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# Farm Soil Testing Techniques, Soil Health, and Potential Impact of Artificial Intelligence as Factors of Small-Scale Farming Soil Management

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**Abstract.** Small-scale farming is vital to global food production, especially in rural communities that may face constraints in resource availability and technology access. This study, conducted in the first quarter of the 2024 in the CALABARZON region (Cavite, Laguna, Batangas, Rizal, and Quezon Province) of the Philippines, investigates soil management practices among small-scale farmers engaged in subsistence and semi-commercial agriculture. It assesses farm soil testing techniques, current soil health, farmers' awareness of Artificial Intelligence (AI) applications and its potential impact on soil management. The study uses a stratified sampling approach to analyze challenges from 103 farmers, with the survey data examined through descriptive and inferential statistics. The findings reveal that small-scale farmers exhibit hesitancy towards soil testing and adopting technological advancements like AI, primarily due to limited knowledge and financial constraints, hindering their ability to address soil health issues and improve management practices, despite recognizing potential benefits. This study offers valuable insights and benefits for small-scale farmers aiming to implement technological applications for their farms and address soil health issues in their management practices.

## 1 Introduction

Three-quarters of rural residents, including small-scale farmers, rely on agriculture for their livelihoods, employing both traditional and modern methods to enhance productivity. Despite urbanization, over half of the population is projected to remain rural by 2050, highlighting the importance of rural growth. Agriculture, traditionally the backbone of rural economies, necessitates a new sustainable development model. This shift in focus has reshaped rural development policies, emphasizing the need for agricultural systems that enhance rural viability through adaptation and transformation. [1,2].

Most of the extremely poor, roughly 80%, reside in rural areas. Rural extreme poverty differs from urban poverty, with income heavily reliant on agriculture, exposing them to climatic shocks. Despite various rural development initiatives, neglect persists due to historical and planning deficiencies [3]. Sustainable rural development necessitates

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addressing rural issues and implementing appropriate policies to enhance socioeconomic opportunities. Agriculture remains the primary revenue source in rural areas, but diversification into non-agricultural activities is common among the rural extreme poor [4].

Small-scale farming is vital for rural livelihoods, emphasizing the importance of proper soil management techniques, including farm soil testing, to maintain soil fertility. This is crucial for sustainable agriculture particularly as rural areas face various shocks such as natural events and policy changes [5]. By implementing sustainable soil management practices, rural communities can enhance their resilience to these challenges. Moreover, the potential integration of artificial intelligence in agriculture could revolutionize farming practices, further improving productivity in rural areas.

In the twentieth century, precision farming revolutionized agriculture by enhancing productivity through technology-driven approaches. It involves measuring, observing, and analyzing individual fields and crop needs to precisely utilize inputs for increased yields and profitability [6]. This study explores the significance of Artificial Intelligence (AI) and the Internet of Things (IoT) in precision farming. Both AI and IoT offer crucial advancements, making modern agriculture, especially in rural communities, more accurate and economically viable [7].

Sustainable development in rural communities also hinges on addressing social, economic, and environmental pillars, with a focus on improving public utilities like sanitation and water management. These efforts are essential for laying the foundation for long-term, sustainable community development while safeguarding soil health and fertility [8,9].

The CALABARZON region, encompassing Cavite, Laguna, Batangas, Rizal, and Quezon, is a vital agricultural hub in the Philippines, with a substantial population of small-scale farmers facing significant challenges such as soil fertility decline due to unsustainable practices. The issue of soil fertility is particularly pronounced, with 82% of farmlands in the Philippines exhibiting moderate to low fertility levels due to unsustainable agricultural practices over the past decade [10,11]. This decline in soil health has significantly impacted crop yields and food availability, which are crucial for the local economy and food security.

The Department of Agriculture emphasizes the need for soil testing to address these challenges, providing farmers with valuable insights into nutrient composition and enabling effective nutrient management [11]. Conducting soil testing provides necessary data for implementing effective nutrient management strategies, optimizing soil health, and improving crop yields [12]. Unregulated cultivation practices in CALABARZON can deplete essential soil nutrients, undermining growth and productivity. By adopting sustainable practices and utilizing soil testing data, farmers in CALABARZON can optimize soil health, enhance crop yields, and contribute to the region's agricultural sustainability.

To combat the challenges posed by inadequate soil fertility, small-scale farmers need the requisite tools for soil analysis and knowledge for proficient soil management [13,14]. This study delves into the soil management practices of small-scale farmers in the CALABARZON region, with a focus on soil testing methods and their awareness of AI applications. By assessing existing soil conditions and understanding farmers' viewpoints, the aim is to identify obstacles and recommend strategies to improve both soil management techniques and agricultural productivity in this specific region.

Soil analysis is fundamental for assessing soil health, revealing pH levels and nutrient composition [15]. Soil fertility and productivity are crucial for driving increased crop production, highlighting the importance of applying the correct amount of fertilizer to boost yields. Fertilizer application is essential for conserving and replenishing soil nutrients, ensuring maximum yield and fruit quality [16]. Understanding current soil nutrient levels is essential for accurately assessing fertilizer requirements and enhancing agricultural productivity [17].

Soil management is essential for maximizing fertilizer usage efficiency, emphasizing the significance of methods, dosage, timing, and irrigation to optimize fertilizer economy [18]. Highlighting soil analysis and sampling techniques is crucial for addressing soil property variations, which, if overlooked, can lead to uneven fertilizer distribution and reduced crop yields. Implementing precision farming methods is suggested as a means to attain sustainable soil fertility and efficient management of plant nutrition, resulting in improved fertilizer utilization, and decreased nutrient wastage [19].

Tailored research is crucial to addressing their unique needs and developing effective soil management practices. Understanding the demographic and economic characteristics of these farmers is essential for integrating advanced technologies like artificial intelligence (AI) to enhance agricultural productivity and sustainability [20].

Across 16 different regions of the Philippines, the proportion of workers in the prime working age bracket closely aligns with the national average of 67 percent. While the distribution of workers in the youngest and oldest age groups varies significantly, CALABARZON stands out with one of the largest shares of older workers. Specifically, 18% of farmers in CALABARZON are aged 55 and up, second only to Central Visayas, where 19% of farmers fall into this age group [21]. Older farmers may be more resistant to adopting new technologies, emphasizing the need for targeted education and training programs [22]. Understanding the age distribution within the farming population can help tailor AI-driven soil management solutions to ensure they are accessible and beneficial to all age groups, ultimately enhancing agricultural productivity and sustainability in CALABARZON.

"A shift to new technology is a must," stated Stephanie Orlino of Smart Communications, emphasizing that digitalization is widening the gap in agriculture as farmers age and resist new technologies. Many mobile applications designed for agriculture have not been widely adopted due to a lack of training, underscoring the need for education. Cano highlighted that introducing farmers to digitalization requires more than just access to hardware and software; it necessitates digital literacy. The supply chain disruptions during the pandemic further demonstrated the need for new farm technologies. However, Cano stressed that technology should revolve around people, not the other way around [23]. This highlights the importance of developing user-friendly technological solutions and comprehensive training programs to ensure successful adoption among farmers.

This research explores a novel intersection between soil management practices, small-scale farming, and the potential application of Artificial Intelligence (AI). Conducted in the CALABARZON region of the Philippines, the study investigates the reluctance of small-scale farmers in this area to adopt soil testing and AI technologies, uncovering underlying factors such as limited knowledge and financial constraints. The objectives of this study are: first, to identify current farm soil testing techniques and challenges faced by small-scale farmers regarding soil testing; second, to assess basic soil health parameters; and third, to explore awareness involving AI in sustainable soil management. By addressing these objectives, the study contributes to the understanding of how technological advancements can be leveraged to enhance soil health and management practices in small-scale farming, ultimately fostering sustainability and resilience in rural communities.

## 2 Research method

### 2.1 Study Setting

CALABARZON, comprising Cavite, Laguna, Batangas, Rizal, and Quezon, is located in the southwestern part of Luzon, just south and east of the National Capital Region. The region covers a total land area of 1,641,303 ha, with 912,411 ha of arable land. Out of the potential

97,710 ha irrigable area, 59.77% has been developed [24]. Approximately 30% of CALABARZON's land has a 0-8% slope, making it suitable for agriculture, settlements, and infrastructure development [25].

Choosing CALABARZON as the study setting is ideal due to its diverse agricultural landscape and significant population of small-scale farmers [25,26]. The region also stands out for having a large share of older workers, which may include farmers who are more resistant to adopting new technologies. This underscores the importance of targeted education and training programs to encourage the adoption of sustainable soil management practices. Additionally, the varied topography and soil types in CALABARZON provide a comprehensive setting to test AI-driven soil management solutions, ensuring that findings apply to similar agricultural regions in the Philippines.

## 2.2 Research Design

The research design for this study employs a stratified sampling approach to comprehensively analyze challenges faced by small-scale farmers of the CALABARZON Region, including the potential impact of artificial intelligence (AI) as a factor in soil management [27]. The objective is to ensure a representative sample that encompasses diverse demographics and characteristics of the small-scale farming population. By employing this inclusive sampling strategy, the study aims to thoroughly examine soil testing techniques, soil health, and awareness levels regarding AI applications in soil management. The collected data will serve as a valuable resource for quantitatively assessing and identifying potential challenges within small-scale farming within the community [28]. Through detailed descriptive analyses and inferential statistical techniques, the study will reveal significant patterns, associations, or differences among various demographic strata, enhancing the validity and reliability of the findings [29]. These insights will inform targeted interventions and recommendations to effectively address the identified issues and support the specific needs of small-scale farmers particularly those located in the CALABARZON region, ultimately facilitating the integration of AI technologies to improve soil management practices and enhance agricultural sustainability.

## 2.3 Sampling Strategy

### *2.3.1 Sampling Plan*

The sampling plan for the study utilizes a stratified random sampling method to ensure representation throughout the rural regions of the Philippines in the CALABARZON region and to obtain a diversity of farming techniques. In stratified random sampling, the CALABARZON is divided into five distinct provinces, or strata: Cavite, Laguna, Batangas, Rizal, and Quezon Province. Each of these strata will function as an individual sample unit, providing a fair representation of agricultural practices across different regions.

### *2.3.2 Target Population*

The target population for this study consists of small-scale rural farmers in the CALABARZON region of the Philippines who are actively involved in agriculture. Individuals or small groups engaged in small-scale agricultural production, usually with small farms and resources, are classified as small-scale farmers. This includes individuals or small groups engaged in small-scale agricultural production, typically operating with limited farm sizes, and are managed primarily for subsistence or small-scale commercial purposes

[30]. This specific population is the primary focus of the study because the research objectives are centered on understanding their perspectives on soil testing techniques, soil management practices, and the integration of Artificial Intelligence (AI). The study highlights the critical role of agriculture in the country's economy and the need for detailed research to develop evidence-based strategies. By focusing on small-scale farmers in the CALABARZON region, the study aims to gather significant insights that could potentially improve soil health and agricultural productivity on a broader scale within the region.

#### *2.3.3 Sample Size*

Determining the appropriate sample size is a crucial element in research methodology, as it involves the careful selection of the number of observers or replicates to be included in a statistical sample [31]. The determination of the sample size for this study was guided by the formula below to ensure the validity and reliability of the study findings.

$$Sample\ Size = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + \left(\frac{z^2 \times p(1-p)}{e^2 N}\right)} \tag{1}$$

where ***N*** is the population size, ***e*** is the margin of error, ***p*** is the percentage value, and ***z*** is the confidence level.

The total population of small-scale rural farmers in the CALABARZON region of the Philippines is estimated to be approximately 200,000 [32]. This estimation is based on demographic data from the Philippine Statistics Authority and local government sources. With this population estimate, a sample size of 97 respondents was calculated with a ±10% margin of error and a 95% confidence level. However, for reliability and to account for any non-response or incomplete surveys, a total of 103 respondents were surveyed, by the study's practical considerations.

### 2.4 Data Gathering

This study employed a researcher-constructed questionnaire to collect data from small-scale farmers residing in rural communities in the CALABARZON region. The questionnaire aimed to investigate the perspectives of these farmers on soil testing techniques, soil health parameters, and the application of Artificial Intelligence (AI) in soil management practices. Throughout the survey, researchers actively engaged with 103 respondents of small-scale farmers, providing guidance, and addressing uncertainties. The collected data sought to generate insights into the unique challenges and opportunities faced by these small-scale farmers in adopting effective soil practices and integrating AI technology for sustainable soil management. The questionnaire underwent validation by a research adviser to ensure its reliability. Following data collection, a detailed analysis will inform the development of customized approaches to meet the specific needs of these small-scale farmers. The research findings, supported by statistical analyses, will provide a comprehensive understanding of current practices, and identify potential areas for improvement and innovation in soil management within the small-scale rural farming communities within the region.

### 2.5 Statistical Treatment

For the statistical analysis of the data gathered through a survey questionnaire, the following methods or tools were employed:

#### *2.5.1 Frequency Distribution*

Utilized to present a comprehensive overview of the distribution of responses across various categories within the dataset, offering a detailed exploration of how respondents' answers are distributed across different options or ranges. This method effectively elucidates the frequency and proportion of occurrences for each category or value, providing valuable insight into the distributional patterns and tendencies within the surveyed population [33].

#### *2.5.2 Measure of Percentage Distribution*

The measure of percentage distribution calculates the proportion of respondents falling into each category relative to the total number of respondents. It's calculated by dividing the count of respondents for a specific category by the total number of respondents, then multiplying by 100% to express the result as a percentage. This method provides a clear understanding of the distribution of responses across different categories, enabling easy comparison and analysis of the data [34].

$$Percentage = \frac{Count\ of\ respondents\ for\ the\ category}{Total\ number\ of\ respondents} \times 100\% \tag{2}$$

## 3 Results and discussion

This section presents and discusses the collected data, focusing on the current soil testing techniques and challenges, evaluation of soil health parameters, and farmers' perspectives on AI integration. These findings contribute to the understanding of soil management practices among small-scale farmers in CALABARZON and provide a foundation for potential improvements in sustainable soil management practices.

### 3.1 Current Farm Soil Testing Techniques and Challenges

This section presents an overview of the current soil testing techniques employed by small-scale farmers in CALABARZON and the challenges they face in implementing these methods effectively.

#### *3.1.1 Data Presentation*

The data from Figure 1 shows that the majority of farmers in the CALABARZON region (58.3%) have substantial experience in farming, with over ten years of experience.

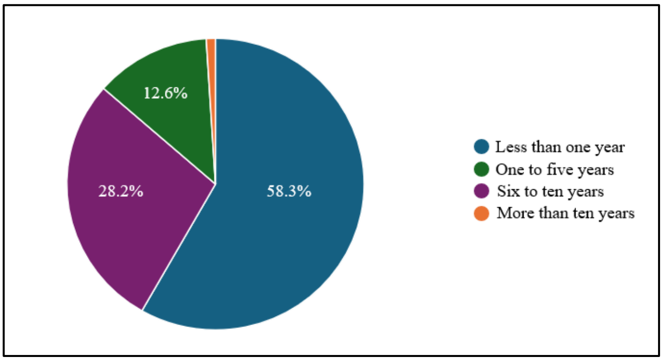


**Fig. 1.** Years of Farming Experience among Survey Respondents

As shown in Figure 2, these experienced farmers primarily rely on visual observation of the soil's physical appearance (92.2%) as their method of soil testing. However, it is concerning that a significant proportion of these farmers (22.3%) reported not conducting soil testing at all.

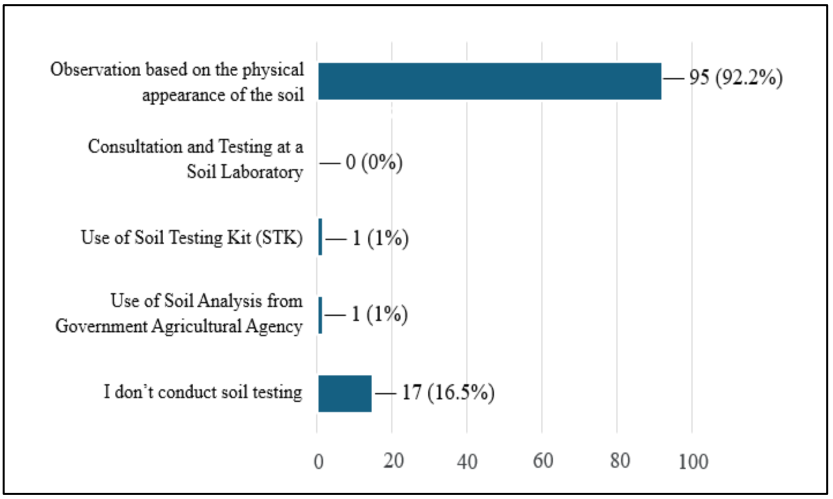


**Fig. 2.** Method of Soil Testing Used

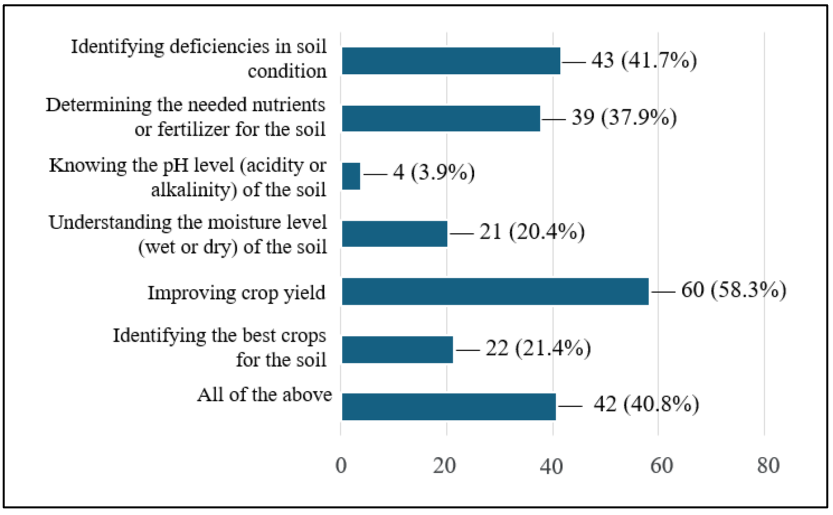


**Fig. 3.** Importance of Conducting Soil Testing

As illustrated in Figure 3, farmers in the region recognize the importance of conducting soil testing for improving crop yield (58.3%) and identifying soil deficiencies (41.7%). Additionally, 40.8% of these farmers perceive that besides improving crop yield and identifying soil deficiencies, soil testing is crucial for determining the needed nutrients for the crop (37.9%), identifying the best crops for the soil (21.4%), understanding the moisture level (20.4%), and knowing the pH level (3.9%). The relatively low emphasis on pH level suggests a need for increased awareness about its critical role in soil health and crop productivity.

### *3.1.2 Interpretation of Results*

The data reveals several key insights regarding current farm soil testing techniques and the challenges faced by CALABARZON small-scale farmers.

**Table 1.** Distribution of Farmers Conducting Soil Testing by Method: Observational, Soil Testing Kit (STK), and DA Soil Analysis Services

| Respondents | Observation based on soil's physical appearance | Laboratory | STK | DA Soil Analysis | Not Conducting Soil Test | Total |
|---|---|---|---|---|---|---|
| Respondents conducting Soil Tests | 95 | 0 | 1 | 1 | 0 | 97 |
| Respondents not conducting Soil Test | 0 | 0 | 0 | 0 | 17 | 17 |

Calculating the percentage distribution of farmers who conduct soil testing by (a) Relying on observational methods based on the physical appearance of the soil, (b) using a Soil testing kit (STK), and (c) DA Soil Analysis services.

$$a)\ Percentage = \frac{95}{97} \times 100\% = 97.94\%$$

$$b)\ Percentage = \frac{1}{97} \times 100\% = 1.03\%$$

$$c)\ Percentage = \frac{1}{97} \times 100\% = 1.03\% \quad (3)$$

As shown in Table 1, the distribution of farmers who conduct soil testing and those who do not are presented. Among the farmers who conduct soil testing in the region, 97.94% rely on observational methods based on the physical appearance of the soil. Meanwhile, 1.03% of these farmers use a soil testing kit (STK), and another 1.03% utilize soil analysis services provided by government agricultural agencies, making a total of 100%.

**Table 2.** Challenges Faced in Soil Testing

| | Lack of knowledge | Lack of funds | Limited access to govt. Services | Limited access to modern technology | Limited outreach programs | Distance to Laboratory | Total |
|---|---|---|---|---|---|---|---|
| Respondents | 83 | 67 | 40 | 50 | 59 | 32 | 331 |
| Percentage | 25.1% | 20.2% | 12.1% | 15.1% | 17.8% | 9.7% | 100% |

The survey data in Table 2 highlights key challenges in soil testing among small-scale farmers. Major issues include a lack of knowledge (25.1%), financial constraints (20.2%), and limited access to outreach programs (17.8%) and modern technology (15.1%). Additionally, restricted access to government services (12.1%) and the distance to testing facilities (9.7%) worsen difficulties in implementing effective soil management practices.

This breakdown offers valuable insights into the first objective: identifying current farm soil testing techniques and the challenges faced by small-scale farmers. It reveals a predominant reliance on observational methods and highlights significant obstacles, such as the lack of necessary knowledge and financial constraints, underscoring the widespread difficulties in these areas.

## 3.2 Evaluation of Basic Soil Health Parameters

Evaluating basic soil health parameters provides insights into soil fertility and condition. These findings form a foundation for targeted interventions and management strategies.

### *3.2.1 Climate Factors*

**Table 3.** Frequency of El Niño and La Niña Experiences

| Respondents | Once every ten years | Twice every ten years | Three times or more every ten years | Never experienced |
|---|---|---|---|---|
| Respondents experiencing El Niño | 32 | 41 | 27 | 3 |
| Respondents experiencing La Niña | 5 | 33 | 63 | 2 |

As shown in Table 3, farmers in the region have experienced both El Niño and La Niña events. El Niño-induced soil dryness or drought occurred most frequently twice every ten years (39.8%), followed by once every ten years (31.1%) and three or more times every ten years (26.2%). In contrast, La Niña events were reported as occurring three or more times every ten years (61.2%) and twice every ten years (32%). These frequencies emphasize the need for farmers to understand their soil's health and requirements to manage and mitigate the impacts of these climate-related events on productivity and crop yields.

### *3.2.2 Fertilizer Usage and Determination*

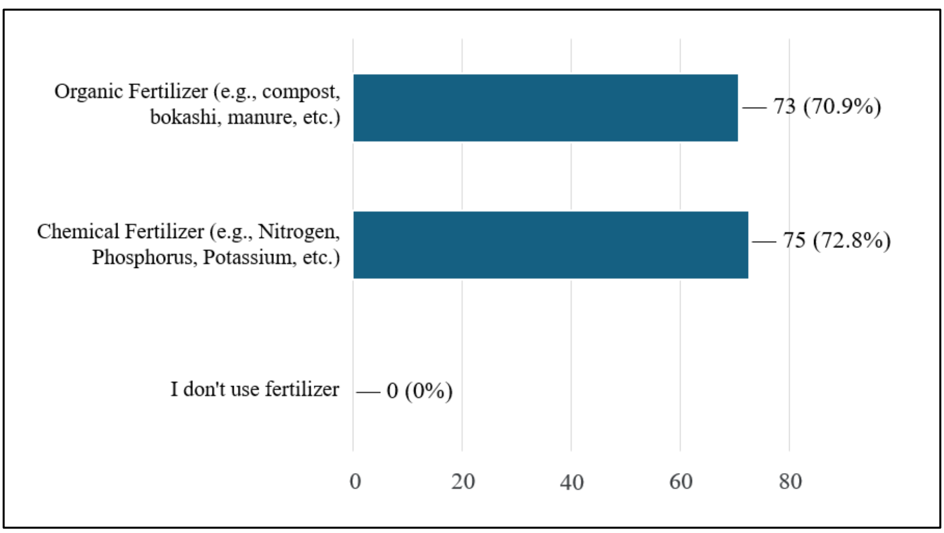


**Fig 4.** Type of fertilizer commonly used

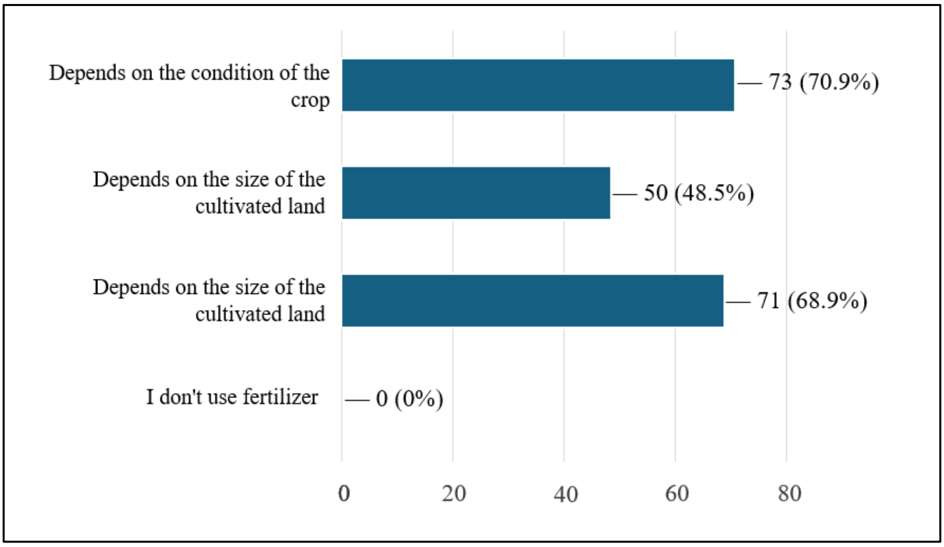


**Fig 5.** Determining the right amount of fertilizer

The majority of the farmers surveyed use both organic (70.9%) and chemical (72.8%) fertilizers on their farms, indicating a diverse approach to nutrient management, as shown in Figure 4. Additionally, Figure 5 illustrates the results indicate that farmers consider multiple factors in determining the right amount of fertilizer, including crop condition (70.9%), land size (48.5%), and crop type (68.9%), when determining the appropriate amount of fertilizer to apply.

The survey results indicate that there is no direct correlation between the types of fertilizer used (organic or chemical) and the factors considered when determining the right amount of fertilizer. This underscores the importance of adopting a more comprehensive and informed approach to fertilizer management, where multiple factors, such as crop condition, land size, and crop type, are thoroughly evaluated to optimize nutrient application and enhance agricultural productivity.

### *3.2.3 Water sources and irrigation management*

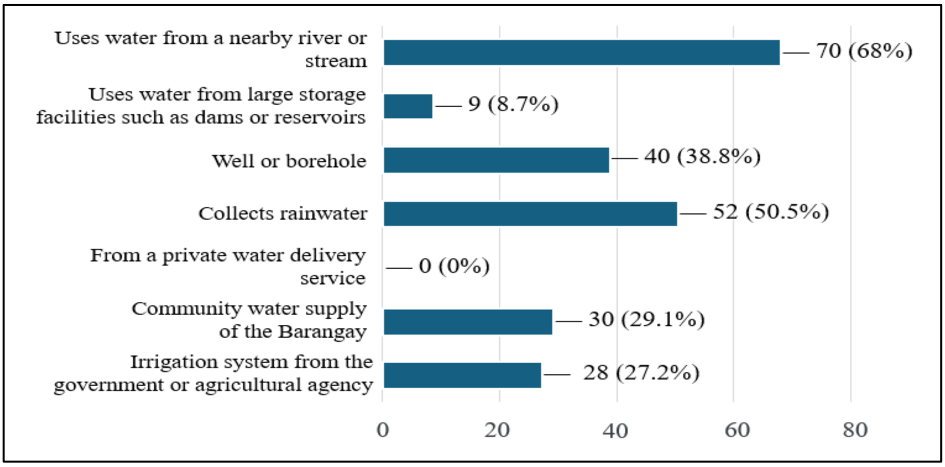


**Fig 6.** Source of water in the CALABARZON region for farming

The data presented in Figure 6 shows that farmers in the CALABARZON region primarily rely on natural water sources such as rivers and rainwater (68% and 50.5%, respectively), indicating potential vulnerability to dry periods. Additionally, these farmers use a variety of water sources, including nearby rivers or streams, large storage facilities, wells or boreholes, rainwater collection, community water supply, and government or agricultural agency irrigation systems. Centralized water systems are less commonly utilized, with only 8.7% relying on reservoirs and 29.1% on community supply, reflecting limitations in infrastructure.

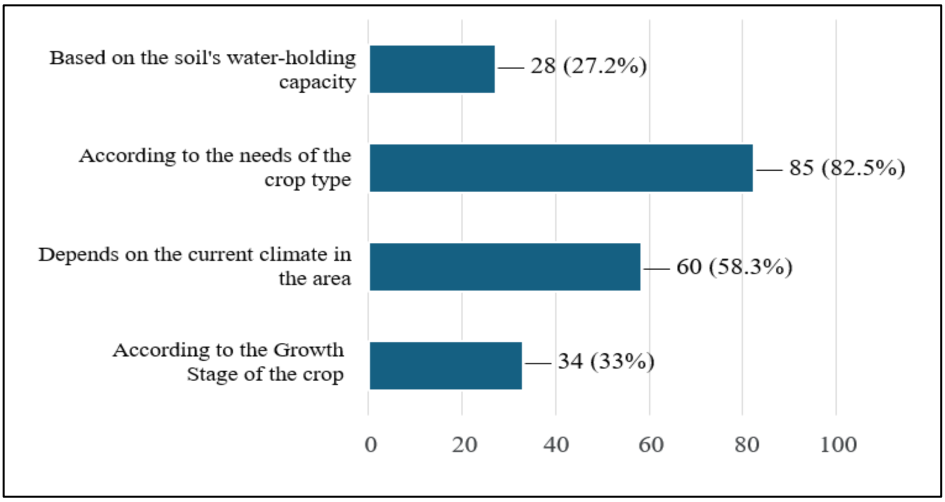


**Fig 7.** Determining the right amount of irrigation for the farm

Figure 7 presents that irrigation decisions are primarily based on experience, with 82.5% of farmers relying on crop needs and 58.3% considering the current climate. In contrast, scientific methods such as soil analysis are used by only 27.2% of farmers, which may result in inefficient water use. Determining the appropriate amount of irrigation involves considering factors such as the soil's water-holding capacity, crop type, current climate, and the crop's growth stage.

The assessment of factors like climate, fertilizer usage, and water sources addresses the second objective: assessing basic soil health parameters. This sheds light on farmers' practices and perceptions of soil health, identifying areas for improvement. Understanding these practices allows for the development of more effective strategies to enhance soil health and crop yields.

### 3.3 Farmers' Perspectives on AI Integration in Soil Management

This section explores the attitudes and opinions of small-scale farmers toward the integration of Artificial Intelligence (AI) in soil management. The findings presented here provide insights into the small-scale farmers' perceptions of AI's ability to optimize soil management, enhance decision-making, and improve agricultural productivity in the region.

### *3.3.1 Limited awareness of government soil testing programs*

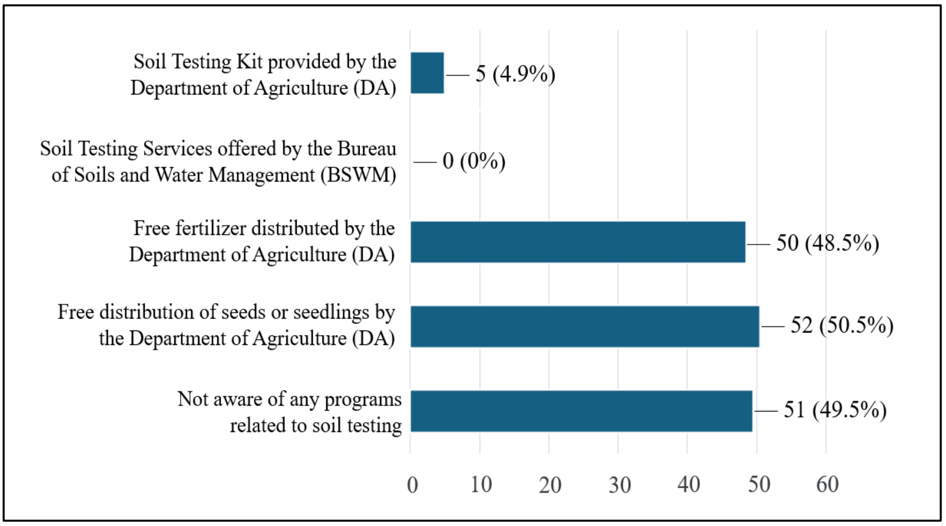


**Fig 8.** Government or Local Programs Supporting Soil Testing and Agricultural Activities Experienced by Farmers

Figure 8 shows that 49.5% of farmers receive free seeds from the Department of Agriculture, and 48.5% receive free fertilizer. However, 49.5% are unaware of any soil testing programs offered by government agencies, and awareness of soil testing kits provided by the Department of Agriculture is low, at just 4.9%. Additionally, there is no awareness of soil testing services from the Bureau of Soils and Water Management. This significant knowledge gap underscores the need for a more accessible and effective approach to soil management support.

### *3.3.2 Low adoption of AI in soil management*

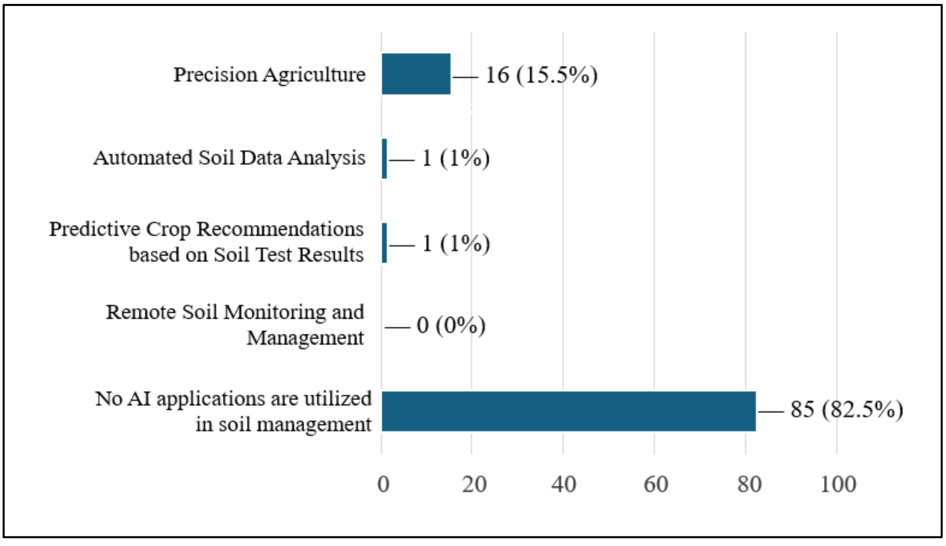


**Fig 9.** Artificial Intelligence (AI) Applications Farmers Used in Soil Management

Figure 9 shows that while 82.5% of farmers do not use AI-powered tools for soil management, a small percentage (15.5%) are early adopters of precision agriculture tools. This low adoption rate highlights significant barriers, including limited awareness, high costs, and lack of training. Addressing these obstacles is crucial for increasing the use of AI technologies in soil management.

### *3.3.3 Significant knowledge and financial barriers*

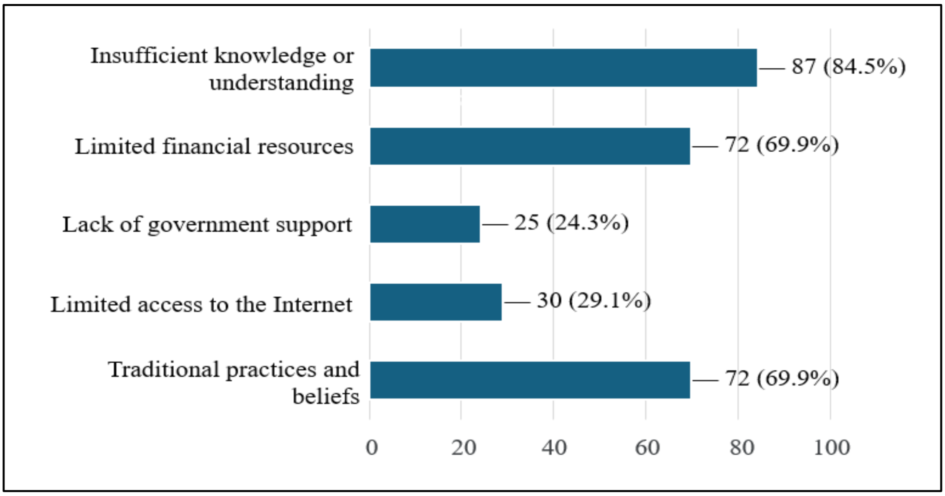


**Fig. 10.** Factors and Challenges Hindering Adoption of AI Technology in Soil Management

The most prominent obstacles to technology adoption are insufficient knowledge or understanding (84.5%) and limited financial resources (69.9%), as shown in Figure 10. These findings emphasize the need for educational programs to bridge the knowledge gap and the development of low-cost, user-friendly AI tools to address affordability concerns.

### *3.3.4 High demand for specific AI features*

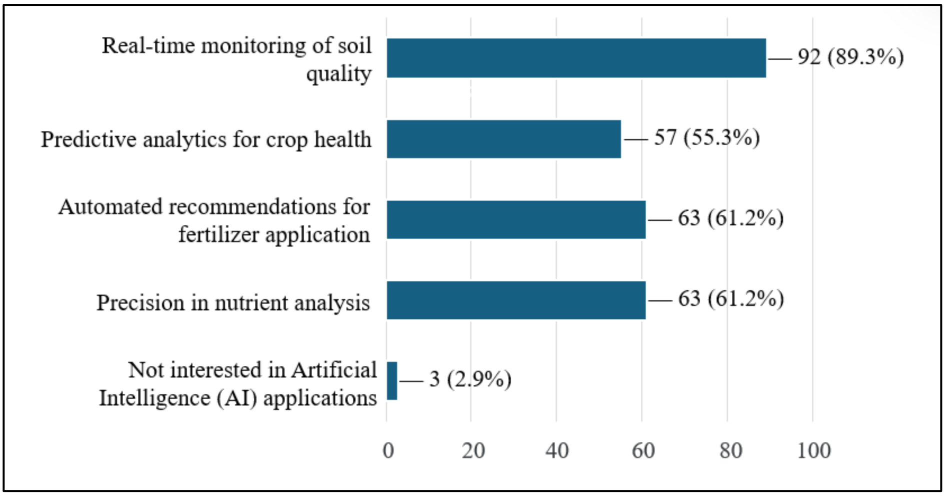


**Fig. 11.** Preferred Features of AI-Integrated Soil Testing Tools

As illustrated in Figure 11, the high demand for features like real-time monitoring (89.3%), predictive analytics (55.3%), automated fertilizer recommendations (61.2%), and precision in nutrient analysis (61.2%) highlights farmers' interest in data-driven decision support for soil management. Meanwhile, only 2.9% of farmers are not interested in AI applications, indicating a significant opportunity to integrate technology into soil management practices.

The analysis of government or local programs supporting soil testing and agricultural activities, AI applications in soil management, challenges hindering AI adoption, and preferred features of AI-integrated soil testing tools addresses the third objective which is to explore farmers' awareness of AI in sustainable soil management. This analysis reveals key insights into farmers' awareness of AI technologies, showcasing their potential to enhance soil management and improve agricultural efficiency.

## 4 Conclusion and recommendations

The analysis of gathered data concerning small-scale farmers' soil management practices in the CALABARZON region reveals several key findings aligned with the study's objectives: Firstly, the study addresses the first objective of identifying current farm soil testing techniques and challenges faced by small-scale farmers. It reveals that farmers predominantly rely on visual observation (92.2%) rather than formal soil testing methods, with 22.3% not conducting any tests. This indicates a significant gap in advanced soil testing usage, primarily due to a lack of awareness and financial constraints, compounded by insufficient knowledge (25.1%), limited resources (20.2%), and restricted access to services and technology. Secondly, the assessment of basic soil health parameters, aligning with the second objective, shows that farmers mainly use natural water sources (68% rivers, 50.5% rainwater) and base their irrigation decisions on experience (82.5%) rather than scientific methods (27.2%). Environmental stresses like drought and La Niña exacerbate challenges related to water retention and fertilizer application, highlighting the need for improved management strategies. Thirdly, the study addresses the third objective of exploring awareness and adoption of AI tools in sustainable soil management, revealing that 82.5% of farmers do not use AI despite a high interest in features such as real-time monitoring (89.3%) and predictive analytics (55.3%). This gap between interest and adoption is due to limited knowledge, high costs, and adherence to traditional practices.

Based on the findings, several recommendations can be made to improve soil management practices among small-scale farmers. First, implementing targeted educational programs to increase awareness and knowledge about standard soil testing methods and their benefits is crucial. Improving access to affordable soil testing services and equipment, possibly through subsidies or partnerships with agricultural organizations and local governments, can also help. Providing financial assistance or micro-loans to small-scale farmers to invest in advanced soil testing tools and AI-integrated technologies is essential.

Training sessions on proper use of organic and chemical fertilizers, focusing on accurate application based on soil and crop conditions, can improve fertilizer practices. Developing precise irrigation strategies tailored to crop types and climate conditions will enhance water efficiency and mitigate environmental stress. Promoting AI adoption in soil management through demonstrations, success stories, and hands-on training can showcase its benefits. Community support networks for sharing experiences and integrating AI will further aid adoption. Incorporating local knowledge, enhancing data collection, collaborating with research institutions, and promoting sustainable practices will strengthen soil management, boost crop yields, and support sustainable farming among small-scale farmers.

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