

Research Article

Comparative Analysis of Digital Agriculturist Support Tools: Evaluating Efficiency in Reducing Costs

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ABSTRACT

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Digital agriculture leverages advanced technologies to optimize farming, enhance crop yields, and promote sustainability. Precision farming improves resource management, with soil pH, electrical conductivity (EC), temperature, and moisture being key factors influencing soil chemistry, nutrient availability, and plant health. However, inconsistencies in measurement tools can lead to suboptimal decisions, affecting productivity and sustainability. This study compares the accuracy, efficiency, and cost-effectiveness of two portable soil analysis tools: the YY-1033 Soil pH Meter and the A-2. The YY-1033 offers a pH range of 0.0-14.0 (± 0.1 accuracy) and an EC range of 0.00-20.00 mS/cm (± 0.1 accuracy), using a puncture electrode and bluetooth connectivity for real-time data logging. The A-2, with a pH range of 3.5-9.0 (± 0.5 accuracy) and an EC range of 1.5-15.0 mS/cm (± 0.5 accuracy), employs an aluminum electrode and lacks digital connectivity. A randomized complete block design (RCBD) was used and data were analyzed through Analysis of Variance (ANOVA) and Least Significant Difference (LSD) tests at a 95% confidence level. Results showed significant differences in pH and EC measurements, with the YY-1033 demonstrating higher precision, particularly in extreme soil conditions. However, both devices provided reliable temperature and moisture readings. The coefficient of determination (R^2) values for pH (0.930) and EC (0.911) confirmed accuracy differences. Despite the benefits, research in this area remains limited, especially in Thailand. Adopting efficient and cost-effective soil measurement tools can enhance precision farming, improve yields, and support sustainability. Expanding research in this field will ensure that farmers have access to reliable technologies. Integrating GIS and AI-based soil monitoring can further optimize agricultural decision-making, while future studies should assess the long-term cost-effectiveness and reliability of these tools.

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1. Introduction

Precision agriculture technologies enhance farm management and optimize resource use through the integration of drones, automated irrigation systems, and sensor networks for soil nutrient measurement. Additionally, artificial intelligence (AI) plays a crucial role in farm management, particularly in soil management. Agronomy, the scientific study of soil structure, chemical composition, and biological properties, is fundamental to agricultural success. By analyzing key soil properties such as pH, temperature, moisture, and nutrient content, farmers can improve soil management practices to match specific crop requirements, ultimately enhancing both yield quality and quantity (Slessarev *et al.*, 2016).

Soil pH significantly influences chemical and biological reactions, including the dissolution and precipitation of minerals. It serves as a key determinant of nutrient availability for plants (Tecon and Or, 2017). The digital transformation of agriculture is becoming increasingly important worldwide due to the rising demand for food driven by population growth. Traditional breeding methods alone cannot keep pace with this demand. However, precision agriculture technologies help increase yields while minimizing environmental impact. In addition to climate-adaptive systems, effective land-use management is essential. By leveraging digital data, farmers can monitor, analyze, and assess soil quality before planting seasons, enabling proactive soil health improvements tailored to specific crops. Standard soil pH determination involves dissolving soil samples in distilled water or a 0.01 molar calcium chloride solution. Although different soil-to-liquid ratios exist, suspension-based pH measurement is widely accepted due to its simplicity and effectiveness. This method provides an accurate representation of the soil's acid-base balance and its influence on nutrient solubility. For most crops, an optimal pH range of 6.0-7.5 is recommended (Everhart, 1994). Managing soil pH is crucial for maximizing nutrient availability, supporting high-yield production, and maintaining soil health. Proper pH adjustments not only promote plant growth but also enhance soil fertility, reducing unnecessary costs associated with soil amendments. Recent advancements in agricultural technology have improved

field-based pH measurement accuracy, making it comparable to laboratory instruments. Traditionally, soil samples were collected and analyzed in laboratories or tested with litmus paper. However, modern portable meters can now measure pH directly in the field under appropriate moisture conditions. These meters operate using potentiometry, which measures the electrical potential difference between a reference electrode and a solution containing H⁺ ions. Portable pH meters, calibrated with standard buffer solutions (pH 4.0, 7.0, and 10.0), offer high precision (± 0.001 pH units) and mobility, making them ideal for on-site agricultural applications. However, they are relatively expensive, and inaccurate buffer solutions can lead to erroneous readings (Butraphon, 2019). Soil pH variability significantly influences nutrient uptake in plants, requiring site-specific pH adjustments tailored to different crops and growth stages. Maintaining an optimal pH range not only enhances plant health and productivity but also fosters beneficial microbial activity while mitigating pest and disease outbreaks.

Currently, portable soil meters are widely used to measure physical and chemical soil properties, including pH, nitrogen, phosphorus, and potassium, offering rapid and convenient alternatives to laboratory testing. These devices vary significantly in price depending on features, accuracy, and certification. The advancement of sensor technology has led to the development of pH measurement devices that provide real-time, continuous data, thereby enhancing soil management efficiency. However, permanently installed sensors are prone to interference from environmental factors (Yuzhakov *et al.*, 2021). Soil acidity and alkalinity serve as indicators of overall soil health. pH levels regulate numerous chemical and biological reactions, impacting nutrient availability and biogeochemical cycles (Tecon and Or, 2017). Studies have shown that microbial diversity and activity increase with higher pH levels and decrease with lower pH levels (Fierer and Jackson, 2006; Rousk *et al.*, 2010; Cao *et al.*, 2016). Various environmental factors, including erosion, mineral composition, water balance, and shifts in mineral concentrations, also influence soil pH (Slessarev *et al.*, 2016).

However, innovative electrochemical sensor has continuous development for instance This research introduced an innovative electrochemical sensor designed for direct, real-time, continuous monitoring of soil pH without the need for soil pre-treatment. The sensor features a composite matrix coating of alizarin and Nafion applied to the working electrode. The study evaluated the sensor's performance using electrochemical impedance spectroscopy (EIS) and square wave voltammetry (SWV) across various soil textures, including clay, sandy loam, and loamy clay. Results indicated that SWV provided pH-dependent responses consistent across different soil types, with a sensitivity range from -50 mV/pH to -66 mV/pH and a high correlation coefficient ($R^2 > 0.97$) within a pH range of 3 to 9. Validation tests demonstrated an error rate of less than 10% between the sensor's measurements and reference pH values across multiple soil textures. A seven-day in situ study further confirmed the sensor's capability to monitor soil pH dynamically, maintaining an error rate below 10%. This advancement offers a practical solution for continuous soil pH monitoring, which is crucial for sustainable agriculture and soil health management (Eldeeb *et al.*, 2023). In addition, Maleki *et al.* (2010) study to design and develop a portable soil electrical conductivity (EC) detector to address agricultural challenges in Iran, such as soil salinity and arid climate conditions. The researchers developed a four-electrode EC detector comprising disk electrodes, a power source, a function generator, and a data acquisition unit. The device injects a constant electrical current into the soil through two electrodes, while the voltage drop is detected between the other two electrodes. This setup allows for rapid and reliable field-scale measurements of soil EC, which are essential for assessing soil salinity, cation exchange capacity, soil water content, and temperature. The portable nature of the detector facilitates on-the-go soil EC measurements, providing valuable data to improve agricultural yield and sustainability in regions with challenging soil conditions.

Soil properties vary primarily based on structure and composition rather than weather conditions. Additionally, the market for agricultural measurement

devices is highly competitive, resulting in more affordable and accessible solutions for farmers. However, excessively low-cost equipment may be ineffective in practice, leading to inaccurate measurements that negatively impact agricultural management. In the worst-case scenario, such inaccuracies could reduce crop yields or even cause plant mortality. Conversely, high-quality modern soil measurement equipment is often prohibitively expensive, making it difficult for farmers to justify the investment. Assessing the effectiveness of low-cost yet high-quality equipment as a viable alternative to expensive devices is crucial for informed decision-making. The transition from traditional to precision agriculture necessitates reliable soil monitoring tools. Furthermore, digital agriculture education plays a vital role in equipping farmers with knowledge about advanced tools and technologies. Comparing the efficiency and accuracy of various soil measurement devices is essential for selecting the most suitable solutions for farm management. Cost-effective and accessible technologies help farmers minimize reliance on expensive laboratory testing while ensuring precise soil monitoring. This study explores recent advancements in real-time soil monitoring and their implications for precision agriculture. By introducing innovative sensor-based measurement techniques, this research contributes to the evolution of smart farming, providing practical insights into cost-effective and efficient soil management strategies.

The purpose of this research is to develop and evaluate the effectiveness of advanced soil measurement technologies, particularly portable and sensor-based devices, in improving precision agriculture. This study aims to investigate the latest advancements in soil measurement technologies, including real-time monitoring using sensor-based systems; compare the accuracy and efficiency of portable meters with traditional laboratory-based testing methods; assess the impact of precise soil management on crop yield and overall soil health; and identify the cost-effectiveness and feasibility of implementing modern measurement tools for small- and large-scale farming operations. By addressing these objectives, this research contributes to the advancement of precision agriculture,

ensuring that farmers can adopt efficient, cost-effective, and scientifically validated soil management techniques.

2. Materials and Methods

The experimental planning process for comparative studies was conducted using digital agriculturist support tools by selecting the area and creating a map of the points where soil chemical values were measured, then statistically analyzing the data and creating a distribution map of soil chemical values. (Figure 1), including the YY-1033 soil pH meter (Figure 2a) and the A-2 measurement device (Figure 2b). In agricultural applications, puncture electrodes are specialized sensors designed to penetrate soil or plant tissues to facilitate direct measurement of various parameters. These electrodes ensure intimate contact with the sample, enhancing measurement accuracy. The YY-1033 soil pH meter is equipped with a puncture electrode, specifically a conical-tip pH electrode. This electrode design allows for seamless penetration into the soil, enabling direct pH measurement without the need for sample extraction. The device measures acid-

alkaline values in the range of 0.0–14.0, with a resolution of 0.1 and an accuracy of ± 0.1 . Additionally, it measures electrical conductivity (EC) values ranging from 0.00-20.00 mS/cm, with an accuracy of ± 0.1 . A notable feature of this device is its capability to connect via Bluetooth to mobile applications, enabling the recording of measurement data as electronic records. An example of a similar soil pH electrode is the HI12943, designed for direct soil measurement. It features a triple ceramic junction and a conical pH sensing tip made with low-temperature glass, making it suitable for various soil types (Seifi and Alimardani, 2010). In contrast, the A-2 measurement device employs an aluminum electrode, which is widely used in various electrochemical agricultural applications due to its high conductivity and effectiveness in processes such as electrocoagulation. Aluminum electrodes play a crucial role in wastewater treatment, soil nutrient sensing, and other agricultural practices. The A-2 device measures acid-alkaline values within a range of 3.5–9.0, with a resolution of 0.5 and an accuracy of ± 0.5 . Its EC measurement capability spans 0.00-20.00 mS/cm, with an accuracy of ± 0.1 .

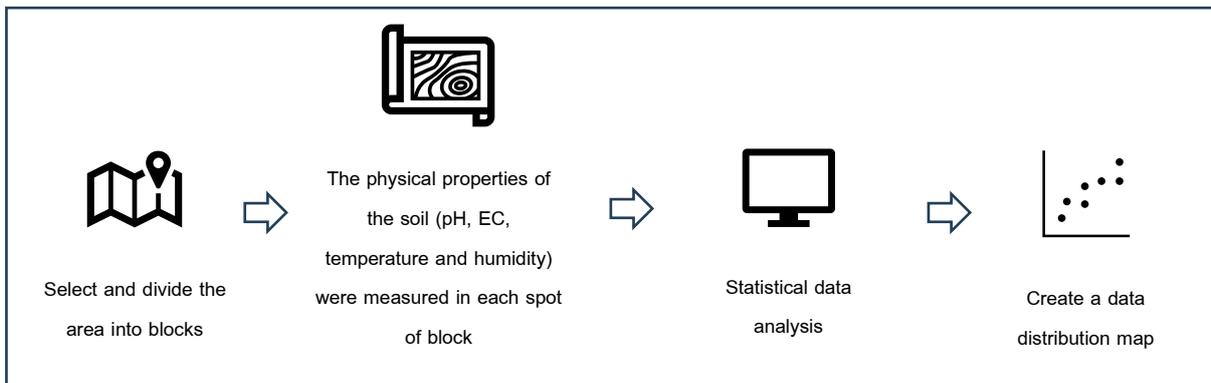


Figure 1 Experimental process diagram



Figure 2 Measuring tool type 1 YY-1033 Soil pH Meter (a) Measuring tool type 2 A-2 (b)

To conduct the study, experimental area was systematically surveyed using Geographic Information System (GIS) technology to ensure accurate spatial analysis. Measurement points were precisely defined, and the collected data were utilized to generate spatial distribution maps representing soil pH, electrical conductivity (EC), temperature, and moisture levels. The study was conducted in three designated areas within the premises of Rajamangala University of Technology Tawan-ok, Chanthaburi Campus (Figure 3). The spatial distribution of soil quality parameters was analyzed to compare variations in measurement outputs between different soil quality assessment instruments.



Figure 3 The area for experiment area

A randomized complete block design (RCBD) was implemented to enhance the reliability and accuracy of the experiment. The experimental area was divided into three distinct blocks: Block 1 (blue), Block 2 (green), and Block 3 (red). Each block comprises a systematically randomized selection of measurement points, ensuring comprehensive coverage of 100 points per block. To distinguish between different soil chemical test points, specific symbols were assigned: crosses (X) for Block 1, triangles (▲) for Block 2, and circles (●) for Block 3. This classification facilitated clear identification and comparative analysis of soil chemical properties across the designated experimental blocks. The collected data were analyzed using descriptive statistics and one-way analysis of variance (ANOVA), followed by the Least Significant Difference (LSD) test at a 95% confidence level. The ANOVA was used to identify statistically significant differences in measurement accuracy and reliability between the two measurement devices. Furthermore, the analysis assessed the impact of these measurement devices on

agricultural decision-making and their perceived benefits among users. Additionally, ANOVA was utilized to evaluate the physical properties of soil (pH, EC, temperature, and moisture) concerning the use of different measurement technologies and their influence on farmers' decision-making processes. The data distribution was observed to be symmetrical, indicating the absence of skewness and reducing the potential for bias. The study considered two primary factors: Factor 1 (YY-1033 measurement device) and Factor 2 (A-2 measurement device). Data collection involved measuring pH, EC, temperature, and moisture levels using both devices, recording values, and subsequently analyzing them using ANOVA within the RCBD framework. The LSD test was applied for mean comparisons to determine significant differences. Finally, the measurement data were utilized to generate spatial distribution maps to facilitate comparative analysis. These maps will be used to assess soil suitability for cultivation and identify areas requiring soil quality improvement for future agricultural development.

3. Results and Discussion

The application of digital technology in soil measurement plays a crucial role in modern agricultural decision-making. The selection of appropriate measurement tools, which range from high-cost to more affordable options, has a significant impact on agricultural efficiency. This study evaluates the effectiveness of different soil measurement devices and their influence on key soil parameters, including pH, electrical conductivity (EC), temperature, and humidity. Additionally, the study examines the relationship between soil physical properties and spatial distribution using Geographic Information Systems (GIS).

The results of the Analysis of Variance (ANOVA) reveal significant differences in the measurements obtained from two distinct soil testing devices. Type 1 measuring tool, YY-1033 Soil pH Meter, recorded an average pH of 4.4, with a minimum of 3.9 and a maximum of 6.5. In contrast, the Type 2 measuring tool, A-2, recorded an average pH of 6.7, with a range from 6.5 to 7.0. These differences suggest that the tools measure pH differently, possibly due to

differences in calibration or sensitivity. (Figure 7) For EC, the Type 1 device recorded an average of 10.70 mS/cm, with a range of 10.44 to 11.01 mS/cm, whereas the Type 2 device measured an average EC of 7.54 mS/cm, ranging from 7.0 to 7.5 mS/cm. These results indicate a significant variation in EC readings between the two devices. (Figure 8) Regarding temperature and humidity measurements, both devices provided comparable readings. The average temperature

recorded by both devices was 27.9°C, with values ranging from 27.0 to 29.0°C. (Figure 9) Similarly, the humidity measurements showed minimal variation, with the Type 1 device recording an average humidity of 32.4%, ranging from 30.0% to 34.9%, while the Type 2 device measured a similar average of 32.4%, ranging from 30.0% to 35.0%. (Figure 10) Statistical analysis revealed no significant differences in temperature and humidity readings between the two tools. (Table 1)

Table 1 The average of measuring tools of physical properties of soil per block under different treatments

Parameter	Measuring Tool	ANOVA F-statistic	Block 1	Block 2	Block 3
pH	Type 1 measuring tool	7460.64	4.48±0.34*	4.43±0.29*	4.44±0.37*
	Type 2 measuring tool		6.71±0.24*	6.77±0.25*	6.78±0.25*
EC (mS/cm)	Type 1 measuring tool	178.51	10.43±0.44*	10.99±0.46*	10.70±0.45*
	Type 2 measuring tool		7.21±0.45*	7.79±0.51*	7.63±0.45*
Temperature (°C)	Type 1 measuring tool	0.229	27.95±0.57	28.02±0.60	27.99±0.63
	Type 2 measuring tool		28.08±0.87	27.96±0.80	27.80±0.80
Humidity (%)	Type 1 measuring tool	0.021	32.42±1.47	32.50±1.42	32.45±1.57
	Type 2 measuring tool		32.34±1.70	32.50±1.76	32.56±1.63

Mean value of measurements ± standard deviation

* different in a column are significantly different level ($p < 0.05$) according to randomized complete block design each block

Table 2 Least Significant Difference (LSD)

Parameter	LSD Value
pH	2.611*
EC (mS/cm)	3.626*
Temperature (°C)	0.195*
Humidity (%)	0.158*

* different in a column are significantly different level ($p < 0.05$)

Using a randomized complete block design (RCBD), it was found that the pH and EC measurements exhibited statistically significant differences between devices, whereas temperature and humidity did not show significant variation. The coefficient of determination (R^2) values for pH and EC were 0.930 and 0.911, respectively, indicating a strong correlation between device type and measurement accuracy. The Least Significant Difference (LSD) test further confirmed that pH and EC measurements differed significantly between devices, whereas temperature and humidity readings remained statistically similar. (Table 2)

Soil pH measurement tools vary in form and cost, with metal rod-based testers being popular due to their affordability. However, when compared to glass electrode pH meters, the latter exhibit greater accuracy due to their calibration with standard solutions in laboratory settings (Merl *et al.*, 2022). The Type 1 device, which utilizes glass electrode technology, demonstrated superior accuracy in pH measurement compared to Type 2. However, it requires careful handling, as impacts with soil particles can damage the fragile glass electrode (Steinegger *et al.*, 2020). The ability of the Type 1 device to record data via a mobile application enhances its suitability for precision agriculture as illustrated in Figure 4. The influence of soil pH on nutrient availability and plant health is well-documented (Staudinger *et al.*, 2019). The findings highlight the importance of selecting accurate measurement tools, as incorrect pH readings could lead to improper soil amendments, affecting crop yields. Meanwhile, temperature and humidity monitoring are essential for soil moisture management, but given the statistical similarity between devices, farmers may opt for more affordable tools for these parameters without compromising accuracy. Incorporating GIS and remote sensing enhances soil analysis, allowing farmers to visualize spatial variability and make data-driven decisions for soil management. The integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies has the potential to further refine precision agriculture, optimizing input use and improving sustainability. The adoption of automated irrigation systems based on real-time soil moisture data can enhance water use efficiency, minimizing resource

waste and increasing productivity. When comparing the pH and electrical conductivity (EC) values measured at various points within the block containing the tested plants using the Type 1 device (Figure 5), it was found that areas with pH and EC values suitable for the tested plant species exhibited superior growth. This was evident through characteristics such as dark green leaves, larger leaf size, overall plant vigor, and higher yields (Figure 6). However, for the Type 2 device, the measured values did not show significant differences, yet variations in plant growth were still observed. Therefore, selecting measuring equipment that is both cost-effective and efficient is crucial to prevent potential losses. Additionally, developing portable soil chemical measurement tools that provide accurate geolocation data at an affordable price will facilitate precise plot management and targeted interventions for problematic plants. This will ultimately help save time, reduce costs, and increase farmers' profits, contributing to the long-term sustainability of the agricultural sector.

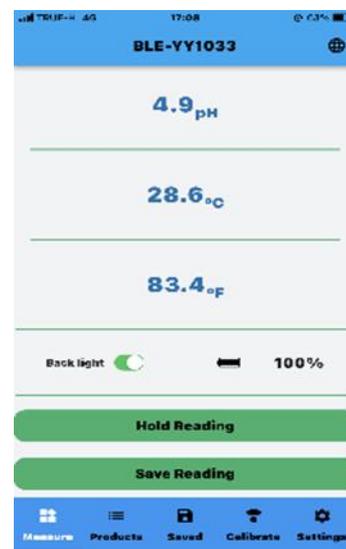


Figure 4 Measuring instrument application type 1
YY-1033 Soil pH Meter

While high-end soil measurement tools offer superior accuracy, their cost can be prohibitive for small-scale farmers. This study underscores the importance of cost-effective alternatives that balance affordability and accuracy. Devices priced low-cost devices (<200 baht) may lack the precision required for

effective soil management, while those costing between 500 and 1,000 baht may offer better reliability.



Figure 5 Area of Type 1 YY-1033 Soil pH Meter with pH and EC values suitable for plant growth



Figure 6 Differences in plant growth in areas tested for soil chemical properties

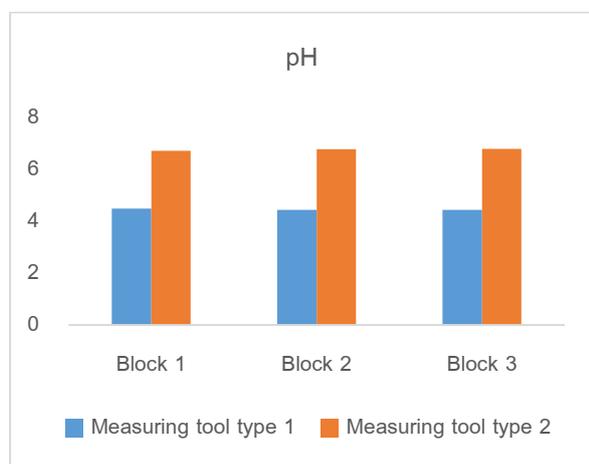


Figure 7 The average of pH under different treatments and area

Considering cost-effectiveness, this study emphasizes the need for further research on soil measurement tools across different price ranges. Farmers require affordable yet reliable devices to make informed decisions. The use of low-cost, uncertified foreign devices poses a risk of inaccurate data collection, leading to potential mismanagement of soil

conditions. In light of climate change and the need for rapid soil assessment, investment in cost-effective, high-accuracy tools is crucial for modern agricultural sustainability. The findings align with the United Nations Sustainable Development Goals (SDGs), particularly in climate resilience, food security, and resource-efficient farming practices. Ultimately, the balance between cost and accuracy should guide the selection of soil measurement tools. While high-end devices provide superior accuracy, economical alternatives that maintain reasonable precision can offer significant benefits for small-scale farmers. Future studies should explore the long-term cost-effectiveness of these tools and assess the feasibility of integrating digital soil mapping technologies to support sustainable agriculture.

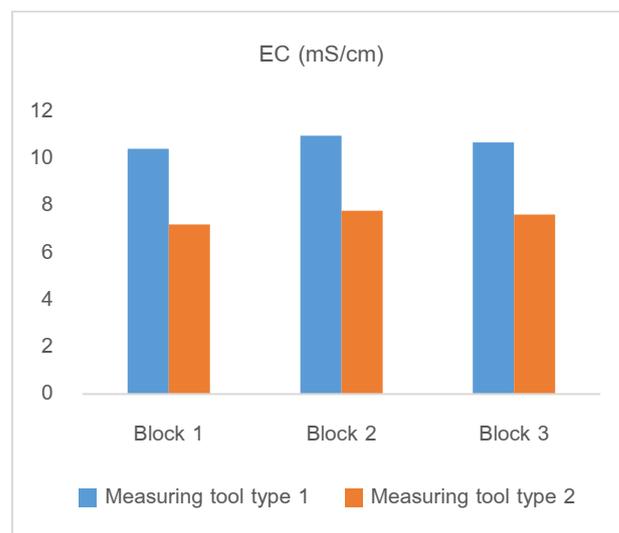


Figure 8 The average of EC under different treatments and area

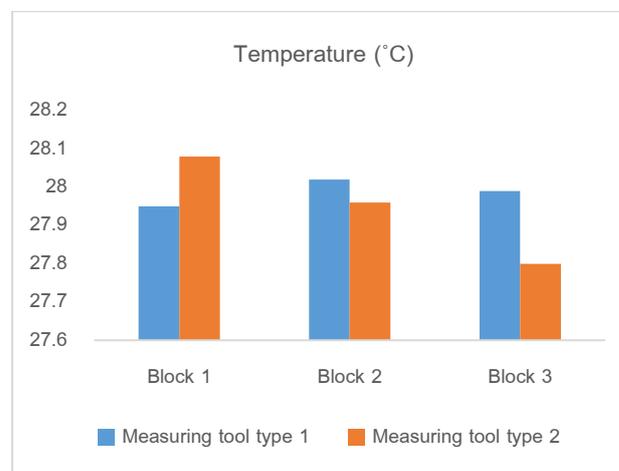


Figure 9 The average of temperature under different treatments and area

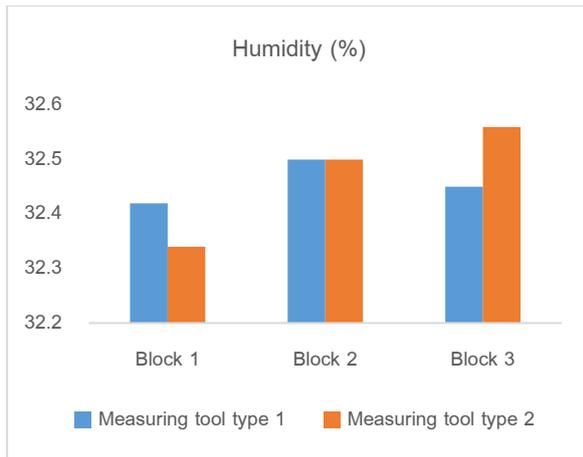


Figure 10 The average of humidity under different treatments and area

4. Conclusion

Selecting appropriate soil measurement tools is a critical factor in achieving sustainable agricultural development. The study findings indicate that while both tested devices provide reliable temperature and humidity readings, there are notable differences in pH and electrical conductivity (EC) measurements. The Type 1 YY-1033 Soil pH Meter demonstrates superior accuracy and additional functionalities, making it a more suitable choice for precision soil analysis. However, the decision to adopt specific measurement tools must balance economic feasibility with accuracy to ensure optimal agricultural applications. The integration of digital technologies, including Geographic Information Systems (GIS) and AI-driven soil monitoring, holds great potential for transforming agricultural management. Investing in efficient and precise measurement tools can enhance soil management practices, reduce input costs, and contribute to sustainable farming in alignment with global climate resilience and food security objectives. To further support informed decision-making in the agricultural sector, future studies should explore the long-term cost-effectiveness and reliability of soil measurement tools. Additionally, developing portable soil chemical analysis devices with accurate geolocation capabilities at an affordable price would enable more precise plot management and targeted interventions for problematic plants. This advancement will ultimately help farmers optimize resources, save

time, reduce costs, and increase profitability, thereby fostering long-term sustainability in agriculture.

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