New Brunswick Soil & Crop Improvement Association Inc.
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1. Project title and project number:

Developing a science-based grass-roots level tool for systematic field evaluation of soil health in New Brunswick.

2. Project leader and collaborators:

Sheng Li (FRDC), soil scientist, project science lead; Sheldon Hann (FRDC), researcher on GIS and land resources, project co-Lead; Ray Carmichael (NBSCIA), project management and farmers outreach; Fangzhou Zheng (NBSCIA/FRDC), data analysis and field work; Xiaoyuan Geng (ORDC), pedologists, digital soil mapping; Louis-Pierre Comeau, Ikechukwu Agomoh (FRDC) and Alex Koiter (Brandon U.), soil scientists, method development, soil sample collection and data analysis; Charles Karemangingo (DAAF), soil specialist, provincial databases; Cedric MacLeod (AANB-NB), Living Lab manager, farmers outreach; Sylvie Lavoie and Yulia Kupriyanovich (FRDC), AAFC technicians, technical support.

3. Specify period of time for which the interim report is being submitted:

April 1, 2023 to March 31, 2024

4. Project Objectives(s):

1) Develop a grass-roots level tool for Field Evaluation of Soil Health (FESH) in New Brunswick.
2) Compare soil health status in a specific field to that on another field or the reference values a the local, regional or provincial levels.

5. Project Deliverable(s):

1) A manual describing the step-by-step procedure for the FESH model
2) An FESH reference database with local reference FESH scores for different regions in NB under different land uses
3) A website and a mobile application for FESH
4) Workshops and field days for FESH training and demonstration
5) Fact sheets, workshop training materials and scientific publications on FESH
6) A report (template attached), which provides the results and necessary information to support the defined objectives and deliverables

6. Summary of Progress:

This project is aimed at developing a grass-roots level tool for soil health evaluation in the field in NB. There are three components in this project. The first component is to develop a scoring system for the evaluation which includes the selection of soil properties as soil health indicators, standardizing methods used to determine the score for each indicator and the calculation procedure for the final score. The second component is to establish a database for those soil health indicators in NB. The last component is to develop a software or mobile app as an interface for collecting the data and presenting the results. In the first year the goal was to establish the scoring framework and test some field methods for selected indicators. The initialization of the project was difficult. There were many paper work to do and procedures to go through to get the research associate hired and the funds to flow. By the time everything was set up, the field season was over, which makes field work impossible. Despite all these challenges, the team did make great progress in the first year. Below is a summary of the progress of research activities on the FESH model.

6.1. FESH framework—Soil health indicators (SHIs) and measurement methods

A draft framework for the FESH tool was established during the proposal stage. This draft version was discussed in two expert panel meetings and via separate communications with individual panel members. Revisions were made and a first working version was finalized (Table 1).

The framework followed a structure similar to the one utilized in the popular Comprehensive Assessment of Soil Health (CASH) assessment tools. It implements a scoring system which determines soil health based on scores assigned to various SHIs, classified into three categories: physical, chemical, and biological. This approach ensures an overall evaluation of soil health while meeting the outlined criteria for simplicity, cost-effectiveness, and adaptability, making it accessible and valuable for farmers in NB.

Table 1. Soil Health Indicators (SHIs) used in the FESH tool and their measurement methods

Soil Health Indicator (SHI)	Method of measurement	Accuracy	Importance	Variation	Best timing for measurement
Physical					
Slope gradient	Inclinometer (mobile app)	5	3	Long term	Any time
Slope curvature (position)	Inclinometer (mobile app)	1	3	Long term	Any time
Tillage layer (Ap) depth	Visual/Ruler				
Depth to restrictive layer	Visual/Ruler	3	5	Long term	Any time
Soil structure	VESS	5	5	Seasonal/long term	Early spring / Late fall
Soil strength (hardness)	Pocket penetrometer	3	3	Seasonal/long term	Early spring / Late fall
Soil infiltration	Infiltration ring test	3	3	Seasonal/long term	Early spring / Late fall
Chemical					
Soil organic carbon	Soil color (mobile app)	3	5	Seasonal/long term	Early spring / Late fall
pH	pH paper and pH meter	5	5	Seasonal/long term	Early spring / Late fall
Biological					
Emergence rate	Count/Visual estimate	3	3	Seasonal	Early growing season
Root length and density	Tape measure/Visual	3	5	Seasonal	Mid growing season
Root coating	Visual	1	3	Seasonal	Mid growing season
Earth worm activity	Count	1	5	Seasonal	Mid growing season
Mycelium development	Visual	1	3	Seasonal	Mid growing season

6.2. Slope gradient and curvature measured with inclinometer mobile apps and manual method

For the evaluation of slope gradient and slope curvature, candidate FESH methods included the use of two mobile apps, the Simple Inclinometer (app 1) and Clinometer (app 2), as well as manual measurements using a wood stick and a measuring tape. The obtained slope gradient (%) results from these methods were compared with those from a digital inclinometer, which was used as the reference for verification, in both the laboratory and field settings.

In the laboratory test, 25 different slope gradients ranging from 0% to 30% were measured using both mobile apps and the digital inclinometer. Results revealed that, with the exception of slope gradients less than 3%, the values obtained from both apps were consistently lower than those from the digital inclinometer (Figure 1). By analyzing the differences between the app results and the digital inclinometer results, it was observed that the absolute errors of Simple Inclinometer were consistently lower than those of Clinometer (Figure 2). Specifically, for Simple Inclinometer, the absolute error was mostly less than 0.5 (slope gradient in %), suggesting its capability to accurately measure slope gradients.

In the field test, slope gradients were measured in three different fields (B2, A and U6 field) at the Fredericton Research and Development Centre (FRDC). Both the mobile phone and digital inclinometer were placed on an approximately 80 cm long wooden board to measure slope gradients. For slope curvature determination, additional gradient measurements were taken 5 meters away from the initial location along the slope, and the slope curvature was calculated as: $\frac{\text{Gradient 1} - \text{Gradient 2}}{\text{Distance}}$. Positive values indicate an upwardly curved convex surface, while negative values indicated an downwardly curved concave surface. Results demonstrated that, with a few exceptions, errors in slope gradient (%) were less than 0.2 (Table 2), and errors in slope curvature (% m^{-1}) were less than 0.02 (Table 3). These findings support the conclusion that the mobile app provides a reasonable estimation of slope curvature in field conditions.

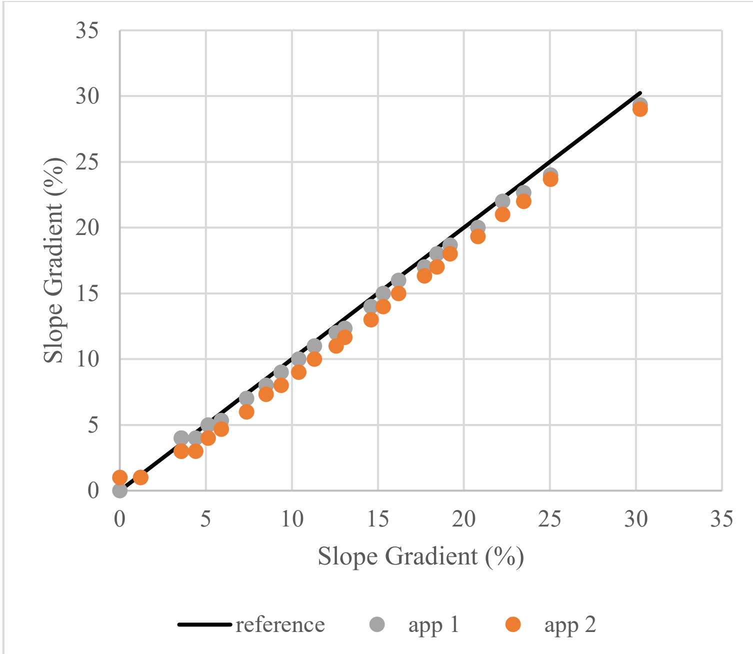

Figure 1. The 1:1 ratio scatter plot to compare the slope gradients (%) measured using both mobile apps (app 1: Simple Inclinometer and app 2: Clinometer) and digital inclinometer (reference).

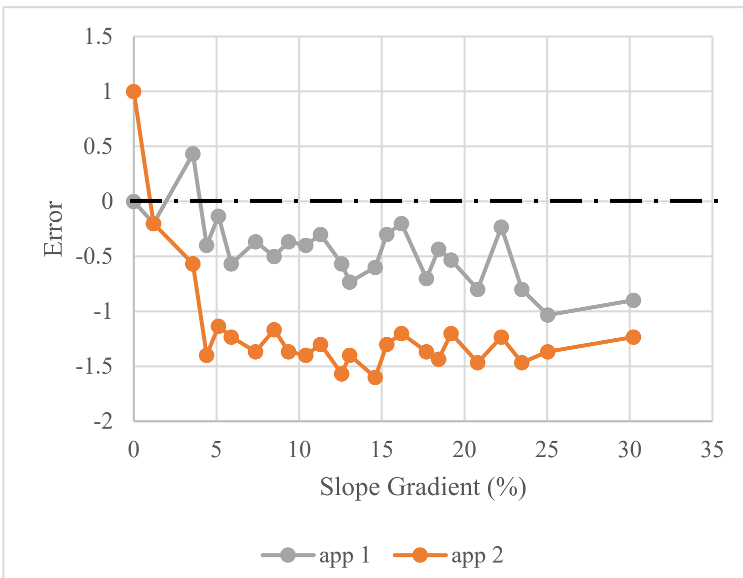

Figure 2. The differences of the measured slope gradients (%) using the reference method and two mobile apps (app 1: Simple Inclinometer and app 2: Clinometer), respectively.

Table 2. The slope gradients (%) measured in three fields using the mobile app (Simple Inclinometer) and the digital inclinometer (reference)

		Slope Gradients (%)		
		B2	**A**	**U6**
App	Left Position	17	6	1
	Right Position	19	1	5
Digital	Left Position	17.2	5.5	0.9
	Right Position	19.2	0.4	4.9

Table 3. The slope curvature (% m^{-1}) calculated for three fields using the mobile app (Simple Inclinometer) and the digital inclinometer (reference)

		Slope Curvature (% m^{-1})		
		B2	**A**	**U6**
App	Left-Right	0.4	-1	0.8
Digital	Left-Right	0.4	-1.02	0.8

6.3. Soil infiltration measured with a infiltration ring

For the assessment of soil infiltration rate, the chosen candidate FESH method was the single ring infiltrometer. The ring was cut from a metal tube of 8.5 cm diameter and 20 cm long. The ring was driven into the ground using a hammer to 10 cm depth (Figure 3). Following installation, water was poured into the tube until it reached 5 cm above the ground. The time taken for the water level to drop from 5 cm to 4 cm was recorded. When the water dropped to 4 cm, water was added until water level reached the 5 cm mark again. This process was repeated until the time duration for water dropping from 5 cm to 4 cm was the same for three times. The control of the water depth was to achieve approximately a constant water head. The results is a curve of infiltration rate from the soil natural condition to the infiltration capacity (Figure 4).

Figure 3. The single ring infiltrometer, with 8.5 cm diameter and 20 cm long, used for the experiment.

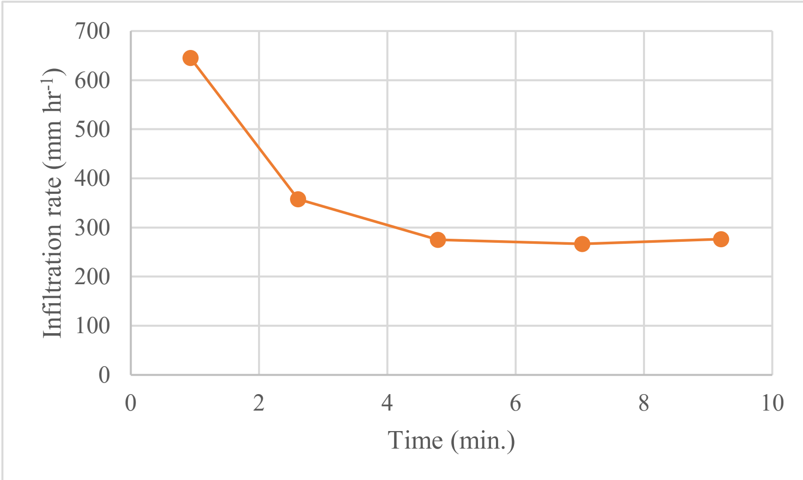

Figure 4. The soil infiltration rate (mm hr^{-1}) measured and calculated for the potato field B2 in FRDC.

Verification methods for soil infiltration included the use of a double ring infiltrometer in field conditions and a soil permeameter in a laboratory setting. However, due to time constraints, the tests were not completed, and additional tests are planned for the upcoming field season to ensure comprehensive validation and refinement of the FESH method for assessing soil infiltration rates.

6.4. Extended VESS for the assessment of soil structure and other soil properties

For the assessment of soil structure, the Visual Evaluation of Soil Structure (VESS) tool was selected as a candidate method for FESH. The VESS tool has been tested and validated for diverse purposes globally. The VESS tool is a scoring system based on the examination of various soil properties of a freshly dug soil block. The evaluation procedure was standardized into seven steps, which was described in a concise one-page (two-sided) field guide that can be easily printed and laminated for field use. The VESS tool was tested in a field site in the FRDC. Three locations in the field selected to represent soils expected to have a range of different soil structures. In each location, a soil block of approximately 15 cm long, 15 cm wide and 30 cm deep was excavated using a shovel with a one foot long spade. Soil structure was evaluated following the seven steps described in the field guide. Two evaluators did the evaluation independently. The results show that the scores reflected the expected soil structure differences among the difference locations (Table 4). However, there are large differences between the evaluators. This indicates that the method is valuable for structure assessment but method standardization and personnel training probably are needed for data consistency.

Several other Soil Health Indicator (SHIs) can be evaluated during the process of VESS (Table 4). These SHIs include soil organic carbon (via soil color), soil strength (hardness), surface layer depth, depth to restrictive layer, root length and density, root coating, mycelium development, and earthworm activity. The determination of soil organic carbon via soil color will be described in detail in next section. Soil strength was measured with a pocket penetrometer during VESS assessment. After excavating the soil block, the undisturbed side of the soil pit was used as the soil profile for soil strength measurement. The pocket penetrometer was horizontally pushed into the soil profile, with the knurled portion of the handle gripped, and the piston pushed into the soil with steady pressure until reaching the calibration groove. Three measurements were taken for the upper layer, followed by another three measurements for the lower layer. The method was tested together with the trial for the VESS tool and it was found that the pocket penetrometer reading does reflect the soil strength difference between the two soil layers but repeatability of the measurement was not ideal. Further validation of the method will be conducted to compare the results of pocket penetrometer readings to a penetrologger measured profile soil strength readings.

For the assessment of surface layer depth, the depth where the soil exhibiting changes in color and structure was determine visually and measured with a ruler. Similarly, the existence of restrictive layer was determined with visual examination of color and structure as well as penetrometer readings. When a restrictive layer was defined, its depth was measured with a ruler. Root development was evaluated by measuring the depth at which 80% of plant roots reached within the soil block, with the longest root depth also recorded. For root coating, a scoring system was developed and the evaluation was conducted for roots within the excavated soil block. The scoring system comprises three levels: 0 - roots white, no soil covering; 1 - some root coated, with partial coverage; and 2 - most or all roots coated, with the majority exhibiting full coverage. Similarly, mycelium development was assessed using a three-level scoring system: 0 – no mycelium; 1 – some mycelium present; 2 – most mycelium observed. For earthworm activity, the number of live earthworms present in the soil block was counted and earthworm activity was calculated as: $\frac{\text{Number of the worm in the soil block}}{\text{Volume of the soil block}}$.

Table 4. The Soil Health Indicators (SHIs) measured and evaluated from the soil block in three different fields in FRDC

Indicators	Field		
	B2	**A**	**U6**
Soil block			
Upper layer VESS score	1	1	2
Lower layer VESS score	2	2	2
Upper layer hardness (kg cm^{-2})	1.1	1.2	1.2
Lower layer hardness (kg cm^{-2})	1.6	2.1	1.1
Surface layer depth (cm)	7	7	7
Rooting depth 80% (cm)	15	14	11
Longest root (cm)	19.5	25	16
Root coating score	1	2	1
Mycelium score	0	0	0
Earthworm Count	1	2	0

6.5. Soil organic carbon assessment with soil color

Soil color is often considered indicative of SOC, making color measurements a valuable proxy for estimating SOC levels. Our goal is to establish a simple method to estimate SOC levels via soil color. In this past year, we explored the possibility to extract color information from mobile phone image of soil samples and correlate the color parameters to SOC measurements. The task was actually three folds, first is to establish color parameters of soil samples to their SOC levels, second is to validate the color information extract from mobile phone images with a true color measurement and the last is to establish mobile phone image color .

For the first step, we used soil colors measured with a FieldSpec4, which was a industry standard device for soil color measurement. The test was conducted with air dried ground soil samples with know

SOC content values taken from different sites in NB. Since soil color can be influenced by factors such as soil moisture, particle size, and surface roughness. We conducted experiments to compare dry versus wet soil, soil samples passing through 2 mm versus 63 µm sieves, rough surfaces with pressed smooth surface. The samples were placed in a Petri dish, prepared according to the designed conditions and then soil color was measured with the FieldSpec4. The color information collected in the FieldSpec4 was converted into the Munsell color space and the Hue, Chrom and Value (HCV) were determined. Munsell value is known to be strongly affected by SOC level so correlation analysis were conducted between the obtained Munsell values and the known SOC contents. Results indicated a significant correlation between soil color and SOC in most cases, with brighter soil colors corresponding to lower SOC content. Notably, the highest R^2 value, reaching 0.9, was observed under the conditions of dry, 2 mm sieved, and a smooth surface, suggesting that soil color measured by the FieldSpec4 accurately estimated soil carbon content under these specific conditions (Figure 5).

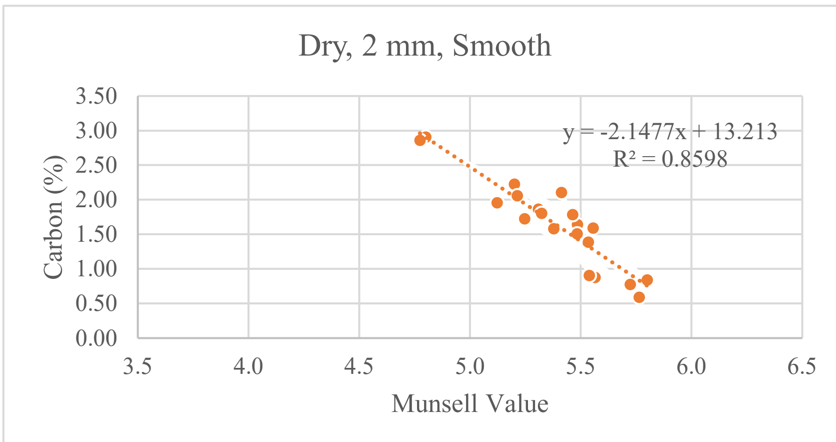

Figure 5. The relationship between soil carbon content (%) and soil Munsell value obtained from the FieldSpec4 under the soil conditions of dry, 2 mm sieved, and a smooth surface.

The second step was to test whether soil color obtained from mobile phone images agrees well with that from the FieldSpec4. This was done by using a commercial color plate with 24 colors as the reference. Each color square in the color plate was measured with the FieldSpec4. For the mobile phone image method, images were taken for the color plate under two lighting conditions were used when the image was taken. The RGB values for each color square in the color plate were extracted and converted to the Munsell color HCV, which was compared to those obtained from the FieldSpec4. Similar paired measurements with the two methods were also conducted for some soil samples. The results show a strong correlation with a Pearson correlation coefficient of 0.95 between the FieldSpec4 and mobile phone image color values (Figure 6).

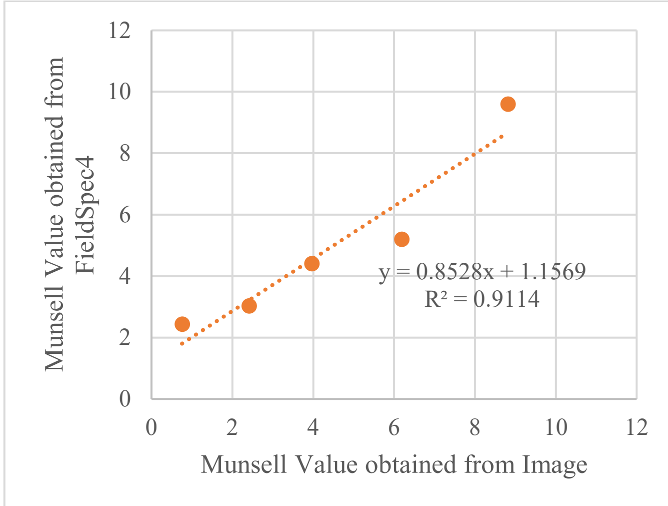

Figure 6. The relationship between Munsell value of the colors in the reference plate (Black, White, Red, Green and Blue) obtained from the FieldSpec4 and those obtained from the mobile phone image.

The last step was to test if SOC content can be successfully predicted using mobile phone images directly. This was tested by taking images of soil samples under dry, 2 mm sieved, and a smooth surface conditions. The soil sample Petri dish was place together with the color plate and mobile phone images were taken. The soil color were adjusted using the color plate as a reference (under the same lighting and camera setting condition with the soil). The adjusted soil color value were correlated with known SOC content. The results show that the R^2 for the relationship between SOC content and soil color value was 0.8, which was slightly lower than that obtained for the FieldSpec4 (Figure 7). For the wet soil condition, the R^2 decreased to 0.7, potentially due to the darker nature of wet soil narrowing the spectrum range of soil colors (Figure 8). Despite this, the results indicated that mobile phone images could serve as a convenient tool for farmers to capture soil color, ultimately facilitating the prediction of soil carbon content. Nevertheless, it is important to note that these tests were conducted under controlled laboratory conditions. Additional field experiments are planned in the upcoming field season to further validate and refine the methodology in real-world scenarios.

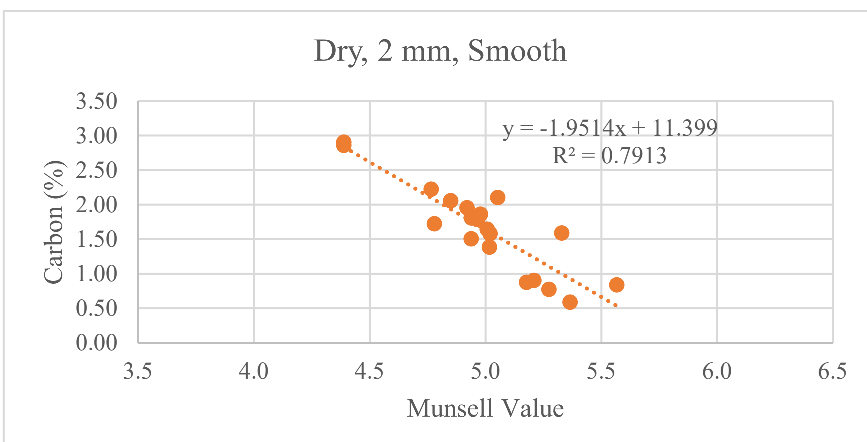

Figure 7. The relationship between soil carbon content (%) and soil Munsell value obtained from the mobile phone image under the soil conditions of dry, 2 mm sieved, and a smooth surface.

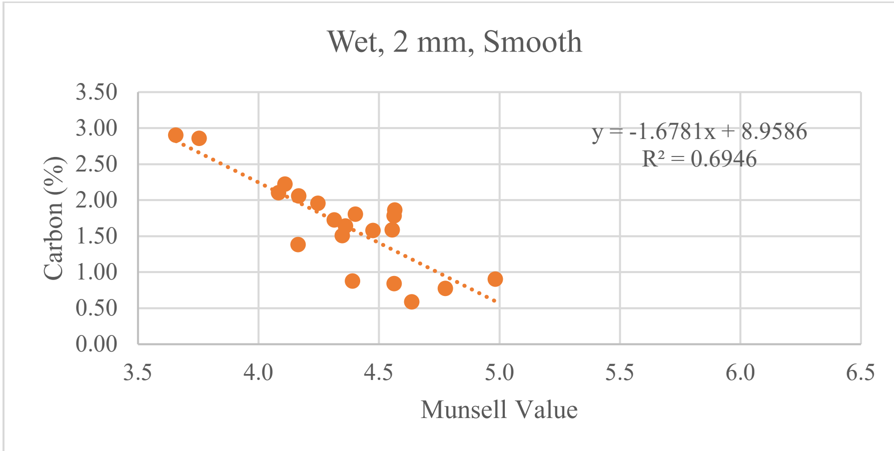

Figure 8. The relationship between soil carbon content (%) and soil Munsell value obtained from the mobile phone image under the soil conditions of wet, 2 mm sieved, and a smooth surface.

6.6. Soil pH measurement with pH sensors and pH papers

Soil pH, a crucial chemical SHI, is assessed through two candidate FESH methods: pH sensors and pH papers. A variety of sensors, including Sonkir, S-1, and TAKEMURA, along with pH papers such as Fisherband, Phiza, and Hydrion, were tested, using the laboratory pH meter as the reference method. These evaluations were conducted both in controlled lab settings and in the field.

In the lab test, five solutions of different pH values (ranging from 4.6 to 8.2) were used. Initially, these solutions were measured using the lab pH meter to establish the reference pH values. Subsequently, the same solutions were measured using various sensors and pH paper. The results indicated that, in most cases, pH values obtained from pH paper were not significantly different from the reference values. However, values measured from S-1 and TAKEMURA sensors were consistently lower than the reference values. Sonkir sensor results did not exhibit a consistent pattern compared to the reference values (Table 5).

Table 5. The averaged pH values obtained from different devices for five different solutions

Device	Solution				
	1	2	3	4	5
Lab pH meter	6.1	4.6	8.1	8.2	7.0
pH paper	5.6	4.5	7.5	7.5	6.0
Sonkir (1)	6.1	6.3	7.4	7.4	7.2
Sonkir (2)	5.3	5.5	7.2	7.3	7.0
Sonkir (3)	5.1	3.5	7.3	7.4	7.0
S-1 (1)	4.4	3.0	7.0	7.0	4.4
S-1 (2)	4.5	3.0	7.0	7.0	4.7
S-1 (3)	4.6	4.3	6.9	7.0	6.5
TAKEMURA	4.6	3.0	6.1	6.8	5.3

In the field test, pH values were measured in three fields in the experimental farm of the FRDC. For the pH paper method, soil samples was taken and mixed with the same amount of distilled water in the field. pH paper was dipped into the solution and the color was compared to a standard color strip to determine the pH value of the soil. For the pH sensors, the sensors were inserted into the soil surface approximately 15 cm deep. Soil samples were also taken and brought back to the lab, mixed with an equal amount of distilled water, and stirred for at least 30 minutes. The solution was measured using the lab pH meter which was used as the reference (true) pH value for the soil sample. Results indicated that the pattern of soil pH in different fields obtained with the pH papers were similar to the reference values, but not with the pH sensors (Table 6). Additionally, some sensors are too easy to break during field test. These findings suggest that further investigation is needed to establish a method for pH measurement in the field.

Table 6. The averaged pH values obtained from different devices for three different fields in FRDC

Device	Field		
	B2	**A**	**U6**
Lab pH meter	5.6	6.0	6.4
Fisherbrand	6.3	6.7	6.9
Hydrion	6.1	6.5	6.7
Sonkir (1)	7.0	7.0	N/A
Sonkir (2)	7.0	7.0	7.0
Sonkir (3)	7.5	7.5	N/A
S-1 (1)	6.2	6.4	5.6
S-1 (2)	6.2	6.4	N/A
S-1 (3)	6.2	6.4	5.4
TAKEMURA	6.4	6.4	6.0

7. Adjustments:

No adjustment has been made.