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Development and Evaluation of a Web-Based Geographic Information System (GIS) for Agricultural Land Management Using Agile Extreme Programming

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Abstract

Precision agriculture is a modern approach that applies technology to improve efficiency and productivity in the agricultural sector. This study develops a Web Geographic Information System (WebGIS)-based agricultural data management system that integrates spatial and non-spatial data into a single platform. The system supports land mapping, crop age monitoring, planting distribution visualization, and harvest status tracking, and was implemented in the administrative area of Indramayu Regency, Indonesia, as the study site. The system was developed using the Agile Extreme Programming (XP) methodology, which provides flexibility in accommodating user requirements throughout the development process. Functional testing was conducted using the Black Box Testing method to verify that all system features performed as intended. System performance was evaluated using the PIECES framework (Performance, Information, Economy, Control, Efficiency, and Service), resulting in scores of 6.70, 5.97, 5.93, 5.83, 5.93, and 5.97, respectively. The evaluation showed that the system met user expectations, particularly those of farmers, with overall performance rated from good to very good. The proposed system provides an effective solution for improving agricultural land management through integrated and efficient monitoring.

Keywords: *Precision agriculture, Agricultural Land Management System, Agile XP, Black Box Testing, PIECES*

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1. INTRODUCTION

Information technology has become increasingly integrated into people's daily activities. Technology users expect access to complete, accurate, and up-to-date information to meet their growing needs. Advances in technology enable information to be searched, processed, and shared more quickly and efficiently. Therefore, in today's digital era, the speed and completeness of information have become essential in supporting various human activities [1].

Technology has also had a significant impact on the agricultural sector. Various innovations, such as smart farming platforms, weather monitoring systems, and agricultural e-commerce platforms, have helped farmers improve efficiency and productivity. By using these technologies, farmers can make better data-driven decisions, optimize the use of resources, and increase agricultural production. Digital transformation in agriculture not only makes farming activities easier but also supports sustainable agriculture and improves community welfare [2].

Agriculture is an activity that uses natural resources to produce various products, such as food, industrial raw materials, and energy sources, while also contributing to environmental sustainability [3]. In a broad sense, agriculture includes all activities involving living organisms, such as plants, animals, and microorganisms, to meet human needs. In a narrower sense, agriculture is commonly understood as the practice of cultivating crops [4].

The agricultural sector plays an important role in Indonesia and is one of the main pillars of the national economy [5]. It not only contributes to improving people's welfare but also supports national food security. The diverse geographical conditions across provinces and districts create different agricultural potentials, providing great opportunities for agricultural development. These potentials help increase agricultural productivity and promote economic welfare throughout Indonesia.

To support agricultural resource management, Geographic Information Systems (GIS) are used to collect, manage, analyze, and present data related to agricultural land, farming

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activities, and harvests [6][7]. GIS enables users to produce thematic maps that simplify land monitoring and evaluation [8][9]. In addition to managing databases efficiently, GIS integrates spatial and non-spatial information, making decision-making in agricultural management more effective [10]. One implementation of GIS is the Web Geographic Information System (WebGIS), a web-based platform that uses internet technology to provide online geographic information services [11][12].

Previous studies have shown that WebGIS applications in agriculture mainly focus on displaying spatial information, such as land locations and crop distribution. Most existing systems do not integrate land management functions, including crop age monitoring, harvest status tracking, and integrated agricultural data management. As a result, monitoring and decision-making processes for farmers and land managers are still not fully effective.

Therefore, this study proposes a WebGIS-based agricultural land management system that integrates spatial and non-spatial information into a single platform. The system provides land mapping, crop age monitoring, planting distribution visualization, and harvest status tracking to support more effective and efficient agricultural land management.

2. RESEARCH METHOD

This study employed the Software Development Life Cycle (SDLC) using the Agile Extreme Programming (XP) approach to develop a WebGIS-based agricultural land management system. The XP methodology was selected because its iterative and flexible development process can effectively accommodate changing user requirements throughout system development [13][14] [15]. The development process consisted of five stages: Planning, Design, Coding, Testing, and Release.

During the Planning stage, a literature review, field observations, and questionnaire distribution to farmers in the administrative area of Indramayu Regency were conducted to identify user requirements, existing problems, and expectations for the proposed system. The collected data served as the basis for defining the system's functional and non-functional requirements. The Design stage involved designing the system architecture, database, user interface (UI), and system models using the Unified Modeling Language (UML), including the Use Case, Activity, and Class Diagrams. In the Coding stage, the proposed design was implemented as a WebGIS application integrating spatial and non-spatial data to support land mapping, agricultural data management, crop age monitoring, planting distribution visualization, and harvest status tracking. The Testing stage employed the Black Box Testing method to verify that all system functions operated as specified. Finally, after system deployment in the Release stage, the system was evaluated using the PIECES framework through questionnaires distributed to farmers in Indramayu Regency. Responses were measured using a seven-point Likert scale to assess user satisfaction and evaluate the overall quality of the developed system for future improvements.

2.1 Planing

In the Planning phase, system requirements and development priorities were systematically identified. Stakeholder consultations were carried out to determine the essential functionalities of the system and to establish a roadmap for subsequent development iterations. The requirements gathered during this stage formed the basis for the design and implementation of a system tailored to user needs, which include:

1) The system accommodates two categories of users: administrators representing the relevant agricultural agency and farmers as end users.
2) Administrators are responsible for managing farmer profiles, maintaining agricultural land information, supervising planting activities, and monitoring crop production and harvest performance.
3) Farmers and farmer groups are provided with functionalities to manage cultivation data, monitor crop growth stages and plant age, as well as record and track harvest data for performance evaluation and decision-making purposes.

2.2 Design

The Design phase involved the development of the system architecture, database schema, and user interface through the application of the Unified Modeling Language (UML). This modeling approach was employed to ensure the optimal functionality and integration of all system components. Within the UML framework, the study addresses three primary aspects, including:

1) Use case Diagram

The Use Case Diagram is employed to represent the functional requirements and behavioral aspects of an information system. As a static modeling tool within the Unified

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Modeling Language (UML), it describes the interactions between system actors and the system itself, thereby providing a clear understanding of the services and functionalities offered by the system. [16]. Figures 1 and 2 present the Use Case Diagrams of the Agricultural Land Management Application. These diagrams provide a visual representation of the interactions between actors and the system, highlighting the functional requirements and services available to each user role.

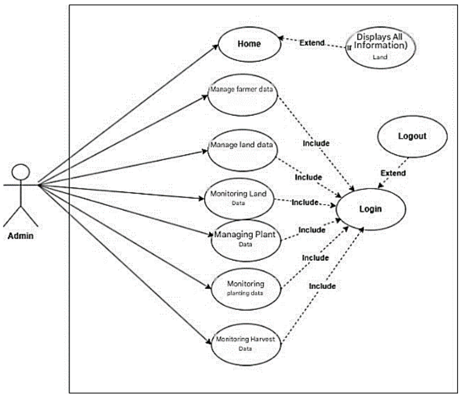

Figure 1. Administrator Use Case Diagram

As shown in Figure 1, the administrator has access to the Home module, which displays agricultural land information. The administrator is also responsible for managing farmer records, maintaining agricultural land data, monitoring land-related information, managing crop data, supervising planting activities, and tracking harvest outcomes. These functionalities enable comprehensive oversight and management of agricultural operations within the system.

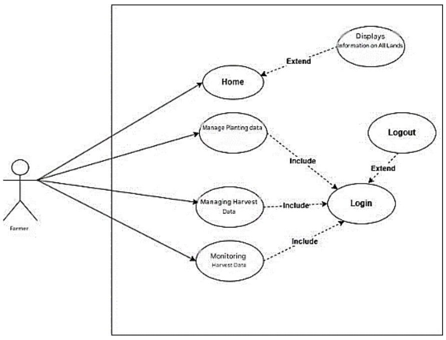

Figure 2. Farmer Use Case Diagram

As shown in Figure 2, farmers are granted access to the Home module, which displays comprehensive agricultural land information. The system also enables farmers to manage planting data, record and maintain harvest information, and monitor harvest outcomes. These functionalities assist farmers in tracking cultivation activities and evaluating agricultural productivity more effectively.

2) Activity Diagram

The Activity Diagram is employed to model the flow of activities within the application by depicting the sequence of actions, control flows, initial and final states, as well as decision points that govern the execution of business processes and system operations [17].

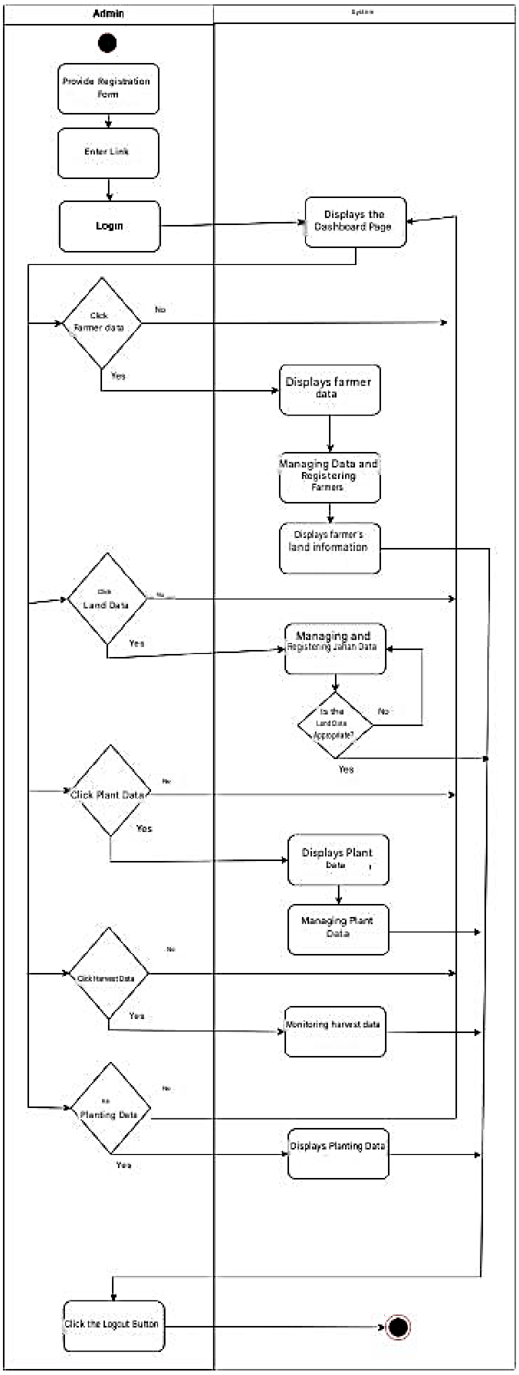

Figure 3. Admin Activity Diagram

As shown in Figure 3, the Administrator Activity Diagram describes the workflow of

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administrative activities within the Agricultural Land Management System. The process starts with the administrator entering login credentials through the authentication form. After successful login, the administrator is directed to the dashboard, which provides access to key functionalities such as managing farmer information, agricultural land data, crop data, and harvest records.

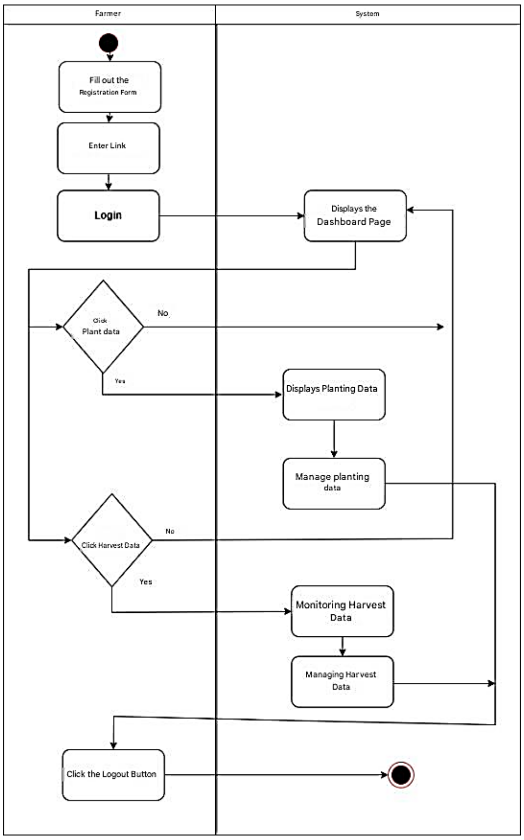

Figure 4. Farmer Activity Diagram

As shown in Figure 4, the Farmer Activity Diagram depicts the sequence of activities undertaken by farmers in the Agricultural Land Management System. The workflow starts with the completion of the registration form, proceeds to the login process for user authentication, and continues with access to the system dashboard. Through the dashboard, farmers are able to manage and monitor land data, crop information, and harvest records, thereby facilitating effective agricultural management and decision-making.

3) Class Diagram

The Class Diagram is used to model the static structure of the system by specifying the classes, their associated attributes and methods, as well as the relationships between classes [18]. The Class Diagram for the Agricultural Land Management System is presented in Figure 5, providing a detailed representation of the system's architecture and component interactions.

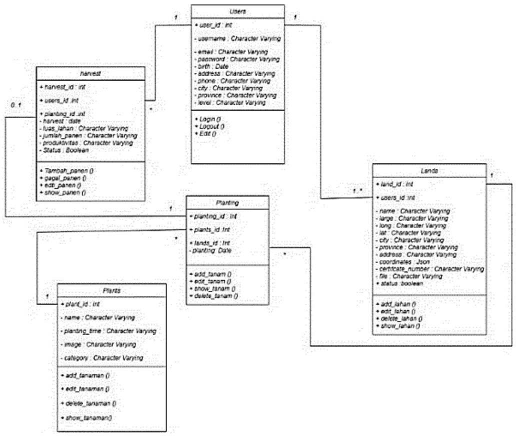

Figure 5. Class Diagram

2.3 CODING

System implementation was conducted using the Laravel Framework and Visual Studio Code as the development environment. PostgreSQL was employed as the database management system to store and manage agricultural land mapping data, providing farmers with efficient access to spatial and non-spatial information.

2.4 *Testing*

Black-box testing is a software testing method that focuses on validating system functionality without considering the internal implementation or source code of the application under evaluation [19]. Black-box testing is a software testing method that focuses on validating system functionality without considering the internal implementation or source code of the application under evaluation

2.5 Release/Software Increment

The Release phase constitutes an essential stage of the iterative system development lifecycle. Following user acceptance and approval by farmers, new services and functionalities are incorporated into the system. The purpose of these enhancements is to expand the system’s capabilities, improve its operational effectiveness, and ensure that it continues to meet the evolving needs of its users.

2.6 System Performance Analysis

The system performance analysis phase was conducted to evaluate the effectiveness of the developed system and determine the extent to which it satisfies end-user expectations. This evaluation focuses on users’ perceptions and experiences when interacting with the system. To achieve this objective, the PIECES framework

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was employed as the evaluation method. PIECES assesses information systems across six fundamental dimensions, namely Performance, Information, Economy, Control, Efficiency, and Service. Consideration of these dimensions enables organizations to identify potential weaknesses, improve system quality, and ensure optimal operational performance [20]. The analysis was performed by administering questionnaires to respondents in order to measure the performance and usability of the Agricultural Land Management System. The detailed questionnaire items are presented in Table 1, whereas the Likert scale weights applied in the assessment process are shown in Table 2.

Table 1. Questionnaire Items

Indicator	Questionnaire Item
Performance	1. The system enables users to access its features and menus easily and with minimal delay. 2. The system demonstrates efficient response and loading times during operation.
Information	1. The system provides current and regularly updated information relevant to user needs. 2. The information generated by the system is accurate, relevant, and dependable.
Economy	1. The system improves time efficiency for users in carrying out their tasks and activities. 2. The system minimizes the costs associated with agricultural land management and related operations.
Control	1. The system implements adequate access control mechanisms to regulate user permissions. 2. The system demonstrates stability and reliability by functioning without operational errors during use.
Efficiency	1. The system effectively fulfills the requirements and expectations of its users. 2. The system provides a user-friendly interface that facilitates ease of use for first-time users.
Service	1. The system is accessible through different devices and platforms, ensuring flexibility for users. 2. The system delivers the necessary data and information to support user activities and decision-making.

Table 2. Likert Scale Weighting Scheme

Response	Positive Score	Negative Score
Strongly Agree	7	1
Agree	6	2
Somewhat Agree	5	3
Neutral	4	4
Somewhat Disagree	3	5
Disagree	2	6
Strongly Disagree	1	7

Once the average questionnaire score has been calculated, the data are presented in a table and processed to determine the interval scale based on the Range Scale (RS) formula.

$$RS = (m - q)/b \tag{1}$$

Equation (1) is the formula for calculating the Likert scale assessment:

RS : The desired scale range
m : The maximum value in the questionnaire measurement used in the study. In this case, the score ranges from 1 to 7, with 7 being the highest value and 1 being the lowest.
q : The minimum value in the measurement, which is 1
b : The number of available options, which in this study is 7.

The scale range obtained from the 0.85 interval value can be seen in Table 3.

Table 3. Assessment Categories

No	Scale	Assessment Category
1	1,00 – 1,85	Very Poor
2	1,85 – 2,70	Poor
3	2,70 – 3,55	Fairly Poor
4	3,55 – 4,40	Adequate
5	4,40 – 5,25	Fairly Good
6	5,25 – 6,10	Good
7	6,10 – 6,95	Very Good

3. RESEARCH RESULT

3.1 System Interface Results

As shown in **Figure 6**, the implemented interface and spatial features demonstrate that the WebGIS effectively integrates geographic and agricultural data into a single platform. The interactive map on the home page displays land locations and planting distribution using map markers, allowing users to identify agricultural areas quickly and accurately.

The spatial information is linked with non-spatial data, including landowner information, crop type, crop age, productivity, and harvest status, providing comprehensive information for each mapped location. In addition, the system automatically calculates crop age and updates productivity data in real time, supporting efficient land monitoring and evaluation. The integration of spatial and non-spatial information improves the effectiveness of agricultural land management, accelerates information retrieval, and supports better decision-making for farmers and land managers.

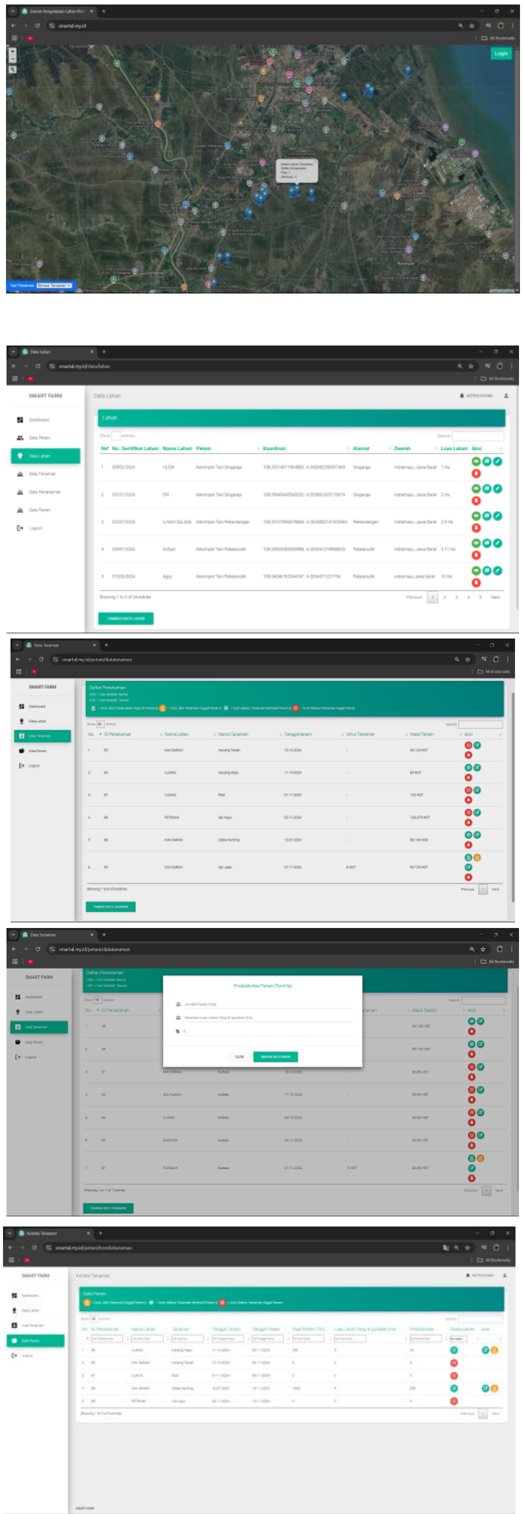

Figure 6. WebGIS System Features

3.2 System Validation Test

The results presented in Table 4 indicate that all system functions performed as expected. The login module successfully validated user authentication by rejecting invalid email addresses or passwords. The land and planting modules effectively supported data entry, editing, and display while validating incomplete inputs to prevent invalid data from being stored. The harvest productivity feature accurately saved calculation results and rejected incomplete submissions. In addition, the harvest module successfully displayed and updated harvest data based on user input. Overall, the Black Box Testing results demonstrate that all core system features function correctly, meet user requirements, and effectively support agricultural data management. Therefore, the developed WebGIS-based system is considered suitable for assisting farmers in managing agricultural land in Indramayu Regency.

Table 4. Black Box Validation Test Results

No	**Page**	**Test Scenario**	**Expected results**	**Process**	**The final result**
1	Visitor Start (Login)	Email and password are filled in incorrectly.	The system will prompt you to enter the correct email address and password	The system rejects then returns to the login page display.	As Expected
2	Land Data	Adding Land Data	If filled, adding land data will add new land data.	The system will add land data	As Expected
		Editing land data	If filled in, the system will successfully change the data.	The system will save the new data after editing.	As Expected
3	Planting Data	Displaying farmer planting data	Displaying farmer planting data	System Displays Farmer Planting Data	As Expected
		Adding Planting Data	If Filled adding Planting data will add new planting data	The system will add planting data	As Expected
		Editing planting data	If filled in, the system will successfully change the data.	The system will save the new data after editing.	As Expected

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No	Page	Test Scenario	Expected results	Process	The final result
		If the planting data adder is not filled in, click save	The system will refuse to add planting data and give a warning	The system refuses to add planting data and gives a warning	As Expected
		Improving Harvest Productivity	The system will save the harvest productivity calculation data.	The system stores data on harvest productivity calculations.	As Expected
		If you add productivity data, do not fill it in and click save.	The system will reject the addition and give a warning	The system rejects the addition of productivity data and gives a warning.	As Expected
4	Harvest Data	Displaying farmer harvest data	The system will display farmer harvest data	The system displays farmer harvest data	As Expected
		Changing harvest data	The system will update the harvest data	The system updates harvest data	As Expected

4. DISCUSSION

4.1 System Performance Testing

System performance was evaluated using the PIECES framework through a questionnaire distributed to 30 farmers in Indramayu Regency as users of the developed agricultural land management system. The evaluation aimed to measure user satisfaction with the system. The results showed that all PIECES indicators achieved average scores above 5.00, while the Performance indicator obtained the highest score of 6.70. Based on the established evaluation criteria, these results indicate that the system effectively meets user needs and provides a satisfactory level of performance. The detailed scores for each PIECES indicator are presented in Tables 5–10.

Table 5. Total Performance score

Answer Options	Statement		Amount	Satisf. Score	Avg. Satisf.
	S1	S2	S1+S2		
Strongly agree	26	17	43	301	6.70
Agree	4	12	16	96	
Quite Agree	0	1	1	5	
Enough	0	0	0	0	
Somewhat Disagree	0	0	0	0	
Don't agree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Sum			**60**	**402**	

Table 6. Total score value of Information

Answer Options	Statement		Amount	Satisf. Score	Avg. Satisf.
	S1	S2	S1+S2		
Strongly agree	3	3	6	42	5.97
Agree	22	24	46	276	
Quite Agree	5	3	8	40	
Enough	0	0	0	0	
Somewhat Disagree	0	0	0	0	
Don't agree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Sum			**60**	**358**	

Table 7. Total Economy score

Answer Options	Statement		Amount	Satisf. Score	Avg. Satisf.
	S1	S2	S1+S2		
Strongly agree	1	6	7	49	5.93
Agree	25	17	42	252	
Quite Agree	4	7	11	55	
Enough	0	0	0	0	
Somewhat Disagree	0	0	0	0	
Don't agree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Sum			**60**	**356**	

Table 8. Total Control score value

Answer Options	Statement S1	Statement S2	Amount S1+S2	Satisf. Score	Avg. Satisf.
Strongly agree	2	2	4	28	5.83
Agree	19	23	42	252	
Quite Agree	9	5	14	70	
Enough	0	0	0	0	
Somewhat Disagree	0	0	0	0	
Don't agree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Sum			**60**	**350**	

Tabel 9. Nilai total skor Efficiency

Answer Options	Statement S1	Statement S2	Amount S1+S2	Satisf. Score	Avg. Satisf.
Strongly agree	1	3	4	28	5.93
Agree	24	24	48	288	
Quite Agree	5	3	8	40	
Enough	0	0	0	0	
Somewhat Disagree	0	0	0	0	
Don't agree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Sum			**60**	**356**	

Table 10. Total Service score

Answer Options	Statement S1	Statement S2	Amount S1+S2	Satisf. Score	Avg. Satisf.
Strongly agree	5	4	9	63	5.97
Agree	19	21	40	240	
Quite Agree	6	5	11	55	
Enough	0	0	0	0	
Somewhat Disagree	0	0	0	0	
Don't agree	0	0	0	0	
Strongly Disagree	0	0	0	0	
Sum			**60**	**358**	

Based on the evaluation of all PIECES indicators, the developed WebGIS system demonstrates that its integrated features effectively address several limitations identified in previous studies. Overall, the WebGIS-based agricultural land management system meets user requirements and provides an effective solution for improving agricultural land management and supporting higher crop productivity in Indramayu Regency.

5. CONCLUSION

The WebGIS-based agricultural land management system developed in this study provides an effective solution to agricultural land management challenges. Using the Agile XP methodology, the system supports efficient management of land, crop, and harvest data while automatically calculating plant age and displaying harvest indicators to facilitate real-time crop monitoring.

The black-box testing results verified the system's functionality across multiple testing scenarios. The PIECES evaluation also produced average scores between 5.83 and 6.70, indicating that the system is effective and easy to use. These findings suggest that the system efficiently supports WebGIS-based agricultural land management.

6. SUGGESTION

The findings of this study provide several directions for future research. Further development of the proposed system is expected to enhance its functionality and enable broader implementation in real-world agricultural management, as follows.

1. Future development of the WebGIS-based agricultural land management system should incorporate a land analysis module capable of recommending optimal planting patterns, suitable crop rotation strategies, and appropriate agricultural commodities based on local geographic and climatic conditions. The integration of these capabilities is expected to optimize land utilization, reduce the risk of crop failure caused by unsuitable environmental conditions, and promote sustainable agricultural practices through data-driven decision-making.
2. The system should also be enhanced by incorporating a feature for calculating agricultural land productivity, enabling users to evaluate the success of crop production more effectively.
3. To improve the effectiveness of system implementation, training and educational programs should be provided for farmers. These initiatives are intended to strengthen farmers' ability to utilize WebGIS technology effectively, thereby maximizing the system's

benefits and improving agricultural land management practices.

4. This study was limited to Black Box testing. Therefore, future research is recommended to include White Box testing to perform a more comprehensive evaluation of the WebGIS-based agricultural land management system. White Box testing can verify the correctness of the system's internal logic and source code while identifying potential security vulnerabilities and hidden defects that may not be detected through Black Box testing. Consequently, this approach can improve the system's reliability, efficiency, and security.
5. Future studies are also encouraged to adopt alternative approaches for system performance evaluation, such as advanced statistical analysis methods. The application of these methods would enable a more comprehensive examination of performance indicators that have not yet achieved satisfactory results, leading to more robust and reliable conclusions regarding overall system performance.

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