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Research Article

USING THE ROOT ASSESSMENT METHOD TO CHOOSE THE OPTIMAL SOLUTION FOR MUSHROOM CULTIVATION

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Abstract: In this study, an investigation was conducted into two essential aspects of mushroom cultivation. Firstly, the selection of the best type of fertilizer out of ten different options was examined to optimize mushroom growth. The *RAM* (Root Assessment Method) method was used in conjunction with five different weighting methods to evaluate the alternatives. The research results revealed the two most outstanding fertilizers for mushroom cultivation. Next, the selection of the best cultivation mixture out of six proposed options was investigated. Using the same *RAM* method and various weighting methods, a unique and efficient mixture for mushroom cultivation was identified. This study provides valuable information for farmers and those interested in mushroom

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cultivation with specific and effective solutions to improve the mushroom growing and care process.

Keywords: Fungus plant care, fertilizer, mixed planting, MCDM, RAM method, weight method.

MSC: 90B50.

1. INTRODUCTION

The development and growth of crops have always been the top concern of farmers and agricultural researchers. Crops are a fundamental food source for humans, and the efficient growth of crops plays a vital role in ensuring social well-being. Fertilizers and crop mixtures also play a significant role in enhancing agricultural production, providing food to the global population, and maintaining the prosperity of the food system. This was not only an important topic in agricultural discourse but was also closely related to plant resilience, their development, and the nutritional value of the food consumed daily [1, 2]. Additionally, crop mixtures, which involve using various types of fertilizers and nutrients in a crop growing system, also play a crucial role in ensuring that crops receive all the necessary elements for robust growth. The plant cultivation mixture can be adjusted based on the specific crop and local conditions, creating a customized system to provide sufficient nutrients for the plants [3-6]. The growth of crops is the process of development from the seedling stage to the mature, reproductive stage. The type of fertilizer and the plant cultivation mixture play a decisive role in this process. Providing an adequate amount of nutrients at each stage of plant growth is essential to ensure healthy growth and optimal performance [7, 8].

Mushrooms, also known as fungi, are a highly important food source and are actively cultivated to provide food for humans. The significance of mushrooms lies not only in the nutritional value they offer but also in their culinary diversity and their vital role in the environment [9]. The first advantage of mushrooms is their high nutritional value. They contain various essential nutrients such as vitamins, minerals, proteins, and especially vitamin D, making them an important part of a balanced diet. Moreover, actively cultivating mushrooms helps control product quality. It ensures that mushrooms are grown in a clean environment, free from parasitic worms or harmful mushroom spores, enhancing food safety. Mushrooms also contribute to environmental protection by reducing the need to harvest wild mushrooms, thereby preserving biological diversity and natural resources. Furthermore, recycling organic waste by using it as fertilizer for mushroom cultivation helps minimize organic waste [10]. In summary, mushrooms not only provide high-nutrient food but also offer various other important advantages, including product quality control and environmental protection. This is an excellent example of how humans can intelligently utilize and protect natural resources.

To ensure the robust growth and high nutritional value of mushrooms, careful selection of crop mixtures and cultivation processes is of utmost importance. However, the diversity of fertilizers and methods for creating crop mixtures can pose a challenge for farmers in finding the optimal solutions. Therefore, this research was conducted to address this challenge specifically for mushroom farmers. Two primary tasks were performed in this study: firstly, selecting the best fertilizer for mushroom cultivation, and secondly, choosing the best mixture for mushroom cultivation.

There are various types of fertilizers that can be used to care for mushroom crops, such as fresh cow manure, dried cow manure, fresh chicken manure, etc. However, the content of important elements like nitrogen, phosphate, and potash in these fertilizers varies significantly. To choose the best fertilizer, all three criteria need to be considered. This means that a multi-criteria decision-making process needs to be undertaken [11, 12]. Similarly, there are several ways to mix different combinations for mushroom cultivation. Parameters of mushroom crops, such as mushroom size, biological productivity, disease infection rate, etc., will also differ when grown with different mixtures. This implies that selecting the best mixture for planting mushrooms is also a multi-criteria decision-making (*MCDM*) process to ensure optimal mushroom characteristics. With over 200 existing *MCDM* methods, choosing one for use becomes a complex decision [13]. In this study, the RAM method was employed. The reasons for choosing the *RAM* method and a summary of its application steps are presented in Chapter 2. When making multi-criteria decisions, determining the weights for each criterion is necessary [14, 15]. This is because the best alternative may change if the weights of the criteria change [16, 17]. Five weight determination methods, including the Equal method, Entropy method, *MEREC* (Method Based on the Removal Effects of Criteria) method, *LOPCOW* (LOgarithmic Percentage Change-driven Objective Weighting) method, and *SPC* (Symmetry Point of Criterion) method, will be used in this research. The reasons for selecting these five methods and a summary of each method will be discussed in in Chapter 2 of this article. Two exemplary cases, including the selection of the best fertilizer and the choice of crop mixtures, are discussed in Chapter 3. Conclusions and directions for future research are presented in the final section of this article.

2. MATERIALS AND METHODS

2.1. The RAM Method

RAM is known as the newest method among those used to support decision-makers in selecting the best option from the available alternatives [18]. The advantage of *RAM* is its ability to balance beneficial and non-beneficial criteria. Overcoming the issue of rank reversal is another advantage of *RAM* [18]. However, it is new, introduced in September 2023, and no references are available for this method. This is the reason for its application in this research.

The steps to use the *RAM* method to rank alternatives are as follows [18]:

Step 1: Construct a decision matrix with *m* rows and *n* columns. Here, *m* and *n* correspond to the number of alternatives that need to be ranked and the number of criteria for each alternative. Let x_{ij} represent the value of criterion *j* for alternative *i*, with $j = 1$ to *n*, $i = 1$ to *m*. The letters *B* and *C* are used to signify the respective criteria of benefit and cost.

Step 2: Normalize the data using Equation (1).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{1}$$

Step 3: Calculate the normalized values taking into account the weights of the criteria using Equations (2).

$$y_{ij} = w_j \cdot r_{ij} \tag{2}$$

Where w_j represents the weight of criterion *j*.

Step 4: Compute the normalized score, taking into account the weights of the criteria using Equations (3) and (4).

$$S_{+i} = \sum_{j=1}^{n} y_{+ij} \quad if \quad j \in B \tag{3}$$

$$S_{-i} = \sum_{j=1}^{n} y_{-ij} \quad if \quad j \in C \tag{4}$$

Step 5: Calculate the score for each alternative according to Equation (5).

$$RI_i = \sqrt[2+S_{-i}]{2 + S_{+i}} \tag{5}$$

Step 6: Rank the alternatives in descending order of their scores.

2.2. Methods for Determining Weights

Five methods for determining the weights of the criteria were used: the Equal method, the Entropy method, the *MEREC* method, the *LOPCOW* method, and the *SPC* method. Equal is the simplest method [19], while Entropy and *MEREC* are two methods recommended for use [20]. *LOPCOW* and *SPC* are two recently found methods [21, 22].

When using the Equal weight method, each criterion has an equal weight [19].

To calculate the weights for criteria using the Entropy method, it is necessary to apply the formulas from (6) to (8) [20].

$$r_{ij} = \frac{y_{ij}}{m + \sum_{i=1}^{m} y_{ij}^2} \tag{6}$$

$$e_j = \sum_{i=1}^{m} [r_{ij} \times \ln(r_{ij})] - \left(1 - \sum_{i=1}^{m} r_{ij}\right) \times ln\left(1 - \sum_{i=1}^{m} r_{ij}\right) \tag{7}$$

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m}(1 - e_j)} \tag{8}$$

Apply the formulas from (9) to (14) sequentially to calculate the weights for criteria using the *MEREC* method [20].

$$r_{ij} = \frac{min y_{ij}}{y_{ij}} \quad if \quad j \in B \tag{9}$$

$$r_{ij} = \frac{y_{ij}}{max\, y_{ij}} \quad if \quad j \in C \tag{10}$$

$$S_i = Ln\left[1 + \left(\frac{1}{n}\sum_{j}^{n}\left|ln(r_{ij})\right|\right)\right] \tag{11}$$

$$S'_{ij} = Ln\left[1 + \left(\frac{1}{n}\sum_{k,k\neq j}^{n}\left|ln(r_{ij})\right|\right)\right] \tag{12}$$

$$E_j = \sum_{i}^{m}\left|S'_{ij} - S_i\right| \tag{13}$$

$$w_j = \frac{E_j}{\sum_{k}^{m} E_k} \tag{14}$$

To calculate the weights of criteria using the *LOPCOW* method, it is necessary to apply the formulas from (15) to (17) sequentially [21]. In (16), σ represents the standard deviation.

$$r_{ij} = \frac{y_{ij} - miny_{ij}}{maxy_{ij} - miny_{ij}} \quad if \quad j \in B \tag{15}$$

$$r_{ij} = \frac{maxy_{ij} - y_{ij}}{maxy_{ij} - miny_{ij}} \quad if \quad j \in C \tag{16}$$

$$PV_{ij} = \left| ln \frac{\sqrt{\sum_{i=1}^{m} r_{ij}^2}}{\sigma} \right| \cdot 100 \tag{16}$$

$$w_j = \frac{PV_{ij}}{\sum_{j=1}^{n} PV_{ij}} \tag{17}$$

To calculate the weights of criteria using the *SPC* method, it is necessary to apply the formulas from (18) to (22) sequentially [22].

$$SPC_j = \frac{\max(y_{ij}) + \min(y_{ij})}{2}; \text{ i = 1, 2, …, m; } \forall \text{ j} \in [1 \div \text{n}] \tag{18}$$

$$D = \left| d_{ij} \right|_{mxn} = \begin{bmatrix} |y_{11} - SPC_1| & |y_{12} - SPC_2| & \cdots & |y_{1n} - SPC_n| \\ |y_{21} - SPC_1| & |y_{22} - SPC_2| & \cdots & |y_{2n} - SPC_n| \\ \cdots & \cdots & \cdots & \cdots \\ |y - SPC_1| & |y - SPC_2| & \cdots & |y_{mn} - SPC_2| \end{bmatrix} \tag{19}$$

$$R = \left[r_{ij} \right]_{m \times n} = \begin{bmatrix} \left| \frac{\sum_{i=1}^{m} d_{i1}}{m \times y_{11}} \right| & \left| \frac{\sum_{i=1}^{m} d_{i2}}{m \times y_{12}} \right| & \cdots & \left| \frac{\sum_{i=1}^{m} d_{in}}{m \times y_{1n}} \right| \\ \left| \frac{\sum_{i=1}^{m} d_{i1}}{m \times y_{21}} \right| & \left| \frac{\sum_{i=1}^{m} d_{i2}}{m \times y_{22}} \right| & \cdots & \left| \frac{\sum_{i=1}^{m} d_{in}}{m \times y_{2n}} \right| \\ \cdots & \cdots & \cdots & \cdots \\ \left| \frac{\sum_{i=1}^{m} d_{i1}}{m \times y_{m1}} \right| & \left| \frac{\sum_{i=1}^{m} d_{i2}}{m \times y_{m2}} \right| & \cdots & \left| \frac{\sum_{i=1}^{m} d_{in}}{m \times y_{mn}} \right| \end{bmatrix} \tag{20}$$

$$Q = \left[q_{1j} \right]_{1 \times n} = \left[\frac{\sum_{i=1}^{m} r_{i1}}{m} \quad \frac{\sum_{i=1}^{m} r_{i2}}{m} \quad \cdots \quad \frac{\sum_{i=1}^{m} r_{in}}{m} \right] \tag{21}$$

$$W = \left[w_{1j} \right]_{1 \times n} = \left[\frac{q_1}{\sum_{j=1}^{n} q_j} \quad \frac{q_2}{\sum_{j=1}^{n} q_j} \quad \cdots \quad \frac{q_j}{\sum_{j=1}^{n} q_j} \right] \tag{22}$$

3. CHOOSING THE OPTIMAL SOLUTION FOR MUSHROOM PLANT CARE

3.1. Selection of fertilizer type

Ten types of organic fertilizers, derived from livestock sources, are commonly used for mushroom plant fertilization, as summarized in Table 1 [23]. Each type's main components, including nitrogen, phosphate, and potash, are also mentioned in this table. All three of these parameters are crucial for mushroom growth, and higher values are preferred. The unit for each component is calculated as a percentage of its presence in each option.

The data in Table 1 reveals that rabbit manure has the highest nitrogen content, dried pig manure has the highest phosphate content, and dried cow manure has the highest potash content compared to other fertilizer types. Thus, no single option maximizes all three parameters (nitrogen, phosphate, and potash). An optimal solution is one where all three parameters are considered "maximized." This means that the choice of organic fertilizer must consider all three of these parameters. In other words, multi-criteria decision-making is necessary to achieve this goal. In this study, the *RAM* method was used to perform this task.

Table 1: Types of organic fertilizers [23]

Type	% Nitrogen (N)	% Phosphate (P)	% Potash (K)
Fresh cow manure	0.6	0.4	0.5
Dried cow manure	1.2	2	2.1
Fresh chicken manure	0.9	0.5	0.5
Dried chicken manure	1.6	1.8	2
Fresh pig manure	0.6	0.3	0.4
Dried pig manure	2.2	2.1	1
Fresh horse manure	0.6	0.3	0.5
Fresh rabbit manure	2.4	1.4	0.6
Fresh turkey manure	1.3	0.7	0.5
Fresh earthworm castings	0.91	1.14	0.21

The formulas for calculating the criteria weights in section 2.2 were applied to determine the criteria weights, as shown in Table 2. The criteria weights changed by 1.72 times for nitrogen, 1.43 times for phosphate, and 1.36 times for potash when calculated using different methods.

Table 2: Criteria weights

Weight method	% Nitrogen (N)	% Phosphate	% Potash (K)
Equal	0.3333	0.3333	0.3333
Entropy	0.3425	0.3318	0.3257
MEREC	0.1988	0.3623	0.4390
LOPCOW	0.3243	0.2537	0.4220
SPC	0.2152	0.3427	0.4420
Max/min	1.72	1.43	1.36

The *RAM* method was used to rank the types of organic fertilizers in the following sequence: Normalized values were calculated using (1) and synthesized in Table 3.

Table 3: Normalized values

Type	Nitrogen	Phosphate	Potash
Fresh cow manure	0.0487	0.0376	0.0602
Dried cow manure	0.0975	0.1880	0.2527
Fresh chicken manure	0.0731	0.0470	0.0602
Dried chicken manure	0.1300	0.1692	0.2407
Fresh pig manure	0.0487	0.0282	0.0481
Dried pig manure	0.1787	0.1974	0.1203
Fresh horse manure	0.0487	0.0282	0.0602
Fresh rabbit manure	0.1950	0.1316	0.0722
Fresh turkey manure	0.1056	0.0658	0.0602
Fresh earthworm castings	0.0739	0.1071	0.0253

The normalized values, considering the criteria weights, were calculated using (2). First, the criteria weights were calculated using the Equal method and the results are summarized in Table 4.

The S_{+i}, S_{-i}, and RI_i values were calculated using the corresponding formulas (3), (4), and (5), as shown in Table 5. The ranking of options was determined by the value of their RI_i score, and the results are also summarized in this table.

Table 4: Normalized values considering criteria weights

Type	Nitrogen	Phosphate	Potash
Fresh cow manure	0.0162	0.0125	0.0201
Dried cow manure	0.0325	0.0627	0.0842
Fresh chicken manure	0.0244	0.0157	0.0201
Dried chicken manure	0.0433	0.0564	0.0802
Fresh pig manure	0.0162	0.0094	0.0160
Dried pig manure	0.0596	0.0658	0.0401
Fresh horse manure	0.0162	0.0094	0.0201
Fresh rabbit manure	0.0650	0.0439	0.0241
Fresh turkey manure	0.0352	0.0219	0.0201
Fresh earthworm castings	0.0246	0.0357	0.0084

Table 5: Some parameters in the RAM method and the ranking of options

Type	S_{+i}	S_{-i}	RI_i	Rank
Fresh cow manure	0.0488	0	1.4314	8
Dried cow manure	0.1794	0	1.4763	2
Fresh chicken manure	0.0601	0	1.4353	7
Dried chicken manure	0.1799	0	1.4765	1
Fresh pig manure	0.0417	0	1.4289	10
Dried pig manure	0.1655	0	1.4716	3
Fresh horse manure	0.0457	0	1.4303	9
Fresh rabbit manure	0.1329	0	1.4605	4
Fresh turkey manure	0.0772	0	1.4412	5
Fresh earthworm castings	0.0688	0	1.4383	6

The ranking of organic fertilizer types, when criteria weights were calculated using the Equal method, has been completed. When criteria weights were calculated using the four other methods, the ranking of organic fertilizer types was also conducted in a similar manner. Table 6 summarizes the ranking results in all cases.

According to the data in Table 6, options ranked from 3rd to 10th place are identical when criteria weights were calculated using five different methods. All ten options have the same ranking when using the Equal, Entropy, and *LOPCOW* weighting methods. When using the *MEREC* and *SPC* weighting methods, all ten options also have the same ranking. These results partially reflect the advantages of the RAM method as mentioned earlier [18]. These advantages are further emphasized when the weight of the Nitrogen criterion changes by up to 1.72 times when calculated using different methods. The two best organic fertilizers for mushroom plant fertilization were found to be dried cow manure and fresh chicken manure.

Table 6: Ranking of organic fertilizer types

Type	Weight method				
	Equal	**Entropy**	**MEREC**	**LOPCOW**	**SPC**
Fresh cow manure	8	8	8	8	8
Dried cow manure	2	2	1	2	1
Fresh chicken manure	7	7	7	7	7
Dried chicken manure	1	1	2	1	2
Fresh pig manure	10	10	10	10	10
Dried pig manure	3	3	3	3	3
Fresh horse manure	9	9	9	9	9
Fresh rabbit manure	4	4	4	4	4
Fresh turkey manure	5	5	5	5	5
Fresh earthworm castings	6	6	6	6	6

3.2. Choosing a mixture for mushroom cultivation

To create a mushroom cultivation mixture, various proportions of five components, namely straw, corn core, peat moss, rice bran, and $CaCO_3$, are commonly used. Table 7 summarizes six different mixtures typically used. This table also provides data on mushroom characteristics corresponding to each mixture. The measured mushroom parameters include cap diameter (mm), stalk diameter (mm), stalk length (mm), biological yield (%), and disease infection rate (%). Among these parameters, only the last one is better when smaller, while the other four parameters are preferable when larger [24].

It can be observed that mixture 5 scores the highest in all four criteria, including cap diameter, stalk diameter, stalk length, and biological yield, when compared to the other five options.

Table 7: Mixtures for mushroom cultivation [24]

No.	Straw (%)	Corn kernel (%)	Sawdust (%)	Rice bran (%)	$CaCO_3$ (%)	C1 (mm)	C2 (mm)	C3 (mm)	C4 (%)	C5 (%)
1	40	30	29	0	1	27.7	20.1	96.5	33.5	6.6
2	40	27	27	5	1	35.2	24.3	102.6	41.7	7.1
3	40	25	24	10	1	40.4	27.9	120.1	46.8	8.3
4	40	22	22	15	1	46.8	30.4	132.4	51.4	9.4
5	40	20	19	20	1	50.4	32.6	146.2	59.4	9.9
6	40	17	17	25	1	50.3	32.5	143.4	59.1	10.8

However, mixture 1 has the lowest disease infection rate. This implies that there is no single mixed mixture where all five parameters are the best. Therefore, determining the best mixture requires the use of the *RAM* method. Similar to what was done in Section 3.1, weights for each criterion were computed and presented in Table 8. Notably, the weights of criteria vary significantly when calculated using different methods. In this case, the most significant change is observed in the disease infection rate with a factor of 2.71. The rankings of the mixtures have been compiled in Table 9.

Table 8: Weights of criteria

Weight method	C1 (mm)	C2 (mm)	C3 (mm)	C4 (%)	C5 (%)
Equal	0.2	0.2	0.2	0.2	0.2
Entropy	0.1931	0.2000	0.1825	0.1911	0.2334
MEREC	0.2518	0.2029	0.1484	0.2277	0.1693
LOPCOW	0.1993	0.0730	0.4002	0.2416	0.0860
SPC	0.2350	0.1938	0.1707	0.2080	0.1925
Max/min	1.30	2.78	2.70	1.26	2.71

Table 9: Rankings of mixtures

Options	Weight method				
	Equal	**Entropy**	**MEREC**	**LOPCOW**	**SPC**
1	6	6	6	6	6
2	5	5	5	5	5
3	4	4	4	4	4
4	3	3	3	3	3
5	1	1	1	1	1
6	2	2	2	2	2

The data in Table 9 show that the rankings of all mixtures are entirely identical when different methods are used to compute the criteria weights. Once again, the outstanding advantage of the *RAM* method is confirmed, especially when the weight of the disease infection rate changes by a factor of 2.71. Accordingly, mixture 5 is determined to be the best choice for mushroom cultivation. In other words, to achieve the highest quality mushroom harvest, the optimal mixture for cultivation comprises 40% straw, 20% corn core, 19% peat moss, 20% rice bran, and 1% $CaCO_3$.

4. CONCLUSION

Applied for the first time in this study, the *RAM* method optimized the selection of fertilizer types and mushroom plant care mixtures. The study tackled two specific issues: identifying the optimal type of fertilizer for mushroom plant growth and determining the best mushroom cultivation mixture. The results not only demonstrated the effectiveness and feasibility of the *RAM* method in selecting optimal solutions but also highlighted the scientific rationale of the study, enhancing the reliability and value of the achieved results.

To produce nutritionally and economically valuable mushrooms, cultivating mushroom plants is encouraged to use dry cow manure or fresh chicken manure. Additionally, mixing the cultivation substrate in specific proportions, comprising 40% straw, 20% corn core, 19% sheep dung, 20% rice bran, and 1% $CaCO_3$, provides a specific and detailed guide for researchers and farmers.

However, to ensure a more comprehensive selection of fertilizer and care mixtures for mushroom plants, the study also needs to consider criteria such as the nutritional needs of mushrooms, environmental factors, seasonal influences, and associated costs. This will be a crucial development direction for the future of the research, offering a more comprehensive and detailed understanding of mushroom plant care in various conditions and contexts. The application of the *RAM* method in this study has opened new doors and contributed to a deeper understanding of how to optimize the mushroom plant care process.

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