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Development of an Intelligent System to Determine Land Suitability for Horticultural Crops on Vegetable Commodities

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ABSTRACT

Global climate change has a significant impact on the agricultural sector, including horticulture, with climate fluctuations such as increased temperatures and changes in rainfall patterns potentially affecting crop productivity. Sustainable horticultural agriculture is important for safeguarding natural resources and reducing environmental impacts. However, challenges from climate change and variations in land conditions can affect horticultural crop production. Identifying crops that are suitable for the climate and land conditions is key to agricultural sustainability. An intelligent and adaptive approach is needed in selecting the right crops to grow in the face of climate change. This research develops an artificial intelligence application for the recommendation of horticultural crop types according to land conditions and climate change. The model built involves AHP and MFEP methods. The model takes into account various land parameters with weights determined through the AHP approach, allowing this AI application to provide accurate recommendations based on data and modeling. Based on the tests conducted, the system was able to produce analysis with an accuracy rate of 85%.

INTRODUCTION

Global climate change has had a significant impact on the agricultural sector, and horticulture is no exception. Climate fluctuations, such as increasing temperatures, changing rainfall patterns, and extreme events, have great potential to affect crop productivity (Kumar, 2022). Horticultural agriculture plays an important role in meeting global food needs. Sustainable horticultural agriculture is becoming increasingly important to safeguard natural resources and minimize environmental impacts. However, challenges posed by climate change and variations in land conditions can greatly affect horticultural crop production (Nand et al., 2020; Mukherjee et al., 2022).

Climate change, which includes increasing temperatures, rainfall instability and changing weather patterns, directly affects crop growth and yields. Each land type has unique characteristics that significantly affect plant growth (Tufaila & Alam, 2014) (Holilullah et al., 2015; Widiatmaka et al., 2015). Therefore, it is very important to identify the types of horticultural crops that are suitable for specific climatic and land conditions. Choosing crop types that are suitable for land and climate conditions can help farmers in their efforts to maintain agricultural sustainability and productivity (Rahayu et al., 2018). In the face of ongoing climate change, a smart and adaptive approach is key in choosing the right types of plants to plant, so as to optimize crop yields and maintain the sustainability of horticultural agriculture in the future.

Determining the type of crop suitable for specific conditions is a complex task. The limitations of human knowledge in analyzing large amounts of data and predicting the impacts of climate change make AI applications an attractive option. Artificial intelligence (AI) technology has become a driving force in agriculture (Euriga et al., 2018; Savira et al., 2020) (Ula et al., 2022). With advanced data analysis capabilities, AI can be used to optimize agricultural production and provide appropriate recommendations according to environmental conditions. However, there are not many AI applications specifically focused on horticultural crop recommendations based on specific land conditions and climate change (Sahputra & Ula, 2022).

This research aims to develop an artificial intelligence application that can provide recommendations for suitable horticultural crops based on land conditions and climate change. By offering accurate recommendations derived from data and modeling, this AI application has the potential to enhance agricultural productivity. It is anticipated that this application will assist farmers and agricultural experts in making smarter decisions regarding the choice of crops to cultivate, maximizing harvest yields, and reducing environmental impact.

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LITERATURE REVIEW

There have been several previous studies that have applied computer-based analysis capabilities to the suitability of land for plant types, such as: (Soepomo, 2014) developing a case base reasoning application for the suitability of land types for fruit cultivation. The results of this research state that the application built worth using. (Rahayu et al., 2018) developed a decision support application for selecting food crops using the TOPSIS and electre methods, the model built had an accuracy of 85.7%. (Woda et al., 2019) developed a decision support system for land suitability for food crop types using FAHP, the results of this research stated that the application built was able to produce decisions with the best choices. (Minarwati, 2021) implemented the profile matching method in a decision support application, the results of this research stated that the system built was able to provide appropriate recommendations. Another research conducted by (Sinlae et al. 2021) to determine the suitability of agricultural land for chili plants using the Naïve Bayes method, concluded that the model was able to find suitable land for chili plants based on past case analysis with an accuracy of 89%.

In general, several studies that have been conducted place land as a decision alternative, while plant type is the criterion. This research has an inverted paradigm, by placing types of horticultural crops as vegetable commodities as alternative choices for available land, while land parameters are the assessment criteria. The model developed in this research is a hybrid of the AHP and MFEP methods.

METHOD

Data Collection

This research involves collecting data needed to calculate the values of the parameters used as well as to select the best crop types that suit the land conditions. Crop types are limited to the horticultural category of vegetable commodities. The data used in this study consisted of two types, namely secondary data and primary data. Secondary data were obtained from the technical manual of land evaluation for agricultural commodities in 2011. Meanwhile, primary data was obtained through interviews, and the use of questionnaires filled out by experts. By combining existing secondary data with primary data obtained from experts, this research can present a comprehensive and accurate analysis to support the selection of optimal food crops in accordance with existing land characteristics.

Types of Plants

The types of crops used in this study are vegetable commodity horticultural crops. some types of crops are:

Table 1: Type of crops

No	Crops	No	Crops	No	Crops	No	Crops
1	Kale	6	String Beans	11	Radish	16	Tomatoes
2	Spinach	7	Siamese Pumpkin	12	Onion	17	Chili
3	broccoli	8	Ground Pumpkin	13	Gambas	18	Eggplant
4	cauliflower	9	Potato	14	Cucumber	19	Celery
5	Mustard	10	Carrot	15	Beets		

Parameter Determination

Land suitability with crops is influenced by several parameters. In this study, 8 parameters were used including: Topology, Soil type, Soil structure, Temperature, Rainfall, Drainage, Soil depth, Potential Disaster.

Table 2. Land suitability parameters

No	Parameter	Pilihan	Bobot	Keterangan
1	Topologi (P1)	1. Highlands 2. Hills 3. Lowlands 4. Lebak 5. Slope 6. Small Hill 7. Swamp Area	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type
2	Soil Type (P2)	1. Litosol 2. Latosol 3. Organosol 4. Grumusol 5. Regosol 6. Alluvial	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type

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3	Soil Structure (P3)	1. Sandy 2. Clay 3. Debris Soil 4. Clayey Sandy Soil 5. Debris Sandy Soil 6. Silty Clay Soil	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type
4	Soil Depth (P4)	.... Cm	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type
5	pH (P5)	....	1. Tidak sesuai 2. Sesuai 3. Cukup sesuai 4. Sangat sesuai	The weight of suitability parameters depends on the crop type
4	Temperature (P6)	.... °C	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type
5	Hidrology (P7)	1. Very good 2. Good 3. Less 4. Very less	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type
8	Disaster Potential (Flood/Landslide) (P8)	1. Very heavy 2. Heavy 3. Light 4. No potential	1. Not suitable 2. Appropriate 3. Moderately appropriate 4. Very suitable	The weight of suitability parameters depends on the crop type

System Development

The intelligent system built uses the concept of Decision Support System. The system architecture is shown in Figure 1.

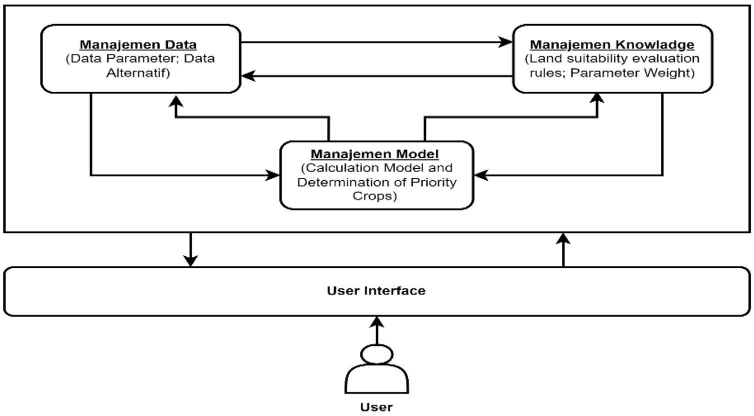

Figure1. System Architecture

The system consists of 4 main components, namely: (1) Data management, to manage data on land evaluation parameters and alternative data in the form of plant species. (2) Knowledge management, to manage knowledge data about land evaluation and parameter weights given by experts. (3) Model management, to manage the calculation model of land suitability with crop types. And (4) User interface, as a place for users to interact with the system. The workflow scheme of the system built is shown in the following figure:

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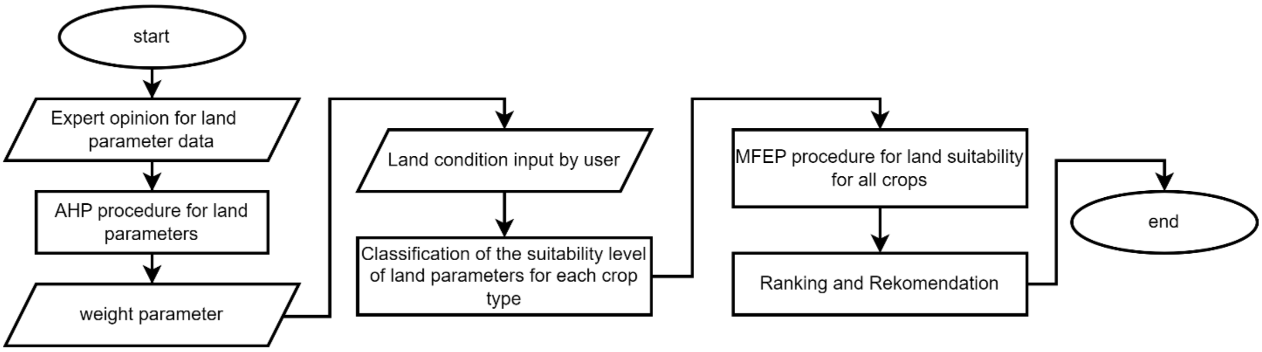

Figure2. System Schematic

AHP Procedure

The AHP procedure is used to determine the importance weight of each parameter by conducting a pairwise comparison of each parameter through the values provided by the expert. The comparison scale used refers to Saaty's standard as shown in table 3. Consistency matrix is calculated using the following equation:

$$CI = \frac{\lambda \max - n}{n - 1} \quad \text{.......... (1)}$$

$$CR = CI/IR \quad \text{.......... (2)}$$

Table 3. AHP comparison scale table

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very strong Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of

Classification of Land Suitability Levels

The classification of land suitability levels refers to the 2011 technical guidelines for land evaluation published by the Center for Research and Development of Agricultural Land Resources of the Ministry of Agriculture, but with minor adjustments based on the parameters used in this study.

MFEP Procedure (Multi Factor Evaluation Process)

The MFEP procedure is applied to assess the level of land suitability for all types of alternative crops. Several stages of the MFEP procedure include:

1. Determining factors and factor weights, factor weights in this study are obtained from AHP procedures based on expert opinion.
2. Calculate Weight Evaluation with the following equation:

   $$\boldsymbol{Y_{ij} = W_j * r_{ij}} \quad \text{.......... (3)}$$

   The weight evaluation value (Y_{ij}) of an i-th alternative on the jth criterion/factor is the result of multiplying the factor weight (W_j) by the factor evaluation (r_{ij}).
3. Calculate the preference value with the following equation:

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$$V_i = \sum_{j=1}^{n} W_j * r_{ij} = \sum_{j=1}^{n} Y_{ij} \qquad \text{...(4)}$$

4. Ranking, the highest preference value is best.

Ranking and Rekomendation

The system ranks the assessment results and provides recommendations for priority plant types based on the MFEP analysis results.

RESULT

AHP Calculation for Parameter Importance Weight

The initial stage is to determine the importance comparison value between the parameters used. Based on expert input, a pairwise comparison matrix is obtained as shown in Table 3.

Table 3. Expert input pairwise comparison matrix

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
P1	1	7/3	7/3	2/1	1	1	1	1/3
P2	3/7	1	1	4/6	3/7	3/7	3/7	1/3
P3	3/7	1	1	4/6	1/2	1/2	1/2	1/3
P4	1/2	6/4	6/4	1	1/2	1/2	1/2	1/3
P5	1	7/3	2/1	2/1	1	1	1	1/3
P6	1	7/3	2/1	2/1	1	1	1	1/3
P7	1	7/3	2/1	2/1	1	1	1	1/3
P8	3	3	3	3	3	3	3	1

Table 4. Pairwise comparison matrix

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
P1	1.00	2.33	2.33	2.00	1.00	1.00	1.00	0.33
P2	0.43	1.00	1.00	0.67	0.43	0.43	0.43	0.33
P3	0.43	1.00	1.00	0.67	0.50	0.50	0.50	0.33
P4	0.50	1.50	1.50	1.00	0.50	0.50	0.50	0.33
P5	1.00	2.33	2.00	2.00	1.00	1.00	1.00	0.33
P6	1.00	2.33	2.00	2.00	1.00	1.00	1.00	0.33
P7	1.00	2.33	2.00	2.00	1.00	1.00	1.00	0.33
P8	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00
	8.36	15.83	14.83	13.33	8.43	8.43	6.43	3.31

Table 5. Normalized matrix and priority weights

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**weight**
P1	0.12	0.15	0.16	0.15	0.12	0.12	0.16	0.10	**0.13**
P2	0.05	0.06	0.07	0.05	0.05	0.05	0.07	0.10	**0.06**
P3	0.05	0.06	0.07	0.05	0.06	0.06	0.08	0.10	**0.07**
P4	0.06	0.09	0.10	0.08	0.06	0.06	0.08	0.10	**0.08**
P5	0.12	0.15	0.13	0.15	0.12	0.12	0.16	0.10	**0.13**
P6	0.12	0.15	0.13	0.15	0.12	0.12	0.16	0.10	**0.13**
P7	0.12	0.15	0.13	0.15	0.12	0.12	0.16	0.10	**0.13**
P8	0.36	0.19	0.20	0.23	0.36	0.36	0.16	0.30	**0.27**
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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From this stage, the parameter weights are obtained, namely: P1 = 0.13, P2 = 0.06, P3 = 0.07, P4 = 0.08, P5 = 0.13, P6 = 0.13, P7 = 0.13 and P8 = 0.13. Furthermore, measuring the consistency of the matrix using equation 1, the CI value is -0.7877. IR for matrix order 8 = 1.41, so the value of CR = CI/IR = -0.558. consistency is accepted because CR <= 0.1. The weight obtained is then used in the MFEP stage.

Classification of Land Suitability with Crop Types

Based on the input of land conditions by users, a classification of the suitability level of each land parameter for plant species is carried out. Here is one example of the classification results based on the following land conditions:

Topology	:	Highland
Soil Type	:	Latosol
Soil Structure	:	Clay
Soil Depth	:	25 cm
pH	:	6.3
Temperature	:	29 0C
Hydrology	:	Very good
Disaster Potential	:	No potential

The classification results based on these land parameters are shown in Table 6.

Table 6. Classification results of suitability of land parameters with plant species

Crops	P1	P2	P3	P4	P5	P6	P7	P8
Kale	not suitable	not suitable	as per	moderately compliant	very suitable	very suitable	moderately compliant	very suitable
Spinach	Suitable	not suitable	Suitable	moderately compliant	very suitable	moderately suitable	moderately compliant	very suitable
broccoli	Suitable	Suitable	Suitable	moderately compliant	very suitable	moderately compliant	moderately compliant	very suitable
cauliflower	appropriate	not compliant	Suitable	moderately compliant	very suitable	moderately conforming	moderately compliant	very suitable
Mustard	moderately conforming	Suitable	appropriate	moderately compliant	very suitable	moderately conforming	moderately compliant	very suitable
String Beans	moderately conforming	moderately conforming	not appropriate	moderately compliant	very suitable	very suitable	moderately compliant	very suitable
Siamese Pumpkin	Suitable	appropriate	Suitable	Suitable	very suitable	very suitable	moderately compliant	very suitable
Ground Pumpkin	Suitable	appropriate	appropriate	Suitable	very suitable	moderately conforming	moderately compliant	very suitable
Potato	Suitable	appropriate	moderately conforming	Suitable	very suitable	moderately conforming	moderately compliant	very suitable
Carrot	appropriate	Suitable	moderately conforming	Suitable	very suitable	moderately conforming	moderately compliant	very suitable
Radish	not appropriate	appropriate	moderately conforming	moderately compliant	very suitable	moderately conforming	moderately compliant	very suitable
Onion	moderately conforming	not appropriate	very suitable	moderately compliant	very suitable	moderately conforming	moderately compliant	very suitable
Gambas	appropriate	moderately conforming	moderately conforming	moderately compliant	very suitable	very suitable	moderately compliant	very suitable
Cucumber	appropriate	appropriate	moderately conforming	moderately compliant	very suitable	moderately conforming	moderately compliant	very suitable
Beets	appropriate	appropriate	moderately conforming	Suitable	very suitable	moderately conforming	moderately compliant	very suitable
Tomatoes	moderately compliant	moderately conforming	very suitable	Suitable	very suitable	moderately conforming	moderately compliant	very suitable
Chili	moderately compliant	not appropriate	Suitable	Suitable	very suitable	very suitable	moderately compliant	very suitable
Eggplant	Suitable	Suitable	very suitable	Suitable	very suitable	very suitable	moderately compliant	very suitable
Celery	moderately compliant	not suitable	Suitable	moderately compliant	very suitable	moderately conforming	moderately compliant	very suitable

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MFEP Calculation

MFEP calculation begins with transforming the classification result data in Table 6 into numerical form and presented in the factor value matrix. Next, calculate the weight evaluation using formula 3 with the factor weights that have been obtained in the AHP calculation stage, P1= 0.13; P2 = 0.06; P3 = 0.07; P4 = 0.08; P5 = 0.13; P6 = 0.13; P7 = 0.13; P8 = 0.27. Then the preference value is calculated using formula 4, the results obtained are as follows:

Factor value matrix

	P1	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***
T1	1	1	2	3	4	4	3	4
T2	2	1	2	3	4	3	3	4
T3	2	2	2	3	4	3	3	4
T4	2	1	2	3	4	3	3	4
T5	3	2	2	3	4	3	3	4
T6	3	3	1	3	4	4	3	4
T7	2	2	2	2	4	4	3	4
T8	2	2	2	2	4	3	3	4
T9	2	2	3	2	4	3	3	4
T10	2	2	3	2	4	3	3	4
T11	1	2	3	3	4	3	3	4
T12	3	1	4	3	4	3	3	4
T13	2	3	3	3	4	4	3	4
T14	2	2	3	3	4	3	3	4
T15	2	2	3	2	4	3	3	4
T16	3	3	4	2	4	3	3	4
T17	3	1	2	2	4	4	3	4
T18	2	2	4	2	4	4	3	4
T19	3	1	2	3	4	3	3	4

weight evaluation / ***preferensi***

	P1	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***	***preferensi***
T1	0.13	0.06	0.14	0.24	0.52	0.52	0.39	1.08	3.08
T2	0.26	0.06	0.14	0.24	0.52	0.39	0.39	1.08	3.08
T3	0.26	0.12	0.14	0.24	0.52	0.39	0.39	1.08	3.14
T4	0.26	0.06	0.14	0.24	0.52	0.39	0.39	1.08	3.08
T5	0.39	0.12	0.14	0.24	0.52	0.39	0.39	1.08	3.27
T6	0.39	0.18	0.07	0.24	0.52	0.52	0.39	1.08	3.39
T7	0.26	0.12	0.14	0.16	0.52	0.52	0.39	1.08	3.19
T8	0.26	0.12	0.14	0.16	0.52	0.39	0.39	1.08	3.06
T9	0.26	0.12	0.21	0.16	0.52	0.39	0.39	1.08	3.13
T10	0.26	0.12	0.21	0.16	0.52	0.39	0.39	1.08	3.13
T11	0.13	0.12	0.21	0.24	0.52	0.39	0.39	1.08	3.08
T12	0.39	0.06	0.28	0.24	0.52	0.39	0.39	1.08	3.35
T13	0.26	0.18	0.21	0.24	0.52	0.52	0.39	1.08	3.4
T14	0.26	0.12	0.21	0.24	0.52	0.39	0.39	1.08	3.21
T15	0.26	0.12	0.21	0.16	0.52	0.39	0.39	1.08	3.13
T16	0.39	0.18	0.28	0.16	0.52	0.39	0.39	1.08	3.39
T17	0.39	0.06	0.14	0.16	0.52	0.52	0.39	1.08	3.26
T18	0.26	0.12	0.28	0.16	0.52	0.52	0.39	1.08	3.33
T19	0.39	0.06	0.14	0.24	0.52	0.39	0.39	1.08	3.21

Ranking and Recommendations

Based on the results of the weight evaluation and preference calculations, a ranking was obtained as shown in table 7.

Tabel 7. Ranking

Id	**Tanaman**	**Pref**	**Rank**	**Id**	**Tanaman**	**Pref**	**Rank**	**Id**	**Tanaman**	**Pref**	**Rank**
T13	Gambas	*3.4*	1	T14	Cucumber	*3.21*	7	T1	Spinach	*3.08*	11
T6	Long beans	*3.39*	2	T19	Celery	*3.21*	7	T2	Spinach	*3.08*	11
T16	Tomato	*3.39*	2	T7	Chayote	*3.19*	8	T4	Cauliflower	*3.08*	11
T12	Onion	*3.35*	3	T3	Broccoli	*3.14*	9	T11	Turnip	*3.08*	11
T18	Eggplant	*3.33*	4	T9	Potato	*3.13*	10	T8	Ground Pumpkin	*3.06*	12
T5	Mustard	*3.27*	5	T10	Carrot	*3.13*	10				
T17	Chilli	*3.26*	6	T15	Beets	*3.13*	10				

It is recommended that on land with the parameters mentioned above, 3 types of plants have the highest level of suitability, namely: Gambas with a preference value of 3.4, long beans and tomatoes with a preference value of 3.39.

System Testing

System testing consists of 2 tests, namely: testing system functionality, and testing the model embedded in the system. Functionality testing was carried out using the black box testing method, the following results were obtained:

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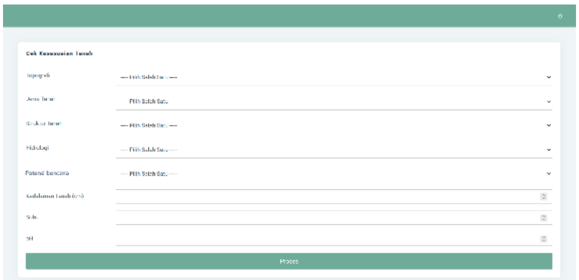
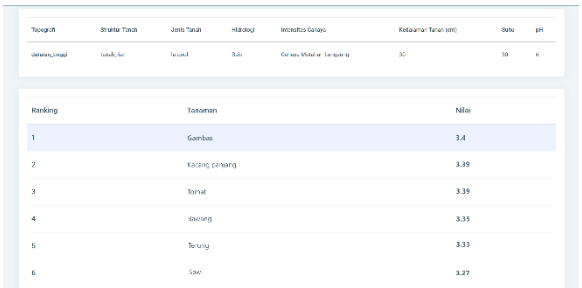
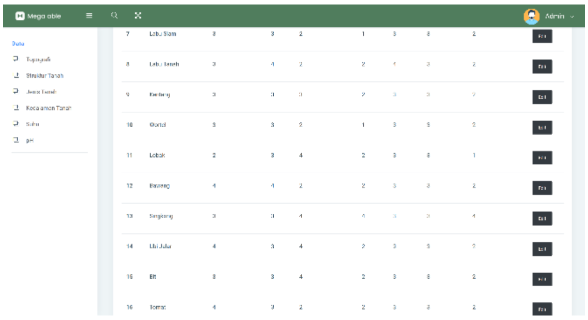
Table 8. System functionality testing results

No	Fungtional	Figure	Explanation
1	Input land parameters		On this page the user inputs land parameter values. This page is working properly
2	Output Results of AHP and MFEP analysis		On this page the results of the AHP and MFEP analysis are displayed This page is working properly
3	Knowledge base		This page contains classification rules for the suitability of plant types with land parameters. All functions on this page work normally

Model testing was carried out by providing 20 cases with various land parameter conditions. The condition of the land and the results of the system recommendations are submitted to experts for inspection. 17 cases were verified as appropriate, and 3 cases were verified as inappropriate. Based on this test, the model has an accuracy of 85%.

DISCUSSION

This research incorporates land parameters as factors in the MFEP method. As per the conducted research, no references were found discussing the importance weights of each land parameter. Therefore, the AHP method was employed to determine these weights based on expert opinions, ensuring the MFEP method could perform accurate analyses. Based on AHP calculations, the priority weights for each land parameter were determined as follows: P1 = 0.13, P2 = 0.06, P3 = 0.07, P4 = 0.08, P5 = 0.13, P6 = 0.13, P7 = 0.13, and P8 = 0.13. The classification of land suitability for specific vegetable crops was conducted in accordance with the guidelines stored in the knowledge base of the built system; the classification results are illustrated in Table 6. Varied values assigned to the land parameters can result in different classification outcomes due to the distinct characteristics of each plant type. To execute the MFEP procedure, the classified land suitability results need to be converted into numeric values, forming a matrix of factor values that are then multiplied by the priority weights to obtain preference values for each plant type. A higher preference value implies a greater suitability of a particular plant type for the specific land. The system's recommendations are based on the best preference values obtained from the AHP and MFEP analyses.

CONCLUSION

The research that has been carried out has succeeded in building an intelligent system that is able to analyze the suitability of land for plant types. The system built can run well without any bugs. The model applied in the system, namely the combination of AHP and MFEP methods, is able to produce analysis with an accuracy level of 85%.

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