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MULTI-CRITERIA DECISION ANALYSIS FOR DETERMINING POTENTIAL AGRICULTURE COMMODITIES IN INDONESIA

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Abstract

The purpose of this study is to determine the potential agricultural commodities in Indonesia. The determination of potential commodities was carried out using Multi-Criteria Decision Analysis (MCDA) by considering criteria related to the economic factors, plant characteristics, and the environment factor. As an alternative, some plants with certain classifications were selected. The method used was the Analytic Hierarchy Process (AHP) method. The use of the AHP method began by forming a hierarchical structure. Then pairwise comparison matrices were used to form relationships within the hierarchical structure. The next step was the matrix normalization process so that the weights of each criterion were obtained. By using Multi-Criteria Decision Making (MCDM), it was found that the economic characteristics have a significant effect on the selection of commodities. Based on the calculations, the results show that cassava, sweet potato, onion, rice, and potatoes are the five plants that have the most potential to be cultivated in Indonesia. By knowing the potential of the commodity, farmers are expected to get a reference when selecting commodities so it can reduce the risk of crop failure.

Keywords: Analytic hierarchy process (AHP), Commodity selection, Decision making, Indonesia agriculture, Multi-criteria decision analysis (MCDA).

1. Introduction

One of the crucial problems in Indonesia is crop failure [1, 2] Every year, crop failures in Indonesia continue to increase [3, 4]. This problem is caused by climate change, floods, and pests. Other problems faced by agribusiness in Indonesia are low product quality, high production costs, and the use of poor-quality seeds [5]. The risk of crop failure is also caused by improper crop patterns and farmers' mistakes in determining commodities [6]. To overcome the problem in the selection of agricultural commodities, one solution that can be used is to create a system to assist farmers in selecting potential commodities.

In this study, a decision-making system was developed using Multi-Criteria Decision Analysis (MCDA). The method used in this decision making was the Analytic Hierarchy Process (AHP) method. This method was developed in the 1970s by Saaty [7]. The core of the AHP method is the process of forming numerical scores to rank each alternative. Research on the use of Multi-Criteria Decision Making (MCDM) in commodity determination has often been carried out, such as the research conducted by Herzberg et al. [8] who used the AHP method to evaluate suitable plants to be developed according to the characteristics of the land in Vietnam. A similar study in India was carried out by Kaur and Anjum [9]. Another study was carried out by Javad on land suitability values in Ardabil province using the AHP method [10]. In Indonesia, there were also several studies on commodity selection using MCDA [3, 5] Different from previous studies, these studies used more alternative criteria that were set according to the actual conditions of agriculture in Indonesia. To determine the criteria used in this research, a literature review was carried out and an online questionnaire was distributed to farmers in Indonesia through the Indonesian Agriculture Forum. The criteria used were economic criteria, plant characteristics, and environmental factors [11-14]. By using criteria that were suitable for the conditions of agriculture in Indonesia more relevant and accurate calculation results is achieved. Commodity assessment results can also be used at a national level not specific to a particular region/province. With the right decision-making system, it is expected that commodities with the most potential and suitable for agricultural conditions in Indonesia can be selected. This system is also expected to help farmers by providing commodity ranking for consideration in selecting commodities.

2. Research Method

2.1. Criteria selection and construction a hierarchy structure

Figure 1 illustrates the shape of the AHP Model hierarchical structure. The first level in the structure was the Decision Goal, the second level was the criteria, and the third level was the alternative.

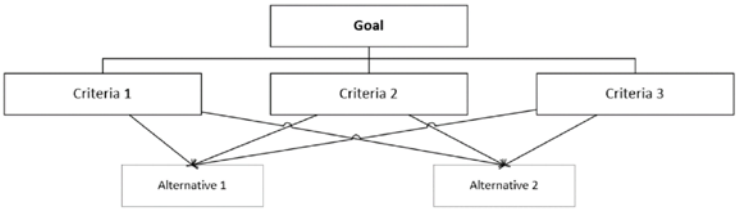

Fig. 1. AHP model hierarchy.

2.2. Pairwise comparison

This step aims to determine the priority order of the criteria. The first stage was to compare each criterion and gave a decimal value based on a predetermined value as described in Table 1 [7, 8]. The second stage was the normalization of the matrix. To synthesize the results of the questionnaire, geometric averages were used.

Table 1. Numerical scale for pairwise comparison [8].

Numeric scale	Definition
9	Criterion x is Absolutely more important than Criterion y
7	Criterion x is strongly more important than criterion y
5	Criterion x is more important than criterion y
3	Criterion x is slightly more important than criterion y
1	Criteria x is equally important as criterion y
2, 4, 6, 8	Intermediate value, when compromise is needed

The first step was to create an original matrix (A). This matrix compared the priority of each element in the hierarchy [7, 8, 15, 16].

$$A = \begin{pmatrix} 1 & C_{12} & C_{1x} & C_{1y} & C_{1n} \\ C_{21} & 1 & C_{2x} & C_{2y} & C_{2n} \\ C_{x1} & C_{x2} & 1 & C_{xy} & C_{in} \\ C_{y1} & C_{y2} & C_{yx} & 1 & C_{jn} \\ C_{n1} & C_{n2} & C_{nx} & C_{ny} & 1 \end{pmatrix} \quad (1)$$

$$C_{xy} = \left(\prod_{k=1}^{m} a_{xyk}\right)^{\frac{1}{m}} \quad (2)$$

where: C_{xy} is the level of importance criterion x compared to criterion y., A_{xyk} is the level of importance criterion x compared to criterion y according to the results of the questionnaire k^{th}., and m is the number of experts who filled out the questionnaire. After the original matrix A was made, the next step was to normalize matrix A to matrix B

$$B = \begin{pmatrix} \bar{C}_{11} & \bar{C}_{12} & \bar{C}_{1x} & \bar{C}_{1y} & \bar{C}_{1n} \\ \bar{C}_{21} & \bar{C}_{22} & \bar{C}_{2x} & \bar{C}_{2y} & \bar{C}_{2n} \\ \bar{C}_{x1} & \bar{C}_{x2} & \bar{C}_{xx} & \bar{C}_{xy} & \bar{C}_{in} \\ \bar{C}_{y1} & \bar{C}_{y2} & \bar{C}_{yx} & \bar{C}_{yy} & \bar{C}_{jn} \\ \bar{C}_{n1} & \bar{C}_{n2} & \bar{C}_{nx} & \bar{C}_{ny} & \bar{C}_{nn} \end{pmatrix} \quad (3)$$

$$\bar{C}_{xy} = \frac{C_{xy}}{\sum_{x=1}^{n} C_{xy}} \quad (4)$$

where: $\bar{C}_{xy}$ is normalized value of C_{xy}., $\sum_{x=1}^{n} C_{xy}$ is sum of C_{xy} by Column y from Matrix A., and n is number of criteria. To get the weight of each criterion, it can be derived from matrix B, as follows:

$$W_i = \frac{\sum_{x=1}^{n} \bar{C}_{xy}}{n} \quad (5)$$

$$W = \begin{pmatrix} w_1 \\ w_2 \\ w_x \\ w_y \\ w_n \end{pmatrix} \quad (6)$$

where: W is weight., w_x is weight of criterion x., and $\sum_{x=1}^{n} \bar{C}_{xy}$ is sum of C_{xy} by Column y from Matrix A.

2.3. Consistency check

To calculate the value of consistency, it is calculated using the following equation:

$$CR = \frac{CI}{RI} \tag{7}$$

where: CI is Consistency Index., CR is Consistency Ratio., and RI is Random index has been defined by Saaty [7]. Meanwhile, Eq. (7) is used to calculate the consistency index

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

$$\lambda_{max} = \frac{\sum \frac{\sum_{y=1}^{n} w_x * C_{xy}}{w_x}}{n} \tag{9}$$

if CR ≤ 0.1 then inconsistency value is acceptable.

3. Results and Discussion

The hierarchical structure was arranged into three levels in order to obtain good criteria (see Fig. 2). The first level was the goal to be achieved in decision making. The criteria and sub-criteria were at the second and third level of the hierarchy. The algorithm for determining the potential value of each commodity was influenced by the characteristics described by each criterion. The criteria chosen must have a major influence on productivity, cultivation opportunities, and the development of the selected agricultural commodities. The sub-criteria were selected and categorized according to data from the Indonesian Ministry of Agriculture, agricultural experts, and relevant literature [3, 8, 17, 18].

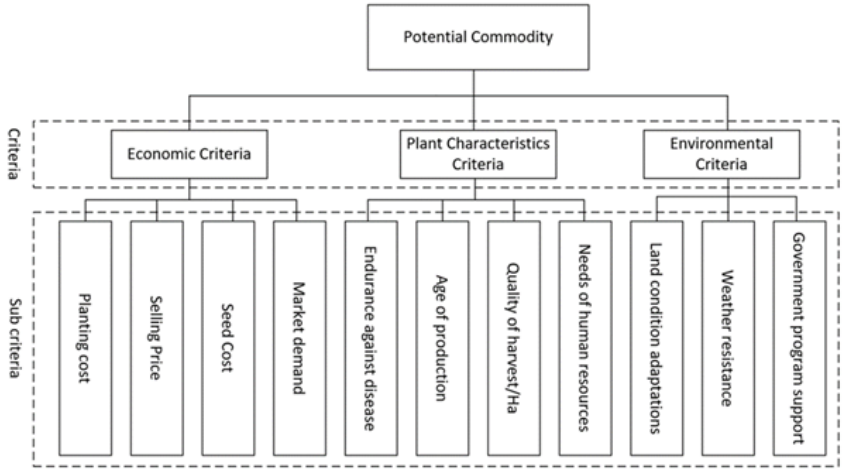

Fig. 2. Hierarchy structure for selecting potential commodity.

To make the decision making more accurate and have a high validity value, plants that are most suitable for Indonesian topography were selected. The criteria for selecting these plants were plants that have a 3 until 6-month harvest period, plants that can be planted at an altitude of 500-2,500 m, and plants that can live at temperatures between

15-30^{o} Celsius. Plants that meet these criteria were rice, soybeans, corn, peanuts, cassava, sweet potatoes, potatoes, onions, cabbage, chili, and tomatoes.

Pairwise comparison matrix calculations are described in Table 2. This calculation was the first step in calculating the weight of each criterion. The first row and column in the table were filled with the criteria that have been selected at the hierarchy determination stage. Each alphabet in the first row and column in the table represented one criterion. The criteria were sorted from right to left based on the hierarchy in Fig. 2. Each criterion was given a value using a numeric scale for pairwise comparison as described in Table 1, then the value was converted into decimal form.

Table 2. Numeric value of pairwise matrix between criterion.

	A	B	C	D	E	F	G	H	I	J	K
A	1.00	0.33	0.33	0.33	0.20	0.33	0.33	0.20	0.33	0.20	0.33
B	3.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	0.33	1.00	1.00
C	3.00	1.00	1.00	1.00	1.00	1.00	1.00	0.33	0.33	0.33	1.00
D	3.00	1.00	1.00	1.00	0.33	1.00	0.33	0.33	1.00	0.20	1.00
E	5.00	1.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	3.00
F	3.00	1.00	1.00	1.00	1.00	1.00	0.33	1.00	0.33	1.00	0.33
G	3.00	1.00	1.00	3.00	1.00	3.00	1.00	0.33	1.00	0.33	1.00
H	5.00	3.00	3.00	3.00	1.00	1.00	3.00	1.00	3.00	1.00	1.00
I	3.00	3.00	3.00	1.00	1.00	3.00	1.00	0.33	1.00	0.20	1.00
J	5.00	3.00	3.00	5.00	1.00	1.00	3.00	1.00	5.00	1.00	3.00
K	3.00	1.00	1.00	1.00	0.33	3.00	1.00	1.00	1.00	0.33	1.00
∑	37.00	16.33	16.33	20.33	8.87	16.33	13.00	6.87	14.33	6.60	13.67

After summarizing each column value, the normalization process was carried out by dividing the sum of each column by the elements in each cell using Eq. (4). Table 3 describes the normalization process that has been carried out. Based on Table 3, the results show that the selling price (J) had the highest priority weight with a value of 0.184 or 18.4%, followed by market demand (H) of 0.149 or 14.9% and quality of harvest (E) of 0.113 or 11.3%. Based on these results, the economy criteria had a more dominant role compared to other criteria. This result is in accordance with the results obtained in previous studies [3].

Table 3. Normalization weight values for each criterion.

	A	B	C	D	E	F	G	H	I	J	K	Weight
A	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.02	0.024
B	0.08	0.06	0.06	0.05	0.11	0.06	0.08	0.05	0.02	0.15	0.07	0.073
C	0.08	0.06	0.06	0.05	0.11	0.06	0.08	0.05	0.02	0.05	0.07	0.064
D	0.08	0.06	0.06	0.05	0.04	0.06	0.03	0.05	0.07	0.03	0.07	0.054
E	0.14	0.06	0.06	0.15	0.11	0.06	0.08	0.15	0.07	0.15	0.22	0.113
F	0.08	0.06	0.06	0.05	0.11	0.06	0.03	0.15	0.02	0.15	0.02	0.072
G	0.08	0.06	0.06	0.15	0.11	0.18	0.08	0.05	0.07	0.05	0.07	0.088
H	0.14	0.18	0.18	0.15	0.11	0.06	0.23	0.15	0.21	0.15	0.07	0.149
I	0.08	0.18	0.18	0.05	0.11	0.18	0.08	0.05	0.07	0.03	0.07	0.099
J	0.14	0.18	0.18	0.25	0.11	0.06	0.23	0.15	0.35	0.15	0.22	0.184
K	0.08	0.06	0.06	0.05	0.04	0.18	0.08	0.15	0.07	0.05	0.07	0.081

The next step was to calculate the maximum eigenvalue (λ_{max}) using Eq. (8). Because there were 11 criteria, the matrix order used was 11. Based on the calculation, the maximum eigenvalue obtained was 12,158. After knowing the maximum eigenvalue, the Consistency Index (CI) value could be calculated using Eq. (9). Based on the calculation results, CI value was 0.1236. For n = 11 then the RI value was 1.51 [7]. Based on calculation using Eq. (7), consistency ratio (CR)

value was 0.0819. Because of CR ≤ 0.100, the pairwise comparison weighting values in Table 3 are consistent [7].

The relationships between criteria and alternatives are explained in Table 4. The first row in the table contained criteria and the first column contained alternatives. The value contained in each cell was the result of the normalization of the paired matrix for each alternative against each criterion. For example, the second column in the table was the result of the normalization of each alternative commodity for the criteria for government program Support (A).

Table 4. the relationship between criteria and alternatives.

	A	B	C	D	E	F	G	H	I	J	K
Rice	0.247	0.065	0.065	0.164	0.044	0.052	0.088	0.164	0.108	0.031	0.103
Soybeans	0.198	0.087	0.087	0.065	0.016	0.055	0.095	0.126	0.071	0.075	0.088
Corn	0.063	0.138	0.138	0.036	0.025	0.195	0.106	0.109	0.057	0.053	0.092
Peanuts	0.060	0.087	0.087	0.046	0.016	0.072	0.095	0.077	0.087	0.165	0.079
Cassava	0.058	0.170	0.170	0.030	0.154	0.014	0.186	0.081	0.246	0.069	0.118
Sweet potato	0.058	0.178	0.178	0.020	0.157	0.050	0.186	0.086	0.246	0.033	0.119
Potato	0.060	0.041	0.041	0.107	0.075	0.162	0.039	0.080	0.072	0.144	0.082
Onion	0.063	0.101	0.101	0.063	0.048	0.101	0.077	0.066	0.039	0.224	0.088
Cabbage	0.063	0.043	0.043	0.135	0.194	0.100	0.041	0.066	0.041	0.045	0.077
Chili	0.063	0.043	0.043	0.146	0.108	0.100	0.048	0.073	0.016	0.079	0.072
Tomato	0.063	0.047	0.047	0.186	0.161	0.100	0.039	0.073	0.016	0.081	0.081

The final ranking could be found by multiplying the weight factor of each commodity/alternative in Table 4 with the weight factor of each criterion in Table 3 (last column). Based on the calculation, the priority weights and the final ranking for each alternative are explained in Table 5.

Table 5. final ranking for each alternative.

Alternative	Total weight	Final Rank
Rice	0.089	4
Soybeans	0.081	8
Corn	0.088	7
Peanuts	0.088	6
Cassava	0.120	1
Sweet Potato	0.117	2
Potato	0.089	5
Onion	0.100	3
Cabbage	0.076	10
Chili	0.072	11
Tomato	0.081	9

Table 5 explains that cassava was the most potential crop to be cultivated, even though other crops such as sweet potatoes, onions, rice, and potatoes had greater potential compared to other commodities. Based on these results, the methodology applied in this study has proven to be appropriate for assessing the development priorities of potential crops in Indonesia. The results of the criteria weight assessment obtained were in line with previous research that showed that economic

characteristics had a significant effect on the selection of commodities [3, 9, 17]. The MCDA procedure was proven to be able to integrate the criteria of commodity, economic, and environmental characteristics with input from the assessment of agricultural experts. However, when compared with similar studies, the assessment showed varied results and has limited independence between criteria [3, 5, 8]. Therefore, in order to obtain accurate results, this study carried out restrictions in choosing alternative plants. This is different from previous studies which included all types of commodities such as vegetables and fruits that had significantly different production ages and treatments.

In this study, it was also found that food crops in general had more potential to be developed than vegetables. This conclusion was supported by the fact that in the 90s Indonesia was once called the world rice granary [18]. Also, it is in line with the aim of the Indonesian ministry to make Indonesia become a world food barn by 2045 [19]. However, every region in Indonesia also has the potential to develop its superior products [1, 17]. This is because the selection of commodities is also influenced by the land characteristics of each region. The existence of superior regional products leads to the conclusion that the local characteristics of each region cannot be covered by the general literature. Therefore, it is recommended to integrate literature and further study the condition of agricultural land in each region. Furthermore, it is necessary to include local knowledge and detailed land characteristics as a basis for decision making.

4. Conclusion

This study provided an overview of how the selection of potential commodities was chosen using Multi-Criteria Decision Analysis. The method used was the AHP method by using 3 main criteria which were derived into 11 sub-criteria. These criteria were chosen based on the actual conditions of Indonesian agriculture. Based on the calculation results, the 5 most potential plants to be cultivated in the Indonesian region are cassava with a weight value of 0.120 (12%), Sweet potato with a weight of 0.117 (11.7%) and Onion with a weight of 0.100(10%), rice with a weight of 0.0892 (8.92 %) and potatoes weighing 0.0890 (8.90%). By calculating using MCDA, it was found that in Indonesia food crops have relatively better potential to be developed compared to vegetable crops. By knowing the potential of the commodity, farmers are expected to get a reference when selecting commodities so as can reduce the risk of crop failure.

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