization decision matrix

In this step, we implement as in the FMOORA method and the normalization decision matrix obtained as in Table 2.

Step 2. Chose the perfect option $P^* = (1,1,1,1,0)$

Step 3. Compute the distance of each alternative to the perfect option P^* . The results are shown in the Table 6.

Step 4. Ranking the alternatives $A_k \succ A_i$ if $d(A_k, A^*) \le d(A_i, A^*)$ for all $i,k = 1,2,...,m$, see Table 6.

In this method, we also see that that A_5 is the best option. It is also consistent with the experimental results shown in [1]. Figure 3 shows the ranking results using FMOORA, FMCDM and experimental methods.

Table 6. Ranking of alternatives in the example 1.

	A_1	A_2	A_3	A_4	A_5	A_6
$d(A_i, A^*)$	0.6892	0.5604	0.4439	0.3508	0.2722	0.2767
Ranking	6	5	4	3	1	2

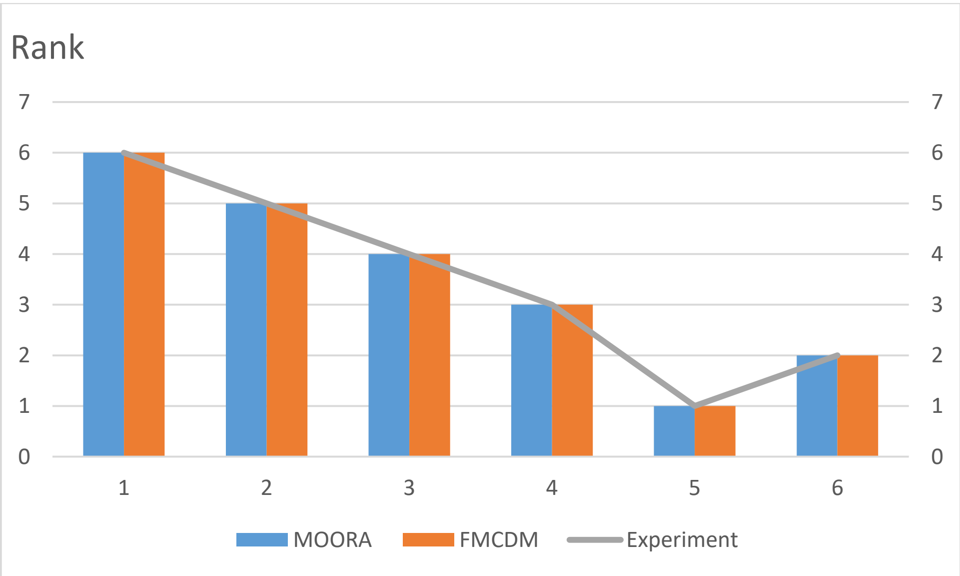

Fig.3. The ranking results using FMOORA, FMCDM and experimental methods in example 1

Example 2 [3]. Pleurotus sajor-caju is a popular and valuable mushroom in tropical countries. Le et al.[3] studied the effects of raw materials (alternatives) such as sawdust (A_1), bagasse (A_2), straw (A_3), rice husk (A_4) and coco-peat (A_5) on biological productivity and mushroom quality to replace used sawdust.

The tracking indicators (criteria) include:

- (C_1) Speed of developing the length of silk thread (cm/day).
- (C_2) Time of silage covered with silage of treatments (days): the number of days from the time of inoculation to the time when silk is fully covered with all the embryos of the experiment.
- (C_3) Starting time for harvesting: from the start of irrigation to pick up mushrooms until there is 50% of the bags in each repeat of the treatments for harvesting.
- (C_4) Biological efficiency (%): productivity of fresh mushrooms / kg of dry matter.
- (C_5) The rate of embryos infected with mold (%) in the substrate
- (C_6) The number of infected embryos on each treatment.
- (C_7) The length of time for harvest is long: since 50% of the bags of the treatments are harvested until 50% of the bags cannot be harvested anymore.
- (C_8) The amount of mushroom collected on each bag (g/bag)
- (C_9) Dry weight of fungi on treatments: mushrooms are dried to constant weight and calculated the dry weight of mushrooms on the treatments.

In which C_5 is the non-benefit and the other criteria are benefit.

The relation between of alternatives and criteria is shown in the Table 7.

Table 7. The relation between of alternatives and criteria in example 2

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.92	24.3	11.1	33.9	5.6	3.1	36.6	305.2	10.2
A_2	0.85	27.7	12.6	39.9	11.3	3.2	37.3	359.2	10
A_3	0.78	30.6	13	24.9	22.2	3	26.6	224.2	8.4
A_4	1.4	16.7	10.4	34	11.1	4.1	36.8	288.8	8.8
A_5	0.8	28	13	11	27.8	2.1	32.7	99.1	8.5

- **Using the FMOORA method**

Step 1. Because of the criteria C_1, C_2, C_3, C_6, C_7 and C_8 are not normalized. For the benefit criteria C_1, C_6 and C_8 having the better if their values are higher; for the non-benefit criteria C_2, C_3 C_7 having the better if their values are lower. So we need to bring it to the normalized fuzzy form by using the eq.(2). Specially, for criterion C_1 we using the eq.(2) with $c = 0.7, d = 1.5;$ for criterion C_2 we using the eq.(1) with $a = 15,\ b = 35;$ for criterion C_3 we using the eq.(1) with $a = 10, b = 55;$ for criterion C_6 we using the eq.(2) with $c = 2, d = 5;$ for criterion C_7 we using the eq.(1) with $a = 30,\ b = 40;$ for criterion C_6 we using the eq.(2) with $c = 80,\ d = 360;$ Then, we get the fuzzy decision matrix of effecting of mixing formula on fruit size, biological productivity and infection rate of king oyster mushroom as see in Table 8.

Step 2: Using the eq.(3) we get the entropy of each criteria (Table 9)

Step 3. Using the eq.(4) we get the weight of each criteria (Table 9)

Step 4. Calculate the weighed normalized decision matrix $W = \left[W_{ij} \right]_{m \times n}$ by using the eq.(5) as see in Table 10.

Step 5. Compute P_i and R_i for all $i = 1, 2, ..., 5,$ see in Table 11.

Step 6. Compute Q_i for all $i = 1, 2, ..., 5,$ see in Table 11

Step 7. Ranking alternatives, see in Table 11.

Table 8. The fuzzy decision matrix king oyster mushrooms

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.2750	0.535	0.78	0.339	0.056	0.3667	0.34	0.8043	0.102
A_2	0.1875	0.365	0.48	0.399	0.113	0.4	0.27	0.9971	0.1
A_3	0.1	0.22	0.4	0.249	0.222	0.3333	0.34	0.515	0.084
A_4	0.875	0.915	0.92	0.34	0.111	0.7	0.32	0.7457	0.088
A_5	0.125	0.35	0.4	0.11	0.278	0.0333	0.73	0.0682	0.085

Table 9. The weight of criteria in Example 1

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Entropies	0.4299	0.5624	0.5688	0.5724	0.4075	0.5447	0.6151	0.4045	0.3063
Weights	0.1242	0.0954	0.094	0.0932	0.1291	0.0992	0.0839	0.1298	0.1512

Table 10. The fuzzy weighed normalized decision matrix in example 2

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.0342	0.0510	0.0733	0.0316	0.0072	0.0364	0.0285	0.1044	0.0154
A_2	0.0233	0.0348	0.0451	0.0372	0.0146	0.0397	0.0227	0.1294	0.0151
A_3	0.0124	0.0210	0.0376	0.0232	0.0287	0.0331	0.0285	0.0668	0.0127
A_4	0.1088	0.0873	0.0865	0.0317	0.0143	0.0694	0.0269	0.0968	0.0133
A_5	0.0155	0.0334	0.0376	0.0103	0.0359	0.0033	0.0612	0.0089	0.0129

Table 11. The results of P_i, R_i and Q_i for ranking of alternatives

	P_i	R_i	Q_i	$100\times\frac{Q_i}{\max Q_i}$	Ranking
A_1	0.3748	0.0072	0.3676	72.61	2
A_2	0.3473	0.0146	0.3327	65.72	3
A_3	0.2354	0.0287	0.2067	40.83	4
A_4	0.5206	0.0144	0.5062	100	1
A_5	0.1830	0.0358	0.1472	29.06	5

In example 2, we see that the biological efficiency of using rice husk (A_4) material is not the highest (C_4), the rate of infection is not the lowest (C_5). However, when considering the overall evaluation criteria, it gives the highest ranking results. This is worthy of consideration for research to implement practical applications in Vietnam because rice husk materials are abundant.

- **Using the FMCDM method based on the distance of fuzzy sets**

Step 1. The normalization decision matrix

In this step, we implement as in the FMOORA method and the normalization decision matrix obtained as in Table 8.

Step 2. Chose the perfect option $P^* = (1,1,1,1,0,1,1,1,1)$

Step 3. Compute the distance of each alternative to the perfect option P^*. The results are shown in the Table 12.

Step 4. Ranking the alternatives $A_k \succ A_i$ if $d(A_k, A^*) \le d(A_i, A^*)$ for all $i,k = 1,2,...,5$.

In this method, we also see that that A_4 is the best option. It is also consistent with the experimental results shown in [3]. Figure 4 shows the ranking results using FMOORA, FMCDM and experimental methods.

Table 12. Ranking of alternatives in the example 1.

	A_1	A_2	A_3	A_4	A_5
$d(A_i, A^*)$	0.5688	0.6156	0.6949	0.4626	0.7550
Ranking	2	3	4	1	5

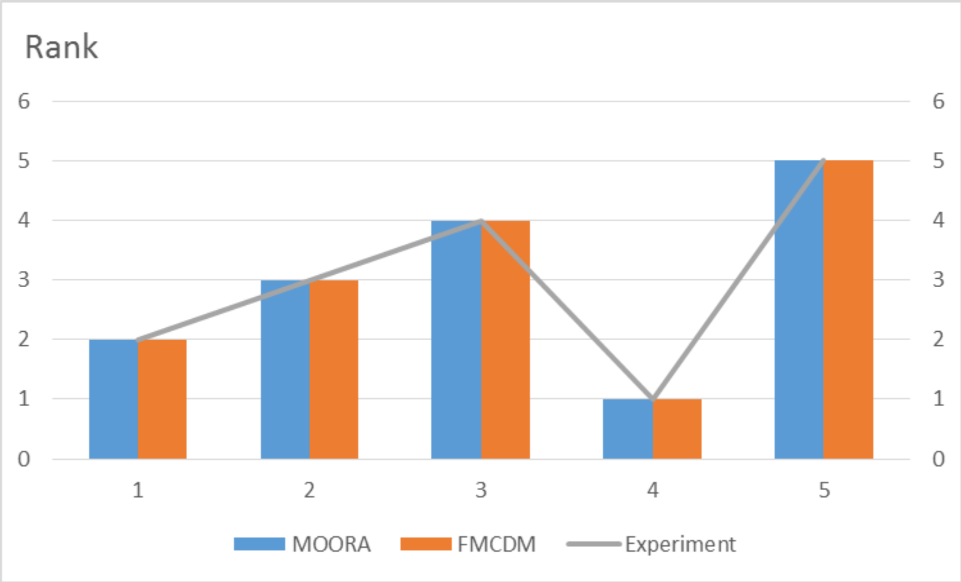

Fig.4. The ranking results using FMOORA, FMCDM and experimental methods in example 1

IV. Conclusion

In this paper, we apply fuzzy MOORA and fuzzy MCDM methods to evaluate the selection of mushroom growing materials or the best options for mushroom cultivation. These methods are suitable for multi-criteria decision-making problems, especially for problems with evaluation criteria sets that may conflict with each other. The results obtained in the methods used in this paper are also consistent with the previously published experimental methods. As we see in example 1, changing components in the right proportion can affect mushroom yield, but if too much change may not yield good results. In example 2, we also consider the incidence of infection along with other criteria to evaluate the best mushroom planting material in the Mekong Delta, Vietnam. In the future, we will apply these methods to the problem of selecting other materials to serve the production process. As well as understanding fuzzy MOORA and fuzzy MCDM models in intuitionistic fuzzy sets and other measures to apply to practical problems such as decision making in health, selecting suppliers and choosing choose investment policy etc. At the same time, we also studied other methods of multi-criteria decision making so that we can compare the evaluation to select the right optimal conclusion. In addition, we will consider studying these models in such directions as using the correlation of intuitionistic fuzzy set [25 -26], Support-intuitionistic fuzzy set [17], Support – neutrosophic set [18], the rough fuzzy set [16], and some other directions [27-29].

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