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Designing Soil Color Sensors to Determine Soil Characteristics Based on Internet of Things (IoT)

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ABSTRACT

Soil color is the important due to its relation with other soil properties. It is usually analysis with the standard Munsell Soil Color Charts (MSCC). While other properties including organic matter need to be analyzed in the laboratory. The objective of this study is to develop IoT sensor for soil that is able to detect rapidly soil color and other properties including C-organic, pH, and cation exchange capacity (CEC). Soil color data from five soil type was analyzed using the MSCC and used as input data to the IoT (internet of things) sensor. In addition, soil properties obtained from lab tests was also included. The designed IoT sensor was used to detect soil color and soil properties of 7 soil types used as the testing samples. The sensor performance was evaluated by comparing soil properties predicted using IoT and lab analysis. Results showed the use of IoT soil sensor succeeded in determining soil characteristics including pH, CEC, and C-organic based on soil color. In addition, the soil color sensor had high accuracy to predict soil properties with a very small difference compared to the lab analysis, namely 0.01% difference for C-organic, and other properties of <5% difference. The development of IoT soil sensor will be important in the fields of agriculture and land management.

1. INTRODUCTION

Plant growth on land depends on the quality of the soil used. Soil quality can be determined most easily by visually observing the color of the soil. The darker the color of the soil, the more nutrients the soil contains. In other words, dark soil color indicates fertile soil. Visually observing soil color can provide clues about the mineral content, moisture, and organic matter content of the soil. Soil color is related to the chemical properties of the soil which include pH, organic carbon and water content (Agustine *et al*., 2023; Nodi *et al*., 2023).

Soil consists of minerals and organic matter, which have chemical, physical, biological and mineralogical properties, and which serve as a medium for plant growth and are therefore one of the most important conditions for agricultural production (Ćiric *et al*., 2023). Soil color can indicate its main mineral content. For example, red soils tend to contain iron oxides, while black soils have a high organic matter content (Needelman, 2013; Jones, 2020). Lighter soils tend to indicate soils richer in calcium, while darker soils indicate high organic matter content. Visual observation of soil color can also provide clues about pH, organic matter content and cation exchange capacity (CEC), although with limited accuracy. Soil color can provide a rough indication of soil pH. For example, very acidic soils (low pH) tend to have a lighter or reddish color, while neutral or alkaline soils (high pH) tend to have a darker color. This is related to the mineral content of the soil.

Soil color is generally determined using the Munsell Soil Color Chart (MSCC). In this case, the soil color is observed visually and compared with Munsell chips to obtain the closest color match. This method is simple, but has several limitations (Kautsar *et al*., 2024). The color of Munsell chips themselves will fade over time, resulting in uncertainty (Sánchez-Marañón *et al*., 2005). The appropriate soil color reading is influenced by several factors such as water content and lighting conditions related to time (morning, afternoon, evening). The determination of soil color is based on the observer's perception so its accuracy varies from person to person (Nodi *et al*., 2023). Furthermore, the values obtained from the Munsell chart based on three coordinates (hue H, brightness level V, and chroma C), cannot be used in direct numerical analysis (Sánchez-Marañón *et al*., 2005). In addition, the wide variation in soil color makes it difficult to determine the color and organic matter content. The method that has been used so far is to compare the colors of the existing soils one by one. This method takes a relatively long time, and the conclusions are largely determined by the quality of light and vision. By utilizing current technology, soil color observation can also be done using a color sensor, an electronic device that detect and measure color objectively. This sensor is used in various applications, including soil sensing and precision agriculture.

Color sensors can provide data on color intensity, brightness, and soil color distribution, which can be analyzed to obtain information about the physical and chemical properties of the soil. The development of a color determination method based on current technological developments is an important step to synergize the role of technology in indicating soil characteristics (organic matter, acidity, and water content) in the agricultural sector including in increasing fertility, efficiency, and productivity. Therefore, this study aims to design an Internet of Things (IoT)-based soil color sensor for determining soil characteristics. The results of the study are expected to produce a method that makes it easier for farmers to identify and control soil quality.

2. MATERIALS AND METHODS

The materials included standard soil samples consisting of five colors obtained from several areas with extremely different color tendencies and test soil samples taken according to the points that have been prepared. This research used a color sensor connected to an Arduino Uno microcontroller. The use of microcontroller technology can control or send data through a module which directly produces output whose data will be received by the server or displayed directly. One of these modules was the TCS 3200 sensor which can be used to detect an object or color being monitored. The TCS3200 color sensor is a programmable sensor consisting of 64 photodiodes as detectors of light intensity on object colors and a frequency filter as a transducer whose function is to convert current into frequency. The TCS3200 color sensor functions to read RGB (red, green, blue) values from the detected soil color (Anwar *et al*., 2018). The resulting RGB value is converted into HVC (Hue, Value, and Chroma) matched to the soil color in the Munsell Soil Color Chart (MSCC). Apart from that, the sensor has a focusing lens which is useful for sharpening the photodiode detection of light intensity with a reading distance of 2 mm from the IC lens. The TCS3200 color sensor can read 4 color modes, namely, red, green, blue and clear through 64 photodiodes which are divided into 4 parts, namely 16 photodiodes for red, 16 photodiodes for green, 16 photodiodes for blue and 16 other photodiodes for reading clear color. In its use to determine organic material, it is based on grouping data which is created in the form of a database containing notations for soil color, acidity range, and CEC (cation exchange capacity) as well as C-organic values and RGB values. The color notation was based on the color notation contained in the MSCC, while the characteristics referred to the laboratory test results of samples that have previously been prepared for data input. Test samples were classified into groups available in the database. The best classification results were displayed in the form of hue value or chroma notation as in the MSCC along with the test results.

In this study, data collected using sensor were compared with those using MSCC. This study was conducted by direct measurements in the field and indirect measurements or through the laboratory test. Direct measurements using tools and guidebooks, and the data taken were soil at a depth of 0-20 cm. Soil samples consisted of 5 samples for input and 7 samples for testing. The accuracy of the data from the tool was calibrated with laboratory test data.

2.1. Data Collection

Direct and indirect data were collected to obtain the right accuracy and precision for the tool. Direct data collection was carried out in the field, with actual soil conditions, fresh soil, soil that still maintains its color, physical and chemical properties. While indirect data collection was carried out as additional input, and additional accuracy that was calibrated with previous data. Indirect data collection is carried out by making soil samples in dry, moist to wet conditions. Dry soil conditions are soil that has been dried with air, while moist and wet conditions are soil that has been changed so that it is at a water content of 10%, 20%, and 30%.

2.2. Calibration

Calibration was carried out using soil color obtained from visual observation and adjusting it to the Munsell Soil Color Chart which was compared to the soil color detected by the sensor. Calibration of soil characteristic parameters included acidity (pH), cation exchange capacity (CEC), and C-organic from sensor readings with laboratory tests.

2.3. Validation

Validation was performed by comparing the results of soil analysis with parameters in the laboratory with the results of the IoT tool according to the input that has been entered through the sensor. This validation is useful to avoid errors when entering data.

3. RESULTS AND DISCUSSION

The land is part of the natural landscape, which includes the physical environment climate, topography, soil, hydrology, and natural vegetation, which influence its potential use. This statement is the opinion of (Ritoharjoyo, 2013), namely that land is a certain area above the surface of the earth, specifically includes an object that makes up the biosphere, which can be considered to be permanent or movable above the area. Several factors that influence land quality include soil texture, soil structure, organic matter content, acidity level (pH), and availability of nutrients. This statement is supported by the opinion that the properties of the soil are very determining in supporting the growth and development of plants, as are the chemical properties of the soil. The chemical properties of the soil that influence include soil pH, C-Organic, CEC, and nutrient content (Isir *et al*., 2022). Fertile soil has a high organic matter content and a variety of nutrients that support good plant growth. Fertile soil can be determined by looking at the thickness of the humus. The thicker it is, the more soil there is rich in organic matter and nutrients (Zuhaida, 2018). The soil samples used in this research were obtained from several areas with different soil colors. Sampling in this research was divided into two samplings, namely the first consisting of five samples of standard soil as an initial reference for the research, then the second sampling was taking samples for testing. The first samples for standards were taken from five areas provided they had extremely different soil color.

Table 1. Soil and color at air-dry and water content condition up to 30% based on the Munsell Soil Color Charts

NO	Area Code	Location Coordinate	Soil Type	Soil color			
				Air-dry	10%	20%	30%
1	Dawung Tuban (red)	6°55'56.5"LS 112°06'53.5"BT	Alfisol	2.5YR 6/6	2.5YR 4/2	2.5YR 4/1	10R 5/4
2	Simo Tuban (yellow)	7°07'52.7"LS 111°54'46.7"BT	Ultisol	2.5Y 8/1	2.5 Y 7/3	10YR 8/2	10YR8/4
3	Tambak Rejo Malang (black)	8°23'46.6"LS 112°43'13.9"BT	Alfisol	5YR 4/1	10R 3/4	10R 3/6	10R 3/1
4	Soko Tuban (white)	7°06'17.0"LS 111°54'47.5"BT	Inceptisol	2.5Y 6/4	2.5Y 4/4	10YR 5/4	10YR8/6
5	Tulung Gresik (grey)	7°18'36.6"LS 112°30'21.1"BT	Entisol	2.5YR 4/1	5YR 4/2	5YR 3/1	10YR3/3

3.1. Standard

Table 1 presents the soil color of standard soil samples collected from five different places, namely Dawung (Tuban), Simo (Tuban), Tambak Rejo (Malang), Soko (Tuban), and Tulung (Gresik). The soil color is observed based on the Munsell Soil Color Charts at different water content conditions (air-dry, water content 10%, 20%, and 30%). Parameters that can be used to see land quality through soil color include soil color, C-organic, soil pH, CEC, and water content. This is also a standard reference for the use of IoT tools to detect soil characteristics through soil color. Table 2 details the range of soil characteristic values including soil color, C-organic content, pH, CEC, and organic matter of the five standard soil samples. The range of soil characteristic values is entered as input to the IoT tool.

Based on Table 2, the input data on the IoT device uses range data, making it easier for the sensor to identify the tested soil whose values are in that range. For standard soil of Dawung, the soil color ranges from 2.5YR 6/6 (pink) at air-dry conditions, to 10R 5/4 (weak red) at 30% water content. The oxidation or reduction process of certain minerals, or changes in pH when the soil becomes moist, can affect soil color. In addition, when the soil is dry, soil particles tend to be further apart, so that light can penetrate deeper and produce different colors. However, when the soil becomes moist, water fills the pores of the soil and causes the soil particles to become denser. Therefore, water content can affect how light is reflected from the soil surface, changing the perception of color that is seen visually. The range of C-organic content (%) is 1.54%–1.60%, indicating that the soil has a medium organic carbon content. This organic carbon is important because it plays a role in the availability of nutrients for plants, soil balance, and maintaining soil quality and fertility. Then the acidity level has a pH range of 8.40–8.46 which indicates that the soil tends to be alkaline. Soil with a neutral pH is in the range of 6 to 8 or the best condition has a pH of 6.5 to 7.5. Soil with a neutral pH level allows the availability of various balanced soil chemical elements. That is why in soil conditions that are too acidic, a liming process is needed which aims to return the soil pH to neutral conditions (Zuhaida, 2018). Next is CEC which is the ability of the soil to exchange cations, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}). The CEC range of 5.55–7.89 cmol(+)/kg, which is high and indicates the ability of soil to exchange cations in the range between these values. A high CEC usually indicates that the soil is fertile and able to provide nutrients for plants (Mautuka *et al*., 2022). Range of organic matter is 2.65% to 2.76%, which is quite good to provide a healthy soil structure and increasing air retention and nutrient availability for plants. This organic material is important because it affects the structure, texture, and fertility of the soil. These parameters provide an overview of the overall soil condition, which influences the soil ability to support plant growth and the ecosystem within it.

Table 2. Standard color data range for sensor input

No	Area	Soil Color		C-organic (%)	pH	CEC (cmol(+)/kg)	Organic matter (%)
		Air-dry	30% MC				
1	Dawung Tuban	2.5YR 6/6 (light red)	10R 5/4 (weak red)	1.54–1.60	8.40–8.46	5.55–7.89	2.65–2.76
2	Simo Tuban	2.5Y 8/1 (white)	10YR 8/4 (very pale brown)	0.54–0.59	7.88–7.94	3.55–4.71	0.93–1.02
3	Tambak Rejo Malang	5YR 4/1 (dark gray)	10R 3/1 (dark reddish gray)	2.61–2.66	5.56–5.60	21.12–25.9	4.50–4.60
4	Soko Tuban	2.5Y 6/4 (light reddish brown)	10YR8/6 (yellow)	0.22–0.27	7.80–7.86	4.89–5.95	0.38–0.47
5	Tulung Gresik	2.5YR 4/1 (dark reddish gray)	10YR3/3 (dark brown)	0.73–0.79	7.73–7.77	4.51–5.55	1.26–1.39

Standard soil from Simo has the color of air-dry soil is 2.5Y 8/1 (white) and changes to 10YR 8/4 (very pale brown) when water content is 30%. The soil has C-organic range of 0.54%–0.59%. C-organic in the soil are the main indicator of soil fertility. The acidity (pH) of the soil is in the range of 7.88–7.94. This pH range indicates that the soil is neutral. Soil with a pH like this is generally suitable for growing plants that require neutral or slightly acidic pH conditions. Cation exchange capacity (CEC) ranges at 3.55–4.71 cmol(+)/kg. Organic matter range from 0.93% to 1.02%. Organic matter in soil contains important nutrients and helps maintain soil structure.

Standard soil from Tambak Rejo shows soil color of 5YR 4/1 (dark gray) and changes to 10R 3/1 (dark reddish gray) at 30% water content. The C-organic range of 2.61%–2.66% shows that the soil has a higher organic carbon content. This could indicate more fertile soil or more decomposed organic matter. The soil has a pH range of 5.56 to 5.60, which indicates that the soil tends to be acidic. Soil with a pH like this may require treatment to raise it to make it suitable for the growth of certain plants. The CEC range of 21.12–25.9 cmol(+)/kg shows that the soil has a high CEC, which means the soil can store more nutrients for plants. Organic matter in the range of 4.50%–4.60% indicates that the soil has a fairly high organic matter content, which can provide important nutrients for plants and maintain good soil structure. Develop a root system that is large enough to obtain nutrients and water so that it becomes a good soil structure (Johnston *et al*., 2009).

Soil from Soko shows a color value of 2.5Y 6/4 (light reddish brown) at air-dry condition to 10YR8/6 (yellow) at water content 30% with C-organic range of 0.22–0.27. This indicates low organic carbon content in the soil, which can affect soil fertility and health. The soil pH range at 7.80–7.86 indicates neutral to slightly alkaline soil, which is suitable for many plants. The range of CEC 4.89–5.95 cmol(+)/kg indicates a moderate cation exchange capacity of the soil, which is sufficient to support plant growth. Organic matter of a range 0.38%–0.47% indicates very low, which can affect soil fertility and health. Soil organic matter is classified as low levels with an interval value of 1.01–2.00, while very low levels are a class with an interval value of <1.00 (Kumala *et al*., 2023).

Finally, soil from Tulung has a color 2.5YR 4/1 (dark reddish grey) that change to 10YR 3/3 (dark brown). C-organic range 0.73 to 0.79 indicates the organic carbon content in the soil is sufficient to support plant growth. The soil pH of 7.73–7.77 indicates neutral, which is suitable for many plants. The CEC range of 4.51–5.55 indicates a moderate cation exchange capacity of the soil, which is sufficient to support plant growth. Organic matter at a range of 1.26%–1.39% indicates a fairly high organic matter content in the soil.

3.2. Test Results

The results of the study indicate that the soil color sensor has a high level of accuracy in detecting soil color. This is evidenced by the comparison of detection results using the MSCC and soil color detection with IoT devices in air-dry conditions and at water content of 10%, 20%, 30%. Table 3 compares the soil color as detected by the sensor versus the MSCC. The data in Table 3 shows that the use of IoT (color sensor) successfully reads the Hue (H) soil color component exactly the same as that produced from soil color analysis using MSCC. For example, T1 soil (Red soil, Tuban) has the same Hue color component whether analyzed using MSCC or detected using a soil sensor, namely 2.5YR in air-dry conditions and 10R in 30% water content conditions. The table also reveals that all tests resulted in exactly same for Value (V) component. The only exception occurred for T5 soil at 30% water content conditions where the soil sensor reading produced a Value component of 2.5 (lighter), while analysis using MSCC produced a Value component of 3 (darker). The main differences between the two methods of color assessment occur for the Chroma (C) component. Using MSCC analysis, the soil color for T1 has a saturation or Chroma of 8 at air-dry condition, while a saturation of 4 using sensor, indicating that the MSCC results in more saturated or rich in color than the sensor. At 30% water content the same soil (T1) has color 10R 4/6 (using MSCC) and 10R 4/3 (using sensor). The main difference between the two is in Chroma (C). The MSCC method result in a Chroma of 6, which means it is more vivid and saturated, while the sensor produces a Chroma of 3, which means soil is less vivid. They both have the same Hue and Value components. Thus, the difference between these two sets of color codes lies primarily in the level of brightness, which can result in differences in color intensity and depth.

Table 3. Comparison of soil color based on the Munsell color chart versus color sensors

Code Area	Coordinate	Soil Type	Soil Color (air-dry)		Soil Color (water content 30%)	
			Munsell Chart	Sensor	Munsell Chart	Sensor
T1 (Red soil, Tuban)	6°56'34.3" S 112°06'00.8" E	Alfisol	2.5YR 6/8 (light red)	2.5YR 6/4 (light reddish brown)	10R 4/6 (dark red)	10R 4/3 (weak red)
T2 (Calcareous soil, Tuban)	7°07'04.7" S 111°54'17.0" E	Ultisol	2.5Y 8/1 (white)	2.5Y 8/3 (pale brown)	10YR 8/3 (very pale brown)	10YR 8/2 (very pale brown)
T3 (Yellow soil, Tuban)	7°07'20.1" S 111°54'19.9" E	Ultisol	2.5Y 6/4 (light yelowish brown)	2.5Y 6/3 (light yellowish brown)	10YR 6/8 (brownish yellow)	10YR 6/6 (brownish yellow)
T4 (Black soil, Sarangan)	7°40'38.8″ S 111°13'29.2″ E	Andisol	10 YR 4/6 (dark yellowish brown)	10 YR 4/4 (dark yellowish brown)	7.5YR 3/2 (dark brown)	7.5YR 3/2 (dark brown)
T5 (Black soil, Malang)	8°24'40.8" S 112°41'55.3" E	Alfisol	5YR 4/3 (reddish brown)	5YR 4/3 (reddish brown)	10R 2.5/2 (very dusky red)	10R 3/2 (dusky red)
T6 (Black soil, Gresik)	7°17'46.8" S 112°29'21.2" E	Inceptisol	2.5YR 4/1(dark reddish gray)	2.5YR 3/1 (dark reddish gray)	10YR 3/2 (very dark grayish brown)	10YR 3/3 (dark brown)
T7 (Brown soil, Bandung)	6°56'56.5" S 107°42'41.7" E	Fluvisol	2.5YR 4/4 (reddish brown)	2.5YR 4/4 (reddish brown)	5YR 3/4 (dark reddish brown)	5YR 3/3(dark reddish brown)

Table 4 shows a comparison between soil properties resulted from analysis in the laboratory and predicted based on sensor reading. From the data of T1 from Tuban, the soil is Alfisol soil based on the soil type map of the Tuban area. Alfisol is a type of soil that is generally found in areas with subtropical to tropical climates. Alfisol soil characteristics include having a fairly good organic matter content and a neutral to slightly alkaline soil pH. It can be seen that the T1 soil has a C-organic value during the laboratory test of 1.56%, while the value detected on the sensor is 1.55%, the difference from this data is 0.01%. Then for pH it has a value of 7.79 based on lab analysis, while the sensor detection result is 7.81, the difference in pH is 0.02. Then, the soil has a CEC value of 5.31 cmol(+)/kg based on laboratory test, while the detection sensor shows a value of 4–5.31 cmol(+)/kg, the difference is only 1.31 to 0. The difference between the two methods is around 0.01% so that the sensor is fairly accurate. The range of these values indicates that Alfisol soil from Tuban has the potential to support good plant growth. The pH range between 7.79 to 7.81 indicates that this soil tends to be slightly alkaline. Soil with a neutral to slightly alkaline pH generally supports good plant growth because nutrients in the soil are more easily accessible to plants at this pH range. The CEC range between 4 to 5.31 indicates that the soil has a fairly good ability to provide nutrients for plants. Soil CEC is greatly influenced by soil organic matter. Soil CEC is high if soil organic matter is also high (Purba *et al*., 2018). Overall, the land has relatively good characteristics for farming or certain agricultural activities.

Table 4. Comparison of laboratory test versus sensor test for average values of C-organic, pH, and CEC

Area	Soil Type	C-organic (%)			pH			CEC (cmol(+)/kg)		
		Lab	Sensor	Diff*	Lab	Sensor	Diff*	Lab	Sensor	Diff*
T1 (Red soil Tuban)	Alfisol	1.56	1.55	0.01	7.79	7.81	0.02	5.31	4–5.31	0–1.31
T2 (Calcareous soil Tuban)	Ultisol	0.57	0.56	0.01	7.87	7.94	0.07	2.55	2.44–3.00	0.11–0.45
T3 (Yellow soil Tuban)	Ultisol	0.22	0.23	0.01	8.20	8.37	0.17	4.90	4.85–5.70	0.05–0.80
T4 (Black soil Sarangan)	Andisol	3.61	3.63	0.02	6.24	6.28	0.04	25.67	25.11–25.78	0.11–0.56
T5 (Black soil Malang)	Alfisol	2.61	2.63	0.01	5.53	5.51	0.02	27.77	25.04–27.67	0.11–2.73
T6 (Black soil Gresik)	Inceptisol	0.74	0.75	0.01	7.71	7.80	0.09	5.12	5.01–5.12	0 – 0.11
T7 (Brown soil Bandung)	Fluvisol	1.60	1.64	0.04	6.91	6.90	0.01	5.61	5.55–7.77	0.06–2.16

* Diff is absolute difference between values from lab and sensor, calculated as Diff = | lab – sensor |

The soil type for T2 is Ultisol. Ultisol is acid soil commonly found in tropical and subtropical areas. Ultisol soils are generally found in humid areas that experience high levels of weathering and leaching. Soils belonging to this order are dominated by the clay mineral kaolinite and iron and aluminum oxides (Minardi, 2016). They have a high aluminum content and are often rich in minerals. According to research (Hobley & Wilson, 2016) shows that the mineralogical composition and clay content in the soil has a large influence on the organic matter content and its dynamics in the soil, and the pH-dependent load plays an important role in improving soil quality. Based on lab analysis, this soil sample has C-Organic 0.57%, pH 7.87, and CEC 2.55 cmol(+)/kg. Meanwhile, the IoT sensor predicts the C-organic value of 0.56%, pH7.94, and CEC 2.44–3.00 cmol(+)/kg. The two methods (lab. analysis vs. IoT sensor) resulted some variances, namely 0.01% difference for C-organic, 0.14 for pH, and 0.11-0.45 for CEC. The differences are slightly less than 1% in this test meaning a fairly accurate prediction. In addition, with C-organic 0.56–0.57%, pH 7.87–7.94, and CEC 2.44–3.00 cmol(+)/kg implies that Ultisol soil from Tuban sampled for this reaserch has limited stored air and nutrients. Low organic carbon levels can also indicate a fast decomposition rate and reduce organic matter decomposing in the soil. The slightly high pH range (7.87–7.94) indicates that this soil tends to be alkaline or neutral. This may be caused by factors such as the influence of the subgrade or the use of certain chemicals. The CEC range given (2.44–3.00 cmol(+)/kg) indicates the soil is able to exchange cations with the soil solution. The higher the CEC value, the higher the ability of soil to store and exchange important cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}). Overall, this combination of characteristics suggests that Ultisol soils may have some challenges in terms of fertility and plant productivity that can be overcome with appropriate land management including the addition of organic matter. The soil sensor can be used to justify in improving soil fertility and demonstrate its suitability for the overall scenario of an integrated soil fertility management strategy to improve soil quality, nutrients, and plant nutrition in tropical soil conditions (Saria, 2018).

This data for T3 also has the same soil type as that for T2, but the soil T3 is yellow while the T2 is white. Based on lab analysis for soil T3, the C-organic has a value of 0.22%, pH of 8.2, and CEC of 4.90. The detection using IoT sensor produced C-organic value of 0.23, pH 8.37, and CEC of 4.85–5.70. The variations between the two methods include C-organic is 0.01% difference, pH is 0.17, and CEC have a difference in the range of 0.05 to 0.8. In general the differences are less than 1% so it can be said that the accuracy of the soil sensor is still maintained. The range values of 0.22–0.23% for C-organic, 8.2–8.37 for pH, and 4.85–5.70 cmol(+)/kg for CEC, indicate that the yellow Ultisol soil from Tuban analyzed in this research is acidic. Even though the pH is relatively high (>7), Ultisol soils still tend to be acidic because has low C-organic and low CEC as well. Because the soil pH is quite high, the availability of certain nutrients such as phosphorus (P) and micronutrients such as iron (Fe) and manganese (Mn) may be limited, and this can be a challenge for plant growth. Therefore, proper fertilization and soil management are needed to maintain soil fertility. Due to its low C-organic content, Ultisol soil on this land tends to be less fertile and more susceptible to physical degradation such as soil erosion.

The soil T4 has the Andisol type which tend to have structures that are easy to manage and can be dredged easily. Andisol soil generally has a good granular structure and high drainage capacity due to its varying sand and clay content, making it suitable for agriculture and crop cultivation that requires good drainage. The soil T4 tested in the laboratory had a C-organic value of 3.61%, pH 6.24, and CEC 25.67 cmol(+)/kg, while the results of testing using a sensor obtained a C-organic value of 3.63%, pH 6.28, and CEC range of 25.11–25.78 cmol(+)/kg. The difference between laboratory and sensor test results is C-organic 0.02%, pH 0.04, and CEC ranging from 0.11 to 0.56, implying that the differences between the two is still within the standard which that the sensor reading is still relatively accurate. The Andisol soil where organic C is 3.61–3.63%, pH is 6.24–6.28, and CEC is in the range of 25.11–25.78 cmol(+)/kg, imply that this soil has high C-organic content. The high organic level of Andisol soil indicates a higher fertility potential compared to Ultisol soil. High organic content can increase the soil's ability to store air and nutrients, as well as increase the activity of soil microorganisms. With a pH ranging from 6.24–6.28, this soil tends to be more neutral or slightly acidic. This suggests that Andisol soil may be more suitable for plant growth without requiring special treatment to neutralize its acidity. The high CEC value ranging from 25.11 to 25.78 indicates that Andisol soil has a good ability to store and exchange cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), which is important for the availability of nutrients for plants. Andisol soil generally has a good granular structure and high drainage capacity due to its varying sand and clay content. Andisols generally have a granular structure to disturbances of root mat and soil fauna, enhanced by the accumulation of organic matter (5 to 20%). Andisol soil type, medium granular soil structure, field pH 6.0 (Siswanda *et al*., 2023). This makes it suitable for farming and growing plants that require good drainage.

This T5 sample is Alfisol soil type. Based on the laboratory test, this soil sample had C-organic value of 2.61%, pH 5.53, and CEC of 27.77 cmol (+)/kg, whereas using IoT sensor, the C-organic value was 2.63 %, pH 5.51, and CEC of 25.04–27.67 cmol (+)/kg. When compared, a difference of 0.02% is obtained for C-organic and pH, while for CEC the difference ranges from 0.10 to 2.74. The difference of CEC is more than 1%. Several factors may influence the size of the CEC detection based on soil color, namely the possibility of light entering during testing using a sensor so that the sensor is less accurate in detecting the color of the soil sample, but this is still not an error. Because it is still less than 5%, it can still be said that the accuracy is still high. Alfisol soil with C-organic 2.61–2.63 %, pH 5.51–5.53. and CEC 25.04–27.77 cmol (+)/kg is classified as fertile soil. Relatively high levels of organic matter indicate the ability of soil to provide nutrients for plants, while a slightly acidic pH (5.51–5.53) is suitable for most agricultural plants. Fairly high CEC (25.04–27.77) indicates the ability of soil to store and exchange nutrient cations with plant roots, an important aspect of healthy plant growth. Thus, the land is considered fertile and suitable for agriculture.

The soil T6 sample is taken from the southern Gresik region. The soil type is Inceptisol. The laboratory analysis obtained C-organic value of 0.74, pH 7.71, and a CEC of 5.12 cmol (+)/kg, while when tested using a sensor the C-organic of 0.75%, pH 7.80, and CEC of 5.01–5.12 cmol (+)/kg. The difference is 0.01% for C- organic, 0.09 for pH, 0 to 0.11 cmol(+)/kg for CEC. The high accuracy is maintained by the sensor in predicting the soil properties according to the detected soil color. The soil T6 looks like it is still in the early stages of formation. The process of soil formation such as due to mineralization, translocation, and accumulation has not yet reached a high maturity. The recorded C-organic levels (0.74–0.75%) indicate that this soil has little organic matter. This organic material is important for soil fertility because it affects the availability of nutrients and water retention. The soil pH range (7.71–7.80) indicates that the soil tends to be neutral to alkaline. Soil pH affects the availability of nutrients for plants as well as microbial activity in the soil. The CEC range (5.01–5.12 cmol(+)/kg) indicates the soil's ability to retain and release cations such as calcium, magnesium, and potassium. A higher CEC usually indicates the soil's ability to provide nutrients for plants. The nature of the soil greatly influences the availability of water, air and plant nutrients (Mahi, 2013).Therefore, this T6 soil is considered in the early stages of formation with chemical properties that reflect that stage and may require appropriate management to increase their fertility and productivity.

The T7 soil sample taken from a rice field area in Bandung is Fluvisol. When it tested in the laboratory the C-organic value was 1.6%, pH 6.91, and CEC 5.61 cmol(+)/kg. The test using a sensor revealed C-organic value of 1.64%, pH 6.90, and CEC ranged from 5.55–7.77 cmol(+)/kg. Tests using sensors (IoT) resulted in a difference of 0.04% for C-organic, 0.01 for pH, and for CEC a difference of 0.06 to 2.16 cmol/kg was obtained. The differences show that the IoT sensor is still accurate because the difference is still below 1% except for the CEC. The difference for CEC could be caused by external factors including the improper placement of the color sensor and the position of the photodiode probe on the color sensor that greatly affect the results because of the sensitivity of the photodiode sensor probe (Lamsani & Adriantho, 2023). Fluvisol soils are usually found in floodplain areas that are often renewed by river sediment. With C-organic of 1.60–1.64%, pH 6.91–6.9, and CEC of 5.55–7.77 cmol(+)/kg, this soil has good organic material content. Organic material is important for increasing soil fertility and supporting plant growth. Soil pH range (6.91–6.9) is close to neutral and is usually considered suitable for plant growth because most plants can grow optimally in neutral or slightly acidic soil pH conditions. The CEC range is quite wide (5.55–7.77) indicating the ability of soil to retain and release cations such as Ca^{2+}, Mg^{2+}, and K^{+}. This is also an indication that the soil can provide nutrients for plants. Based on its chemical characteristics, Fluvisol soil has good quality, with a fairly high organic matter, suitable pH for plant growth, and the ability to provide nutrients for plants. This makes it suitable for a wide range of agricultural activities.

4. CONCLUSION

Based on the results of the study it was concluded that the use of IoT in this research succeeded in determining soil color as well as its characteristics including pH, CEC, as well as C-organics and soil organic matter based on the soil color detected by the tool. Based on the overall test results, the percentage difference in numbers obtained from laboratory and sensor tests is only less than 10% difference, so that the accuracy of this tool, both soil color and soil characteristics, reaches 90%, which means it is close to the expected accuracy. The development of this soil color detection tool has important utility in the fields of agriculture and land management. Using this tool can speed up the soil analysis process, reduce costs, and increase efficiency in agricultural decision making. However, to increase the accuracy and validity of this soil color detection tool, further research and more extensive testing on various types of soil is needed, in order to obtain maximum results.

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