

Development of a Soil Organic Matter Measuring Device using Ultraviolet and Visible Light Spectroscopy



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Abstract: A study is focused on the development of an electronic device capable of measuring Soil Organic Matter (SOM) content in a given soil sample using Ultra-Violet and Visible Light (UV/Vis) Spectroscopy. SOM measurement is a high valued procedure in any sustainable agricultural production system. The SOM content measurement was done through image processing and uses the Munsell Colour System as the reference to analyse the soil samples. Fluorescence which causes some substances including organic matters emit light at visible wavelengths when exposed to Ultraviolet and Visible light spectrums was the key phenomenon used in the design and development of the prototype measuring device. By capturing the amount of radiation through a camera, the image will be sent to a computer to quantify the amount of SOM present in a given soil sample. The system was composed of two main parts, the UV/Vis LED array circuit and the computer which runs the developed software to analyze SOM content. The camera used to capture reflected images is integrated to the LED array circuit. A separate testing software was also developed to calibrate the reading consistency of the device. Testing included the effects of moisture content and grain size of the soil samples. Through testing and evaluation of the prototype, the results were compared to the measured SOM using Loss-on-Ignition (LOI) method. Findings show that the measured quantities using the SOM Content Measuring Instrument is comparable with the measured quantities using LOI method.

Index Terms: Image processing, Light Spectroscopy, Precision Agriculture, Soil Organic Matter.

I. INTRODUCTION

Soil organic matter (SOM) is considered as one of the most important components of soil quality and has long been recognized as a key component of terrestrial ecosystems [1]. An important element coming into strategic role in the soil fertility consists of SOM, a major role in maintaining soil quality as it positively influences a wide range of soil properties such as the provision of nutrients, water retention and release, as well as reducing the risks of soil compaction, surface crusting and soil erosion. Organic matter is probably the most important and most misunderstood of all the components of soil [2]. The factors affecting SOM consist of the amount of organic matter in surface. Soil properties can vary over time as a result of impact by climate and land

management [3]-[4]. Organic material is anything that was alive and is now in or on the soil. For it to become organic matter, it must be decomposed into humus. Humus is an organic material that has been converted by microorganisms to a resistant state of decomposition. Organic material is unstable in the soil, changing form and mass readily as it decomposes. As much as 90% of it disappears quickly because of decomposition [5]. Many production practices can influence the long-term build-up or depletions of SOM e.g. tillage, crop rotation, erosion, cover crops, crop residue management, fertilization, organic amendments, etc. [6]. Measurements of SOM are usually done in the laboratories using specialized tools and equipment. The procedure also requires that it should be performed by a professional or a highly trained technician to avoid the risk of exposure in handling dangerous chemicals. These measurements, however, have little short-term value to the grower, except for adjusting rates of certain herbicides. Long-term increases in SOM in a particular field reflect a consequence of improved production practices and possibly, higher productivity.

II. MATERIALS AND METHODS

A. Project Research Design

This study focused on the design and development of a measuring instrument for soil organic matter (SOM) using UV/Vis spectroscopy technology. The developed instrument can measure the amount of organic matter present in a specific amount of soil sample in terms of percentage content. Organic matter in soil containing carbon compounds can be captured and measured as a result of the UV and visible light exposure analyzed through image processing technology. The study also covered the effects of grain size and soil moisture in determining the SOM contents. Measurement of soil minerals was not included in the study however; the developed software demonstrated that the same technology can be used in analyzing mineral contents. A prototype was built to test the design concept for the Soil Organic Matter (SOM) measuring instrument. The prototype serves to provide specifications for a real and working system rather than a theoretical one by developing an actual device using optical spectroscopy technology. The study was conceptualized to minimize the problems encountered with Walkley-Black (WB) procedure which includes limited measurement of organic matter in the soil (approximately 6% only) and the production of chromate, which is categorized as a hazardous chemical and requires regulated disposal in compliance with EPA regulations [7].

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This ion produced is a strong acid medium which is a powerful oxidant. It is corrosive to skin, mucous membranes, the respiratory tract and the gastrointestinal tract. It may create a cancer risk. On the other hand, the problems associated with weight loss method are time consuming and the error caused by volatilization of substances other than organic materials like as H₂O, structural OH, CO₂ from carbonates and incomplete oxidation of carbonaceous materials [8]. The results are accurate to 1-2% for organic matter and carbonate in sediment with over 10% organic matter using standard LOI procedure [9]. The objective of the study was to eliminate these disadvantages by developing an electronic device capable of measuring SOM content.

B. Project Development

The total Carbon (C) in soil is the sum of both organic and inorganic Carbon. Most organic C is present in the Soil Organic Matter (SOM) fraction, whereas inorganic Carbon is largely found in carbonate materials. However, not all soils contain inorganic Carbon because of dissolution during soil formation of carbonate minerals originally present in parent material [10].

Soil Organic Matter (OM) is mainly composed of Carbon, Hydrogen and Oxygen but also has small amounts of nutrients such as Nitrogen, Phosphorous, Sulphur, Potassium, Calcium and Magnesium contained within organic residues. Organic Carbon is contained in the soil organic fraction, which consists of the cells of microorganisms, plant and animal residues at various stages of decomposition, stable "humus" synthesized from residues, and highly carbonized compounds such as charcoal, graphite, and coal an elemental form of Carbon. According to the Department of Agriculture and Food of Australia, about 58% of the mass of organic matter exists as carbon. Their website stated a procedure on how to estimate the percentage of soil organic matter from the SOC% using the conversion factor 1.72 (derived from 100/58). With this, the conversion was derived as Organic matter (%) = total organic carbon (%) x 1.72 [11].

Numerous methods are available for assessing soil Carbon. Storer automated the procedure by developing a computerized weighing system [12]. Mehlich extracted "humic matter" with 0.2 M NaOH + 0.0032 M DTPA + 2% ethanol is a method used in North Carolina but have resulted in poor reproducibility in Wisconsin [13]. The two most common methods of organic matter determinations are:

1. Weight loss on removal of the organic matter from the mineral fraction.
2. Determination of some constituent that is found in a relatively constant percentage of soil organic matter such as Nitrogen and Carbon.

SOM molecules can be electronically excited to emit visible light through exposure to Ultra Violet (UV) and Visible light. This phenomenon is termed photoluminescence, which is formally divided into two categories, fluorescence and phosphorescence, depending upon the electronic configuration of the excited state and the emission pathway. Fluorescence is the property of some atoms and molecules to absorb light at a particular wavelength and to subsequently emit light of longer wavelength after a brief interval, termed the fluorescence lifetime. The process of phosphorescence occurs in a manner similar to fluorescence, but with a much longer excited state lifetime.

By introducing a modern method to electronically measure SOM, the problems and risks can be avoided by eliminating the manual process of dissolving organic matter (through ignition method) and the use of hazardous chemicals (WB method) to digest SOM content in soil. The process will be done by exposing a group of soil samples to a UV and Visible light source then capturing the amount of radiation through a camera. The image will then be sent to a computer to analyze and measure the amount of SOM present in a given soil sample.

The light source and the camera will be controlled by the computer which will run the software that analyzes and displays the output of the measurement to a monitor. The measured amount of SOM for a given soil sample will be expressed in terms of percentage content.

The main parts of the device are UV/Vis LED array, digital camera, and image processing software. External power supply is not required since the SOM Meter was designed to use the power provided in a standard USB port which is 5V/500mA. The UV/Vis LEDs emit electromagnetic waves in UV and visible frequencies which causes reaction to organic matter. This reaction produces light (color) in lower but visible light frequencies. The colors are based on the Munsell Chart. This light is then captured by a low-light digital camera. The image is then sent to the computer for analysis using image processing technique.

The analysis begins by scanning each picture element then translating the captured color (Munsell Chart) into its RGB equivalent. Each unique hue has its own RGB combination which corresponds to a certain light frequency to be classified by the software. The output will then be displayed in the computer monitor.

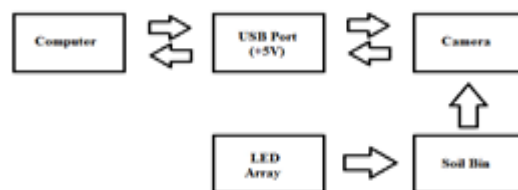


Fig. 1. Block Diagram and Data Flow Diagram

C. Design Principles and Operation

The schematic diagram for the UV LED array circuit is shown in Fig. 2. The prototype used twelve (12) UV LEDs and four (4) white LEDs to produce the light needed to

excite the SOM molecules. UV LED was chosen over fluorescent black light due to its strict tolerance characteristic and narrow bandwidth compared to its CFL counterpart. Twelve LEDs with 30° footprint were needed to cover the 300 x 300 pixel resolution sampling area. The LEDs operates at 3.3 Volts nominal voltage to a maximum 3.6 Volts at 15-20 milli Amperes. The available power supplied by the USB port has an output of 5 Volts and can deliver current up to 500 mA. With this, the circuit was further simplified by removing the need to construct another circuit for the external power supply. The same port was also used for the data (image) captured by the camera.



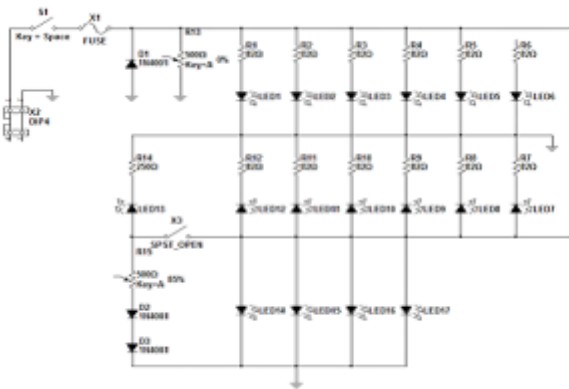


Fig. 2. SOMM Circuit Schematic Diagram

The value of the resistors to limit the voltage and current flowing through each LED was computed using Kirchoff's Laws KVL/KCL. The total power consumption of the whole circuit during the operation of the device was also determined using the same techniques. To protect the device from over loading and accidental short circuits, a rectifier diode and fuse were added. As shown in Fig. 2, the rectifier diode was connected in reverse bias condition to the power source. This orientation will protect the circuit during unintentional reversal of power terminals by clipping the voltage to about 0.7 Volts which is too small to turn ON the LED circuit. The fuse rated at 250 mA was connected in series with the power source to cut the current if over loading or an accidental short circuit occurred. A blue LED was also used to indicate if the sample tray was placed properly in the soil bin. Four (4) white LEDs were added to cover the visible spectrum. Two (2) IN4001 rectifier diodes were connected in series with four LEDs to clip the 5V supply voltage source to 3.6 V since the LEDs has a forward voltage of 3.3 V to 4.1 V. The current is controlled by a 500 Ω potentiometer.

D. Fabrication

The chassis of the device houses the LED array, camera, and the sample bin. Prior to the installation of these parts, a temporary chassis was built to enable the author to measure and determine the minimum distance that the camera can capture clearly. An adjustable plastic enclosure was also made to align the camera with a magnifying lens using High Impact Plastic Sheets (HIPS). The magnifying lens was necessary to focus the camera in a very short distance from the soil sample. The lens also contributed in the chassis size reduction. The original camera required for the device is the one with manual focus capability to capture images in distances below 10 cm. Magnifying lens was used to compensate the disadvantage of using autofocus camera to enhance its focusing ability.

E. Software Development

A great significance of this study is to make a complex instrument made available to local farmers by developing a similar device which is much cheaper compared to equipment available in specialized laboratories and is easier to use. Another design consideration is the selection of an inexpensive but powerful front-end programming tool that is user friendly and interactive. Visual basic provides a comprehensive interactive and context sensitive online help system and the structure of the basic programming language

is very simple, it is not only a language but primarily an integrated, interactive development environment (IDE).



Fig. 3. Graphical User Interface

The operation of the SOM Meter system starts by plugging the device in a USB port of a computer where the software is installed. The switch will turn ON both the LED array circuitry and the Camera. Detection of the camera will be the first task that the software will do during the initialization of the program. The GUI shown in Fig. 3 will display the entire camera installed on the computer then the user must choose the camera mounted in the SOM Meter. If the appropriate camera is not included in the list, the user must click the Add Camera button. Once the camera is added, the software will automatically use it as the default camera to be used every test. The device is now ready for soil analysis. The soil sample tray must be completely filled to ensure that the camera will capture the required area which is 300 x 300 pixels. The user must click the Start Camera Button to show a preview of the actual soil sample. Clicking the Snap Shot button will activate the camera to capture an image of the sample then send it to the computer for analysis using image processing technology. By clicking the ANALYZE button, the image captured by the camera will be scanned pixel by pixel. The software will analyze the amount of Red, Green, and Blue components of each pixel. These combinations correspond to a certain wavelength which we perceive as colors. Soil organic matter when exposed to UV light absorbs energy then release it in a form of photon of different wavelength compared to UV. These colors of emitted light depend on the type of absorbing molecules which is then translated based on Munsell Chart. The process will stop once the last pixel was analyzed then a message box will pop up stating that the analysis was completed. Analysis can be stopped at any point during the process by clicking the Cancel button.



Fig. 4. Integration of SOM Meter to a Computer

III. TESTING PROCEDURE

A. Testing Program Development

Testing and calibration of the developed prototype was necessary to get an accurate SOM content measurement. A test program was developed to gauge the capabilities of the whole system. The test program shown in Figure 5 was designed to capture the whole visible spectrum (Fig. 6) which is just a combination of primary colors.



Fig. 5. Testing Program GUI

The system must be able to distinguish and quantify the amount of RED, GREEN, and BLUE components in a 300 x 300 pixel image resolution.

Table 1. Color Properties of Some Soil Minerals

Mineral	Formula	Size (mm)	MunsellColor
goethite	FeOOH	1-2.0	10YR 8/6 yellow
goethite	FeOOH	~0.2	7.5YR 5/6 strong brown
hematite	Fe ₂ O ₃	~0.4	5R 3/6 red
hematite	Fe ₂ O ₃	~0.1	10R 4/8 red
lepidocrocite	FeOOH	~0.5	5YR 6/8 reddish-yellow
lepidocrocite	FeOOH	~0.1	2.5YR 4/6 red
ferrihydrate	Fe (OH) ₃		2.5YR 3/6 dark red
glauconite	K(Si ₆ Al ₁₋₃)(Al,Fe,Mg)O ₁₀ (OH) ₂		5Y 5/1 dark gray
iron sulfide	FeS		10YR 2/1 black
pyrite	FeS ₂		10YR 2/1 black (metallic)
jarosite	K Fe ₃ (OH) ₆ (SO ₄) ₂		5Y 6/4 pale yellow
todorokite	MnO ₂		10YR 2/1 black
humus			10YR 2/1 black
calcite	CaCO ₃		10YR 8/2 white
dolomite	CaMg (CO ₃) ₂		10YR 8/2 white
gypsum	CaSO ₄ ·2H ₂ O		10YR 8/3 very pale brown
quartz	SiO ₂		10YR 6/1 light gray

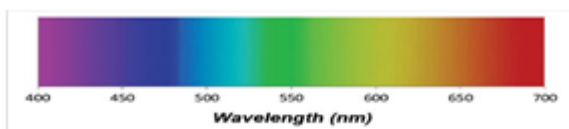


Fig. 6. the Visible Spectrum

The test program was also able to identify the color of organic matter and some minerals including calcite, hematite, todorokite and glauconite. These minerals were identified based on their pigment only though the accuracy was not verified since it is not included in the scope of the study. The study also demonstrated that identification of some minerals can be possibly obtained using the same program. The color of SOM and some minerals were listed on Table 1.

B. Reading Consistency Testing

The objective of this test is to determine if the results of the analysis displayed by the device was consistent. One of the 85 soil samples was chosen as the subject for the test. The soil

sample was tested ten (10) times for SOM content analysis. Stirring the sample for each repetition was necessary to expose some possible organic matter which were hidden below the surface of the soil sample.

C. Effect of Grain Size

The objective of this test is to determine the proper grain size of the soil sample to be examined. An ungrounded soil sample with a maximum grain size of 3mm was used for this test. First, the sample underwent analysis for ten times using the device prototype. Stirring the sample for each repetition was necessary to also determine if the position of the grains affects the reading. Next, the same soil sample was grounded and filtered using a #10 mesh strainer. It was then tested using the device for content analysis. Finally, the results of both steps were recorded and statistically analyzed using two-tailed paired-sample t-test to determine if there was a significant difference between the two readings.

D. Effect of Moisture Content

The objective of this test is to determine if the moisture of the soil sample to be examined affects the analysis of SOM content. A sun-dried soil sample was used for this test. First, the dried sample undergone analysis using the device prototype. Then, the same sample was sprayed with water which is 10% of its total weight. The procedure was repeated with an increment of 10% until the soil become 100% saturated. All the results were recorded then statistically analyzed using one-tailed paired sample t-test to determine the change in readings.

E. Comparison with LOI Method

Since the publication of the paper of Dean in 1974, loss on ignition (LOI) has been widely used as a method to estimate the amount of organic matter and carbonate mineral content (and indirectly of organic and inorganic carbon) in sediments [14]. The Walkley-Black method is more accurate and more precise on soils with less than 2.0% organic matter. On soils very high in organic matter, the Walkley-Black method may result in low test results, due to the incomplete oxidation of the organic carbon in the sample [15]. The soil samples underwent both the electronic method using the developed prototype and then the manual method which was the weight Loss-On- Ignition method (LOI). The results of the two methods were compared and statistically analyzed to determine if there was a significant difference on the results taken from the two methods. A total of eighty-five (85) soil samples were taken randomly from different places including farmlands for coffee plantation, rice fields, grazing land, river side, and some from upland and lowland areas of Cavite. The areas previously specified were expected to contain different levels of soil organic matter contents.

IV. RESULTS AND DISCUSSION

A. Consistency Test

The readings ranged from 2.209% to 2.692% with an average (m) value of 2.350% and standard error from the mean of only 0.05%.

The confidence interval at 95% degree of confidence level is 0.113% as shown in Figure 7. With this, the upper limit will be 2.463% (mean + interval) and the lower limit will be 2.237% (mean – interval). Therefore, the result of the test means is within the 95% consistency since the true mean for which the population sample was taken is between 2.237% and 2.463%.

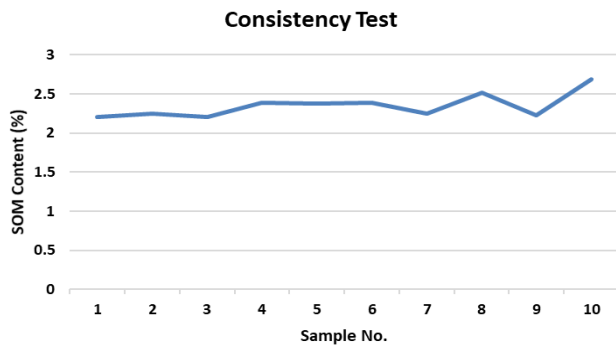


Fig. 7. Graph of SOM Content Consistency Test

B. Effect of Grain Size Test

This test was done to determine if grain size affects the reading of SOM content. The same sample was grounded and filtered using a strainer (mesh #20) then tested again. The test was repeated ten (10) times to determine if there is a significant difference between the readings of ungrounded and grounded sample.

Table 2. t-Test for Paired Sample

	Ungrounded	Grounded
Mean	2.405	2.543
Variance	0.038	0.066
Observations	10.000	10.000
Pearson Correlation	0.393	
df	9.000	
t Stat	-1.707	
P(T<=t) two-tail	0.122	
t Critical two-tail	2.262	

A two-tailed paired samples t-Test revealed that there was no significant difference between the results of the measurements of ungrounded and grounded sample ($m = -1.383$, $s = 0.25618$), $t(-1.071) = 0.122$, $p \geq 0.05$, hence, there is no sufficient evidence to reject H_0 . Therefore, the grain size of the soil sample has no significant effect on the readings obtained during the test.

C. Effect of Moisture Content Test

A soil sample was tested ten times ($N=10$) to determine the consistency in reading with varying amount of moisture content.

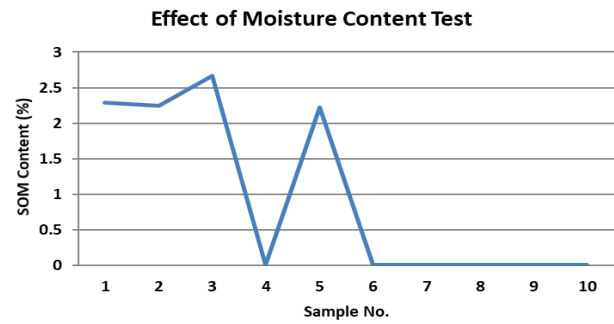


Fig. 8. Graph of SOM content vs Moisture content

Figure 8 shows the inconsistency in the reading in sample no.5. Based on the trend, the reading should be declining starting at sample no.4, meaning the program does not recognize the color of the sample since it has not undergone the drying procedure. The readings ranged from 0.00% to 2.6902% with a mean of 0.856 and standard deviation of 1.193. The median is 0.00 an indicator that most of the readings were 0.00, this is due to the fact that starting sample no.4, the device was unable to read and display significant values.

D. Comparative Analysis

Statistical analysis was done to examine the relationship of the data gathered between the two methods of determining soil organic matter content. The result of the weight Loss on Ignition (LOI) method was compared to the result measured via electronic mean, specifically, the developed prototype of the SOM Meter using UV/Vis Spectroscopy. The data gathered were divided into eleven (11) data sets based on the reading of SOM content as displayed by the electronic measuring device. Each data set is composed of at least five (5) samples representing the ranges of measurements (from below 1% to above 10%) obtained from both methods. A summary of all the data gathered is also presented to give an overall analysis on the performance of the device.

Paired sample t-Test was the statistical method used to analyze the gathered data. This technique is used to compare two population means in the case of two samples that are correlated. Paired sample t-Test is used in experimental researches, when the samples are the matched pairs, or when it is a case-control study. For the study, each sample has undergone two different SOM content measurements. Pearson's Correlation Coefficient or Pearson Product-Moment Correlation was also used for investigating the relationship between the readings taken from both methods. The gathered data were analyzed using the Statistics Tool Pack in Microsoft Excel to perform both tests. The result of the analysis was expected to conclude if the developed prototype is capable of measuring soil organic matter content with accuracy comparable with the manual method.

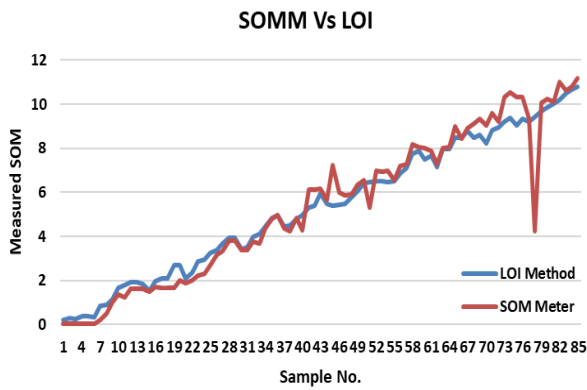


Fig. 9. Overall Percentage Measurement, LOI vs SOM Method

Based on the tests and evaluation conducted as to the functional capability of the Soil organic Matter (SOM) Meter using Ultraviolet and Visible (UV/Vis) Spectroscopy, the following findings were derived:

1. Moisture content has a direct effect in the consistency of reading. The device was unable to read and display significant values starting at 60% moisture content. The grain size on the other hand, showed no effect on the readings obtained during the consistency test.
2. Out of the eleven (11) data sets used to compare the readings of the developed prototype to the manual method, Data Set F or the 4%-5% SOM content range is the most accurate as proven by the Pearson Correlation coefficient ($r = 0.809$) implying that the two variables has a very high positive correlation, that is, the results of both methods has a linear correlation.
3. Only Data Seta A and B or the 0%-1% and 1%-2% SOM content range showed significant difference in measurement proven by the the two-tailed paired samples t-test where both has p-values = $0.001 < 0.05$. This supports the statement that there is enough evidence to infer that the measurements have significant differences.
4. The relationship between the measurements obtained using the manual and electronic method shifted from positive to negative correlation starting from Data Set F or the 5%-6% SOM content range. The Pearson Correlation coefficient ($r = -0.112$) implying that the two variables has a very low negative linear correlation.
5. Data Set J or the 9%-10% SOM content range showed a negligible correlation between the results of the measurements performed using the manual and electronic method. This is supported by the Pearson Correlation coefficient ($r = 0.054$) implying that the two variables have a negligible correlation, that is, the results of both methods were not linear. The statistical test revealed that there is no significant difference between the results of the measurements performed by the two methods which are the LOI method and the developed prototype. For the test of difference using t-Test, the value of $t = 0.131 < 1.989$, also, p-value = $0.897 > 0.05$ supporting the statement to accept the null hypothesis ($H_0; \mu = 0$) that there is not enough evidence to infer that the measurements obtained from the two methods has significant differences. Moreover, the

Pearson Correlation coefficient ($r = 0.975$) implies that the two variables has a very high positive association, that is, the results of both methods has a linear correlation.

6. The grain size of the soil sample has no significant effect on the readings obtained during the test of consistency in reading. This is proven by the two-tailed paired samples t-test which revealed that there was no significant difference between the results of the measurements of ungrounded and grounded sample ($m = -1.383$, $s = 0.25618$), $t(-1.071) = 0.122$, $p \geq 0.05$, hence, there is no sufficient evidence to reject H_0 . In addition, a two-tailed paired samples t-test revealed that there was no significant difference between the results of the measurements of ungrounded and grounded sample ($m = -1.383$, $s = 0.25618$), $t(-1.071) = 0.122$, $p \geq 0.05$, hence, there is not enough evidence to reject H_0 . Therefore, the grain size of the soil sample has no significant effect on the readings obtained during the test.

V. CONCLUSION

Based on the results of the evaluation and supported by statistical analysis, the prototype for the Soil Organic Matter (SOM) content measuring instrument using Ultraviolet and Visible (UV/Vis) light spectroscopy technology was successfully developed. The circuitry designed for the scanning system composing of the LED array and the camera was able to capture and transmit the reflected image to a computer for soil sample analysis. Moreover, the developed software was able to process, interpret, and display the data with accuracy comparable with the measured quantities using LOI method.

VI. RECOMMENDATIONS

Based on the results and findings of the study, the following are recommended:

1. To further extend the capabilities of the device using the same principle, the program can be upgraded to include algorithms that will verify other soil composition such as minerals and other compounds commonly present in most soil samples.
2. To further increase the measurement accuracy of the device, compare the SOM content measuring instrument with other methods of quantifying SOM both electronic and manual means to bridge the gap between the advantages of each methods.
3. To further extend the flexibility of measurement by enabling the device to read unprocessed soil samples. This can be done by conducting more studies regarding soil characteristics and its chemical properties.
4. To improve the portability feature of the developed prototype, rewriting the program in various platform compatible with mobile devices including cellular phones and tablets is recommended. Further reducing the size and power consumption is also recommended to enhance this feature.

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