2021 Technical Report

Date: March 31, 2022

Acknowledgements

The On-Farm Applied Research and Monitoring (ONFARM) program is a four-year, applied research initiative delivered by the Ontario Soil and Crop Improvement Association (OSCIA) on behalf of the Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA) to support soil health and water quality research across farms in Ontario. This program is funded by the Canadian Agricultural Partnership, a five-year federal-provincial-territorial initiative. OSCIA would like to acknowledge the support of several organizations and members of the agricultural community for their contributions to the program:

- Soil health data is collected, compiled, and analyzed by The Soil Resource Group (SRG) located in Guelph, Ontario. SRG plays an instrumental role working directly with ONFARM cooperators to organize and execute the soil health trials, and collect soil health data for the edge of field sites.
- Five partnering Conservation Authorities (CAs) are implementing the Priority Subwatershed Project (PSP) component of ONFARM. They are currently working in six PSPs to collect key water quality, water quantity, and land-use data to achieve the program objectives. CAs are also providing technical advice and working directly with cooperators to carry out ONFARM outreach activities. Partnering CAs include: Ausable Bayfield Conservation Authority (ABCA), Essex Region Conservation Authority (ERCA), Maitland Valley Conservation Authority (MVCA), Lower Thames Valley Conservation Authority (LTVCA), and Upper Thames River Conservation Authority (UTRCA).
- The Watershed Evaluation Group at the University of Guelph is working to complete the modelling component of the program using the water quality, soil health, and economic data to create models using the Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) and Ecosystem Services Assessment Tool (ESAT) tools.
- Representatives from Agriculture and Agri-Food Canada (AAFC), Environment and Climate Change Canada (ECCC), and OMAFRA sit on the ONFARM Technical Working Group and provide valuable input on several technical aspects of the program, such as data management and collection.
- OSCIA would like to highlight the critical role of the participating ONFARM Cooperators in accommodating the research program's objectives on their respective farms. ONFARM is an applied research program that is being implemented on working farms across the province. ONFARM would not be possible without the dedication of cooperating farmers and the agricultural community.

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1.0 Introduction

1.1 Technical Report Overview

The 2021 Technical Report is released at the midpoint of the On-Farm Applied Research and Monitoring (ONFARM) Program. The objective of the Technical Report is to summarize the ONFARM research program and the best management practices (BMPs) being monitored, describe the data being collected, highlight technical achievements, and present preliminary results. Technical reports for ONFARM are released annually.

1.2 Project Description

ONFARM is a four-year initiative funded by the Canadian Agricultural Partnership. It was announced on December 5, 2019, by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). ONFARM is delivered by the Ontario Soil and Crop Improvement Association (OSCIA) with the support from various organizations, including OMAFRA, Agriculture and Agri-Food Canada (AAFC), five Conservation Authorities (CAs), the Soil Resource Group (SRG), and the Watershed Evaluation Group from the University of Guelph. ONFARM is also supported by a network of cooperating farmers who are essential to the success of the program.

ONFARM builds on work completed under the Great Lakes Agricultural Stewardship Initiative's (GLASI) Priority Subwatershed Project (PSP), supporting Ontario's Soil Health and Conservation Strategy and helping the industry meet commitments under the Great Lakes Water Quality Agreement. The three pillars of ONFARM that will benefit Ontario's agricultural industry are:

1. Continuation of the monitoring and modelling established in the PSPs;
2. Establishment of on-farm trials in-field to identify soil health indicators and test the effectiveness of best management practices in cooperation with farmers;
3. Enhanced engagement opportunities with stakeholders and farmers to foster a network of demonstration farms.

1.3 Organizational Structure and Research Sites

ONFARM can be divided into three components based on the three pillars: Soil Health, Water Quality, and Outreach and Engagement. OSCIA administers all components; however, the Soil Health and Water Quality activities are guided by the ONFARM Technical Working Group. Established in 2019, the Technical

Working Group acts as a scientific advisory committee. The Technical Working Group supported the selection of sites and BMPs for the soil health trials, and provides guidance to ensure best practices for data collection, analysis, and reporting across the program. The Technical Working Group includes members from the following organizations:

- Ontario Soil and Crop Improvement Association (OSCIA)
- Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)
- The Soil Resource Group (SRG)
- Ausable Bayfield Conservation Authority (ABCA)
- Essex Region Conservation Authority (ERCA)
- Maitland Valley Conservation Authority (MVCA)
- Lower Thames Valley Conservation Authority (LTVCA)
- Upper Thames River Conservation Authority (UTRCA)
- Environment and Climate Change Canada (ECCC)
- Agriculture and Agri-Food Canada (AAFC)
- University of Guelph (UofG)

In addition to their roles in the Technical Work Group, SRG and the CAs play an instrumental role in collecting ONFARM soil and water data. SRG is responsible for carrying out activities in the soil health component and partnering CAs are responsible for carrying out the water quality component in their respective PSP watersheds.

The ONFARM program is being implemented on working farms across the province in collaboration with partner organizations and cooperating farmers. In total, 33 ONFARM research sites were established in 2019 and 2020. Each research site is owned and operated by an agricultural producer who has agreed to work with researchers to manage the field plots where trials are conducted. Twenty-five sites were selected via a competitive analysis to study soil health BMPs. The other eight sites are Edge of Field (EOF) water quality monitoring stations that are integral to the PSP component. The location of each ONFARM site is shown in Figure 1.

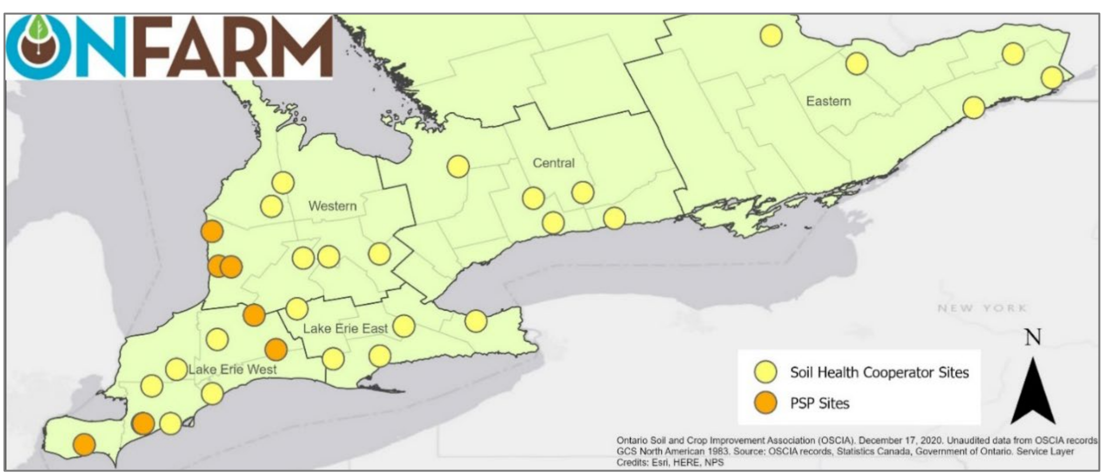

Figure 1. *Map of ONFARM sites by type.*

2.0 Soil Health BMP Trial Sites

2.1 Overview

Section 2.0 highlights the design of the soil health BMP component of the ONFARM program. It provides an overview of the cooperating sites, the types of data collected, and preliminary results from 2020 and 2021. For more information about each site, visit the interactive map located on the ONFARM website: https://www.osciaresearch.org/onfarm-applied-research/interactive-map/

2.2 BMP Trial Sites

Twenty-five farm sites within five regions of the province (Lake Erie West, Lake Erie East, Western, Central, and Eastern Ontario) representing both livestock and field crop operations were selected for soil health studies. A breakdown of the 25 BMP sites by region and operation type is shown in Figure 2, and regional distributions of soil textures are shown in Figure 3. SRG selected the sites in consultation with the Technical Working Group and the OMAFRA Soils Team. These sites implement plot-scale BMP trials to identify soil health indicators and test the effects of BMPs across a variety of soil types.

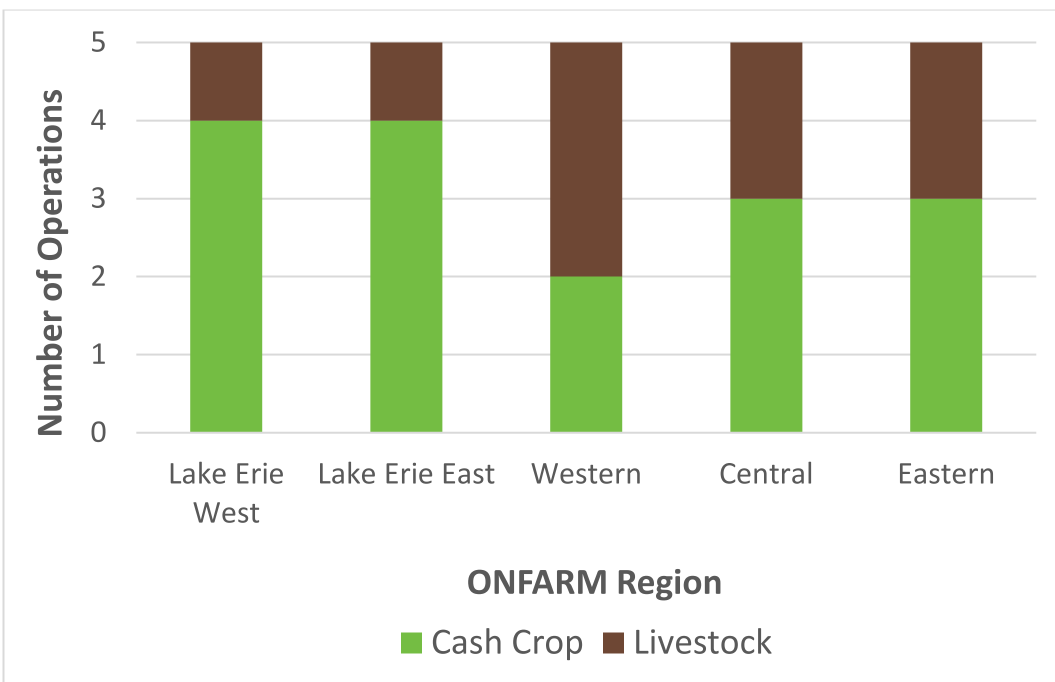

Figure 2. *Overview of the soil health BMP trial sites by region and type of agricultural operation.*

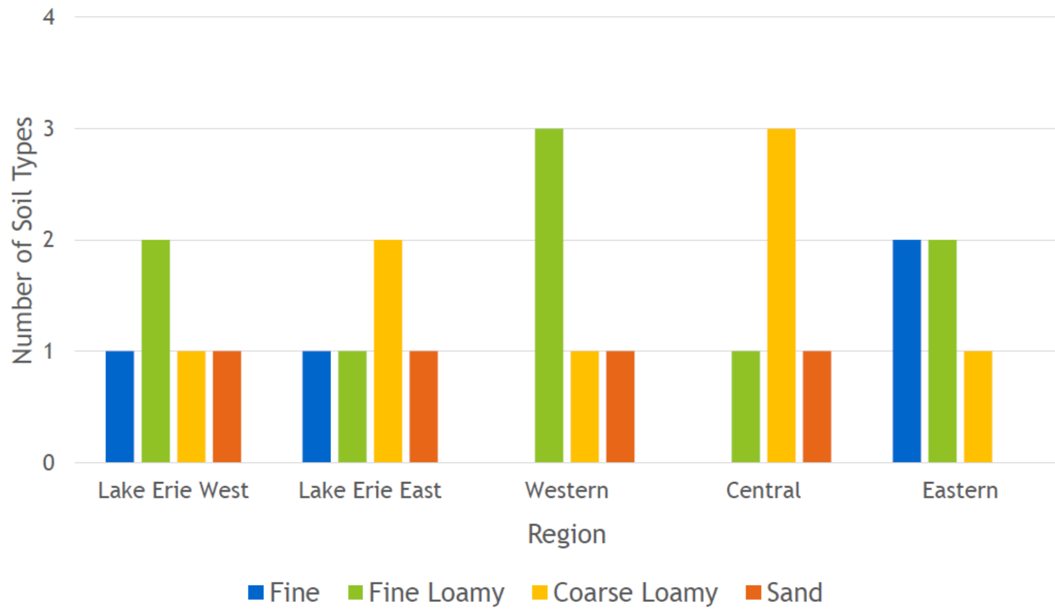

Figure 3. *Predominant soil textures found at each of the soil health BMP trial sites by ONFARM region.*

Trials in 2020 and 2021 have evaluated BMPs, including cover crops, organic amendments, and combinations of the two, to evaluate their impact on improving soil health across time, soil conditions and crop rotations, under various types of no-till or reduced tillage. All 25 trials occur on working farms and are designed and implemented by the cooperators in conjunction with SRG. The cooperators selected BMPs based on their own specific operation procedures, challenges, and goals. As a result, differences exist between operational practices at each site, including crop species, timing and type of tillage, fertilization, and pest management. A breakdown of the BMP treatments implemented in 2020 and 2021 at each soil health BMP trial site can be found in Table 1. All sites are implementing some form of no-till or reduced tillage. Cover crop treatments include different species and blend complexities, timing of planting, and termination practices. Various organic amendments have been applied depending on what is accessible to the cooperators, including agricultural source materials (e.g., manure and anaerobic digestate) and non-agricultural source materials (e.g., municipal compost and biosolids). In 2021, an extremely wet fall delayed harvest and prevented some cooperators from planting cover crops as intended during typical growing conditions; a number of those sites were seeded later in December or frost seeded in March of 2022. In Table 1, only BMP treatments that could not be completed are shown with a strikethrough the text.

2.3 Data Collection

To examine the effect different BMPs are having on soil health, ONFARM is collecting data (detailed in Table 2) from each BMP trial site through various means such as farmer interviews, soil sampling, and agronomic monitoring. ONFARM has collected a full suite of baseline information for each site, and researchers have continued with yearly monitoring of soil and agronomic indicators.

Table 1. *ONFARM soil health BMP trial site cropping and BMPs in 2020 and 2021. Intended BMPs that could not be implemented due to inclement weather are shown with a strikethrough.*

	2020		2021	
Site	Crop	BMPs	Crop	BMPs
1	Winter wheat	Cover crops	Corn	Interseeded cover crops
2	Soybeans	Cover crops, manure	Sugar beets	Interseeded cover crops
3	Soybeans	Cover crops, pelletized biosolids	Corn	Interseeded cover crops, pelletized biosolids
4	Winter wheat	Cover crop, manure	Corn	Cover crops
5	Corn	Cover crops, pelletized biosolids	Soybeans	Cover crops, liquid digestate
6	Winter wheat	Cover crops, digestate and manure	Silage corn	Cover crops, digestate and manure
7	Winter wheat	Cover crops	Corn	~~Cover crops~~
8	Buckwheat	Cover crops (3 mixes)	Corn	Interseeded cover crops
9	Corn	Interseeded cover crops	Corn	Interseeded cover crops
10	Corn	Cover crops, composted manure	Corn	Cover crops, composted manure
11	Winter wheat	Cover crops, pelletized biosolids	Corn	Cover crops
12	Winter wheat	Cover crops, compost	Soybeans	Cover crops, municipal compost
13	Corn	Interseeded cover crops	Corn	Interseeded cover crops
14	Winter wheat	Cover crops, manure and liquid biosolids	Corn	~~Cover crops, organic amendment~~
15	Winter wheat	Cover crops, composted manure	Corn	Interseeded cover crops, ~~organic amendment~~
16	Rye	Cover crops, manure and compost	Rye	Manure and compost
17	Winter wheat	Cover crops, manure	Corn	~~Cover crops~~
18	Winter wheat	Cover crops (3 mixes)	Corn	~~Cover crops~~
19	Winter wheat	Cover crops, compost	Soybeans	~~Cover crops, organic amendment~~
20	Corn	Interseeded cover crops	Soybeans	Cover crops, liquid biosolids and compost
21	Winter wheat	Cover crops, pelletized biosolids	Soybeans	Cover crop, pelletized biosolids
22	Spring wheat	Cover crops (3 mixes)	Corn	~~Cover crops~~
23	Spring wheat	Cover crops, manure	Silage corn	Cover crop
24	Spring wheat	Cover crops, manure	Corn	~~Cover crops~~
25	Soybeans	Interseeded cover crops	Corn	Interseeded cover crops

In 2020, a full pedological assessment was completed to characterize the soil profile and risk of soil degradation across each site. Samples were analysed for baseline properties of pH, organic matter, calcium carbonate, and soil texture (percentage of sand, silt, and clay). In June 2020, samples were also taken for the full suite of soil health indicators and a full crop nutrient analysis. Data was collected again from each site in June 2021 for a subset of key parameters used to indicate soil health. When multiple years of program data are available, these parameters will be linked to the agronomic data to explore their relationship with crop performance measurements.

Table 2. Examples of data being collected at each ONFARM BMP research location.

Data Collected	Examples
Farm-level data	Enterprise type, commodities, crop rotation and tillage system, available equipment
Field data	Plot location, dimensions, digital elevation information, key features, current cropping and tillage systems, management history
Treatment data	• Baseline/control (check) treatment specifications • Tillage + planting equipment changes – reduced tillage management • Crop/cover crop – species, rates, timing, control • Addition of organic amendments – type, source, characteristics (physical/chemical), calibrated rates, application method, timing
Benchmark data	Topographic (slope, geo-referencing), pedological soils information (horizon and profile characterizations, laboratory analysis of sand fractionation, texture, pH, $CaCO_3$), soil health tests (physical: bulk density; chemical: Soil Organic Matter (SOM), Solvita Labile Amino Nitrogen (SLAN), Wet Aggregate Stability, Active Carbon (POxC), Potentially Mineralizable Nitrogen (PMN); biological: Solvita CO_2 burst, total and parasitic nematodes)
Agronomic data	Emergence and stand population, soil temperature, soil moisture, pest and disease pressure, nutrient deficiencies and toxicities, biomass and crop yield, cover crop and/or crop residue
Economic data	BMP cost-benefit analysis

Agronomic assessments were completed in 2020 and 2021 for all 25 sites. The types of assessments performed in 2020 and the approximate time of completion are in Table 3. Weeds, diseases, and insects were noted (if present) during each field visit. In 2020 and 2021, cover crop assessments were performed at each applicable site to evaluate emergence, determine the dominant cover crop species and estimate cover crop biomass (shown in Figure 4). The height of each species, percentage cover of each species, and biomass yields were measured. Data was collected from each organic amendment application, including spreader calibration to determine application rates and nutrient analyses. Several examples of organic amendments applied are shown in Figure 5. Organic amendments applied in 2021 included: composted beef and poultry manure, beef manure, pelletized biosolids, liquid biosolids, mushroom compost, liquid anaerobic digestate, and municipal compost.

Table 3. Timeline of agronomic assessments completed at soil health BMP trial sites.

Assessment Completed	Months Completed
Emergence and plant counts	April-May
Crop Scouting	June
Hand Harvest Yields	July to November
Cover Crop Species Survey	August to September
Organic Amendment Application Assessments	August to November
Cover Crop Biomass Hand Harvest	September to October

***Figure 4**. Monitoring of cover crop treatments at BMP Trial sites in 2020 and 2021.*

***Figure 5.** Application monitoring of various organic amendment treatments used at BMP Trial sites in 2020.*

2.4 Soil Health Sampling Design

In-field trials were established in 2020, including georeferenced benchmark sampling locations to test specific BMPs and serve as reference points for repeat measurements. There are three to five treatment strips at each BMP trial site, with one serving as a control or check, where no new BMPs were implemented. Figure 6 shows a representative plot design example from one BMP trial site.

Figure 7 shows a conceptual sampling design used to determine sample locations at each site. Since slope and landscape position can influence soil properties, all treatments were established to run with the hillslope, and three soil zones (lower, mid, and upper) were established within each strip. Three replicate samples were taken within each zone around each benchmark, spaced out in a trillium pattern, to capture the potential variability in each sampling area. For soil parameters sent for laboratory analysis, each replicated sample was taken from a separate composite sample of approximately 24 soil cores at a 0-15 cm depth. A second composite sample of eight soil cores was taken for nematode analysis at a 5-20 cm depth. Each benchmark location was georeferenced using high accuracy global positioning system (GPS) coordinates to ensure consistency between yearly analyses.

Figure 6. *BMP trial Site 12 with field treatment strips and benchmark sampling locations (represented by the flags).*

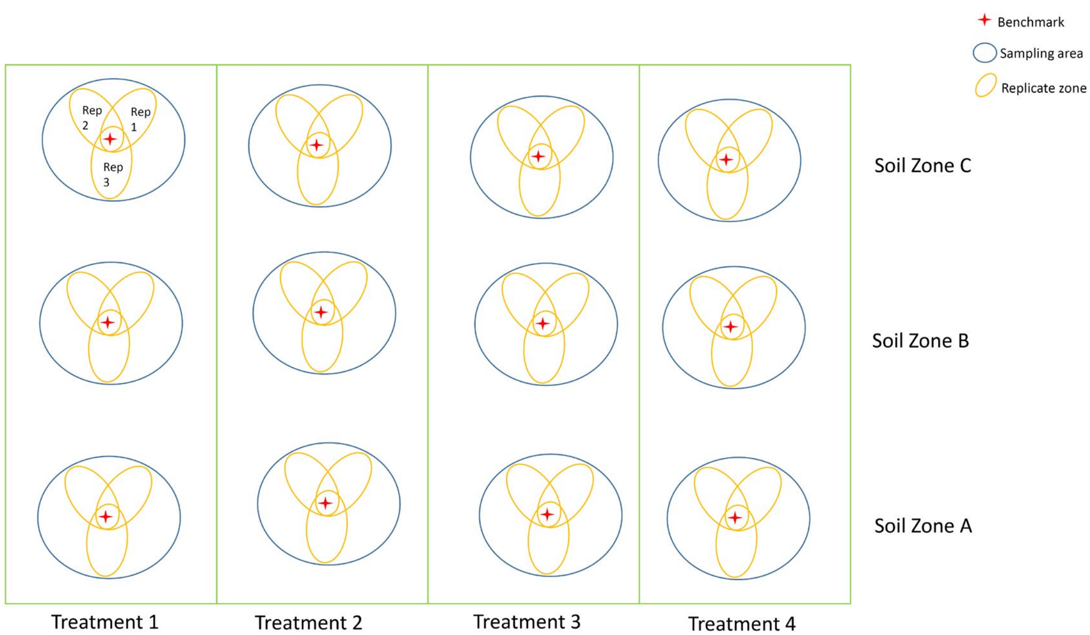

Figure 7. *Conceptual field treatment and sampling design for BMP trial sites.*

2.5 Preliminary Soil Health Data

Soil health data was collected following the sampling plan shown in Figure 7 in 2020 and 2021. A portion of the preliminary 2020 soil health data is publicly available via the ONFARM Data Dashboard (Figure 8), located on the OSCIA Applied Research website. The dashboard includes data from the following soil properties:

- Solvita CO_2-Burst (Solvita)
- Solvita Labile Amino-Nitrogen (SLAN)
- Active Carbon (also POxC)
- Organic matter
- Wet aggregate stability
- Bulk density

Solvita, SLAN, and Active Carbon (also referred to as Permanganate Oxidizable Carbon or POxC) are novel indicators of soil health, and their values can be compared against other common indicators, such as organic matter, to evaluate their potential for broader adoption for measuring soil health (shown in Figure 9). Further statistics from Pearson's r correlation testing are shown in Table 4. The analysis shown in Table 4 was completed on samples collected in June 2020, before any BMPs were implemented, representing baseline conditions at these sites. While most properties show significant correlations varying from weakly to moderately correlated, nothing is shown to correlate with yield, which is not unexpected because this analysis has not blocked for the considerable differences in yield between different crop species. For an example of how yield from a single site and crop can relate to these soil health parameters, see section 2.6.

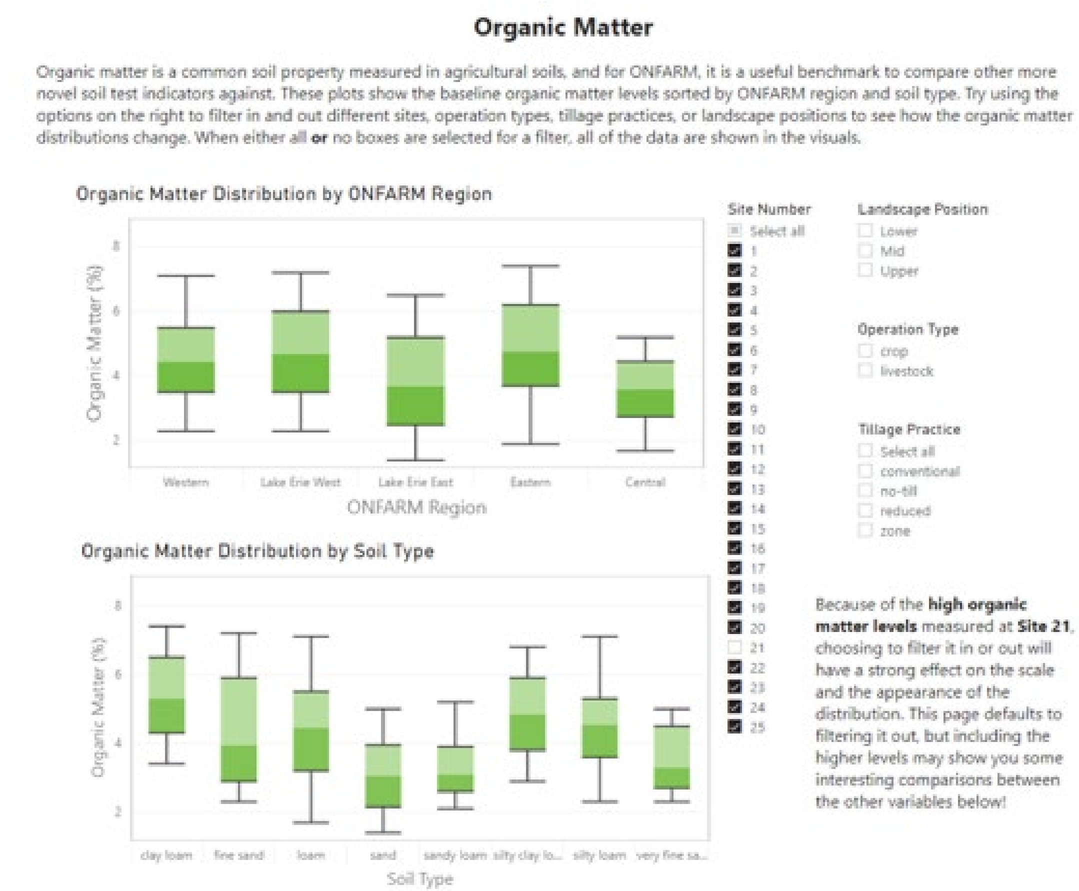

Figure 8. *The ONFARM Data Dashboard showing organic matter distributions by ONFARM region and soil type. Dashboard users can add or remove data from the visuals using filters and explore the effects of various field characteristics.*

***Table 4**. Correlation statistics between various soil health indicators and yield data from 2020 for all sample sites. Each cell shows Pearson's r, indicating the strength of the correlation (top); Prob > |r| under H0: Rho=0, indicating the statistical significance of the relationship when less than 0.05 (middle); number of observations (bottom). Highlighted values indicate moderate to strong correlations.*

2020 Correlation Coefficients All Sites							
	Organic Matter	**Active Carbon**	**Solvita**	**SLAN**	**Bulk Density**	**Moisture**	**Yield**
Organic Matter		**0.57066** **<.0001** **891**	0.24596 <.0001 891	**0.61921** **<.0001** **891**	**-0.50946** **<.0001** **890**	0.49501 <.0001 889	-0.01053 0.7647 811
Active Carbon	**0.57066** **<.0001** **891**		0.34889 <.0001 891	**0.52289** **<.0001** **891**	-0.49317 <.0001 890	0.41823 <.0001 889	0.08661 0.0136 811
Solvita	0.24596 <.0001 891	0.34889 <.0001 891		0.43486 <.0001 891	-0.13891 <.0001 890	0.19248 <.0001 889	0.02442 0.4873 811
SLAN	**0.61921** **<.0001** **891**	**0.52289** **<.0001** **891**	0.43486 <.0001 891		-0.39223 <.0001 890	0.37778 <.0001 889	0.05518 0.1164 811
Bulk Density	**-0.50946** **<.0001** **890**	-0.49317 <.0001 890	-0.13891 <.0001 890	-0.39223 <.0001 890		-0.36784 <.0001 889	-0.13103 0.0002 810
Moisture	0.49501 <.0001 889	0.41823 <.0001 889	0.19248 <.0001 889	0.37778 <.0001 889	-0.36784 <.0001 889		0.06967 0.0475 810
Yield	-0.01053 0.7647 811	0.08661 0.0136 811	0.02442 0.4873 811	0.05518 0.1164 811	-0.13103 0.0002 810	0.06967 0.0475 810	

Table 4 demonstrates that soil organic matter is significantly correlated (($p \leq 0.1$), with several other soil health indicators: Active Carbon and SLAN, followed by bulk density (which shows negative correlations with other indicators as would be expected). Solvita does not show a high correlation with SOM. Active carbon is a portion of the stored soil carbon and is reflective of soils tending towards increasing stable stored carbon; it is considered to be a more sensitive measure of increasing stable soil carbon than soil organic matter. Conversely, Solvita is a measure of microbial respiration resulting from the breakdown of organic matter (i.e. representing a portion of soil fertility in any given year). Therefore, since one represents storage and the other breakdown, at any given point in time and over a wide range of sites they may not be well correlated. However, while they may not move in lockstep with each other, in building soil health the goal is to have high levels of both indicators at a site. Their exact relationship will depend on a number of factors, such as soil type, temperature, moisture, crop, etc. Like Active Carbon, SLAN represents a component of available stored organic nitrogen and shows a good correlation with both Active Carbon and organic matter. Regardless, none of these correlations are so strong as to suggest farmers can only measure one and infer another. For example, having higher organic matter levels may indicate the potential for higher SLAN concentrations, but some farms with higher than 6% organic matter had as much SLAN available for crops as farms with 2 or 3% organic matter. Further analysis of these parameters will take place after 2022 data is collected.

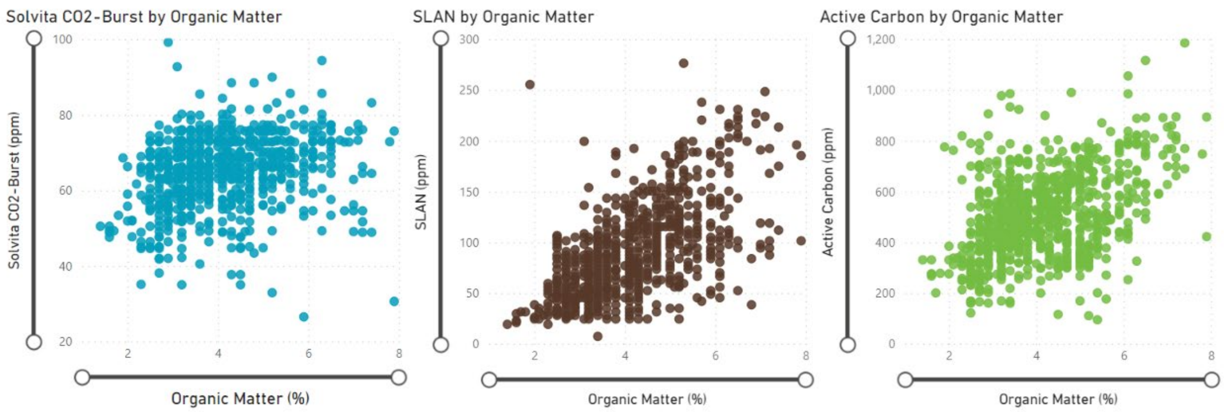

Figure 9. *Solvita CO2-Burst (left), Soil Labile Amino-Nitrogen (SLAN; middle), Active Carbon (right) against organic matter. Data are from all ONFARM sites, sampled by SRG in June 2020, excluding samples with organic matter higher than 8%.*

Analysis of benchmark pedology results has shown many ONFARM sites have soil quality degradation related to slope positions. Figure 10 compares organic matter levels in samples taken from the top of hillslopes with lower slope positions. In some soil types, such as fine sand, the difference is striking. Differences will depend on the degree of slope found on any site, historical management practices, and how long BMPs have previously been applied. For example, many ONFARM cooperators practiced some form of reduced tillage or no-till on their field sites for years before monitoring began, which may have limited the potential degradation which could have occurred under continued conventional tillage.

Figure 11 shows how these differences across slope positions are observable in other parameters. The effects of slope position and historical management have led to portions of ONFARM fields showing organic matter reductions of 1.73% in upper slope positions and 3.83 cm loss in A horizon thickness. This reduction in A horizon quantity and quality has a compounding effect, particularly on water holding capacity in these zones.

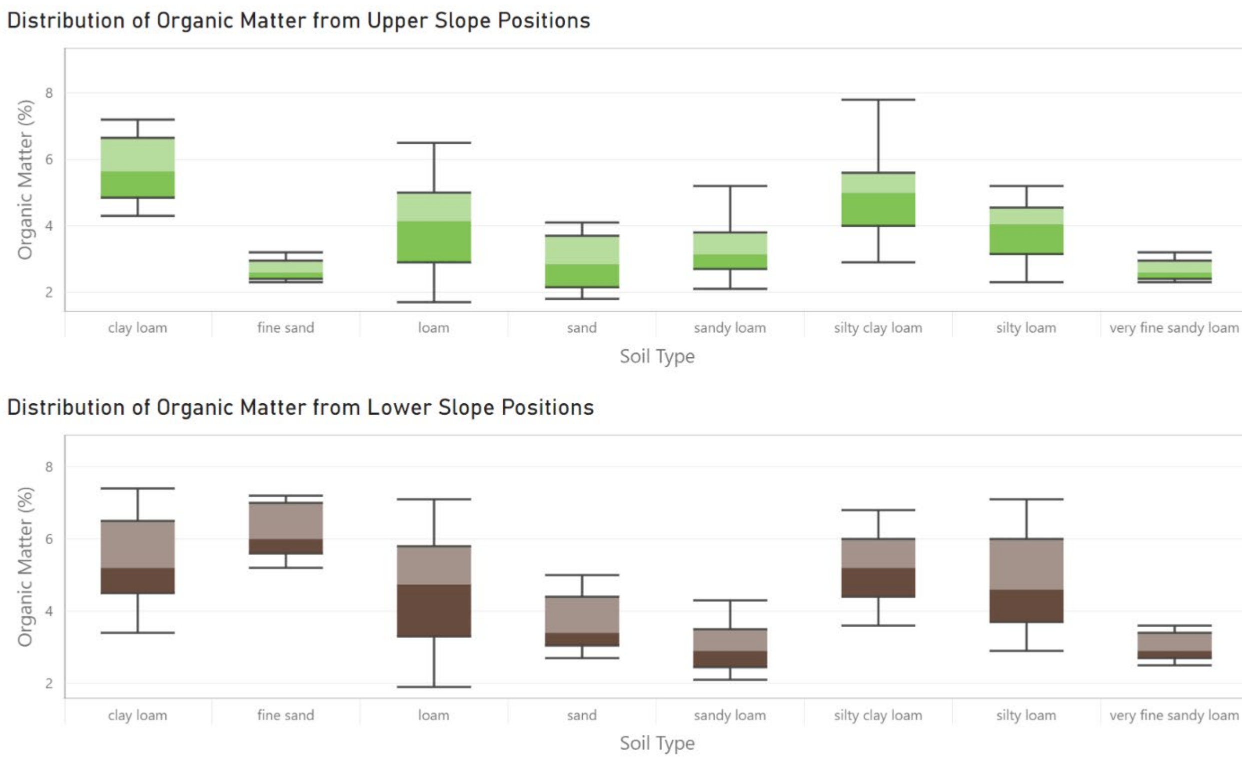

Figure 10. *Distribution of organic matter values taken from all ONFARM sites by soil type, separated by upper and lower slope positions, where organic matter was measured at less than 8%.*

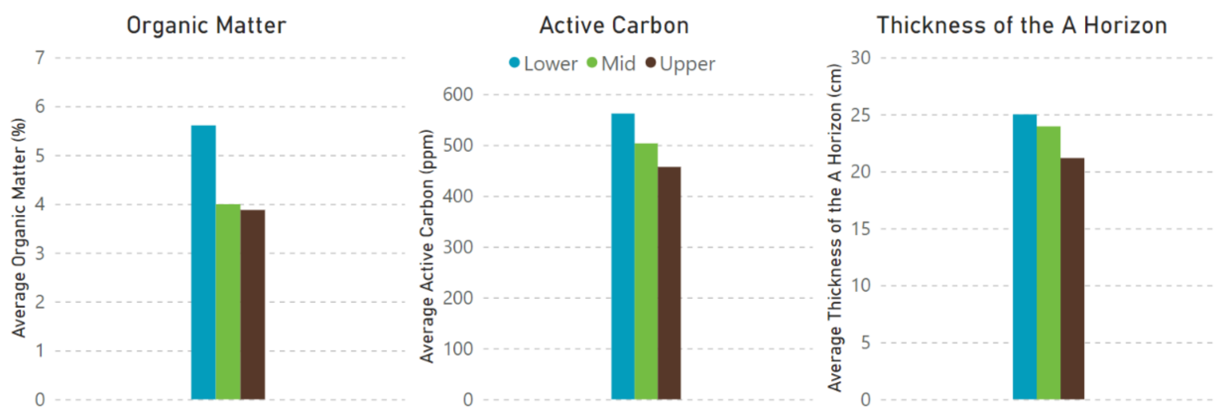

Figure 11. *Mean values of organic matter (left), active carbon (middle), and thickness of the A horizon (right) averaged across all ONFARM sites, separated by landscape position within each treatment.*

The effect of soil degradation from historical management is demonstrated in Figure 12. In the pictured soybean crop, the upslope areas have been modified by tillage erosion that has reduced the depth of the soil profile and the organic rich topsoil, causing less moisture to be available to the crop through the late growth stages, leading to earlier maturity. Downslope areas with higher organic matter and greater water holding capacity continued to grow. This example of degraded soil health visually demonstrates the direct impact management practices can have on yield potential of a crop across a field. Changing management practices to limit further degradation is important for preserving long-term yield potential.

Figure 12. *Aerial photo of Site 12 showing a soybean crop reaching maturity prematurely on degraded hilltops (SRG).*

2.6 Site 4 Case Study

Previous results have shown data combined from all ONFARM sites, whereas this section will examine results from Site 4, a layer poultry operation in Middlesex County. The farm follows a typical corn, soybean, winter wheat rotation, practicing no-till management for every crop. The field treatments are located on a gently sloping, silty clay loam soil, for which the cooperator's goal is to build a more resilient soil. Following the wheat crop in 2020, treatments compared a mixed cover crop planting (Figure 13), poultry manure application, and a combination of the two. The field was planted with another cover crop treatment in 2021 following corn harvest.

Pedological assessment identified that historical tillage erosion led to a reduction in topsoil thickness in the upper slope area by over 12 cm, leaving the Ap horizon half as thick as in the lower slope positions. Calcium carbonates from the parent material were also observed at the soil surface at the most highly eroded sampling locations.

Figure 13. *Site 4 pictured in autumn 2020, capturing the mixed cover crop treatment which followed winter wheat (SRG).*

Data collected for organic matter, Solvita, SLAN, and Active Carbon are shown in Figures 14 and 15; Figure 14 shows mean values aggregated by BMP treatment, whereas Figure 15 shows mean values aggregated by their landscape position along the hillslope. All data from 2020 and 2021 was grouped for each sampling location, and statistical analysis was done using data from 2020 as a covariate to ensure natural spatial variability within the field was not conflated with a treatment effect from the BMPs. Differences were tested with analysis of variance (ANOVA) to determine whether treatments or positions were significantly different ($p \leq 0.1$), and where differences were reported, Tukey-Kramer post-hoc analysis was completed to determine which treatments showed differences. These differences are indicated using the lettering system, where categories sharing a letter (for example, two columns both with an A, or one column with an A and one with an AB) do not show a significant difference, and categories without a common letter were tested as being significantly different.

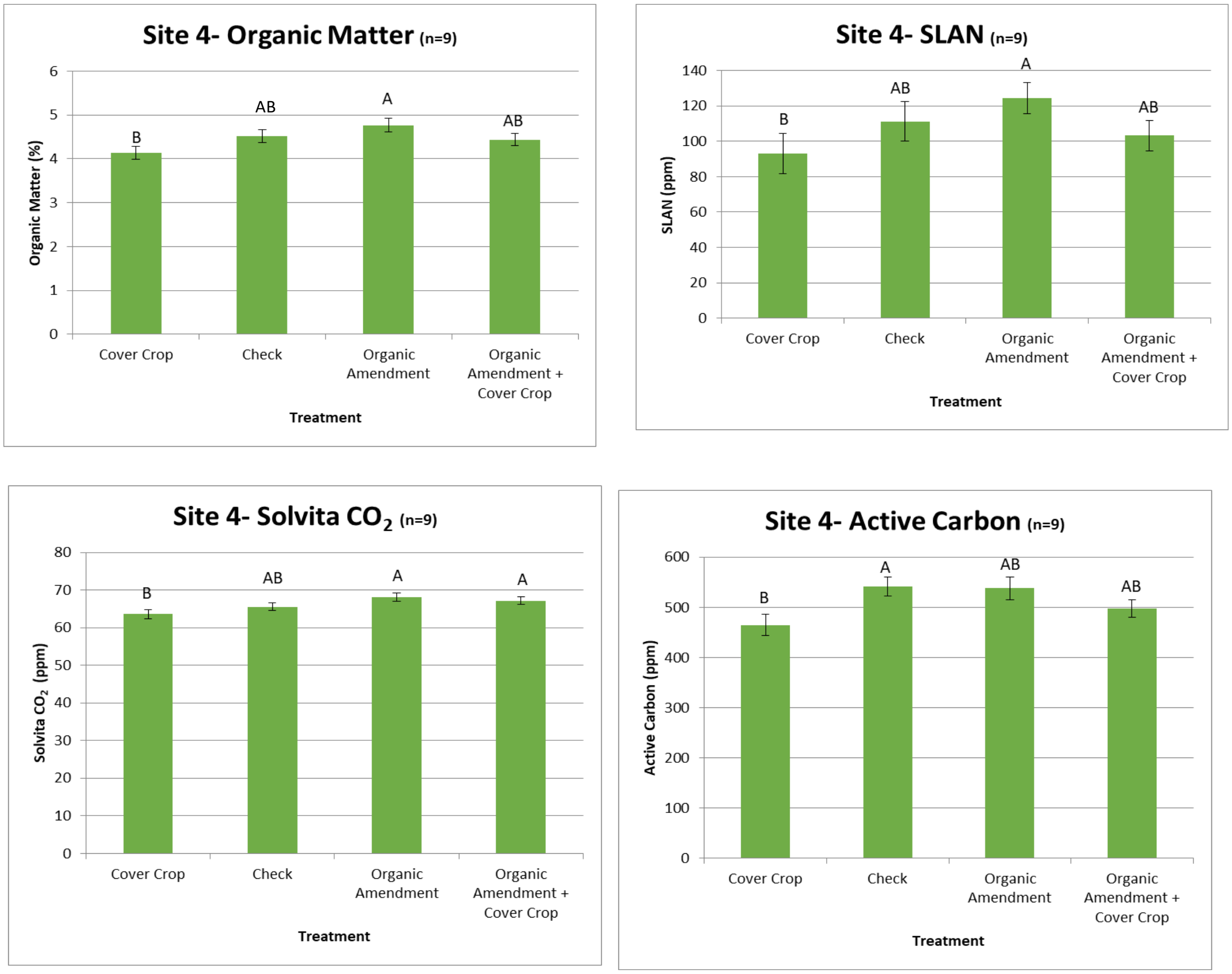

Figure 14. *Mean values and standard deviations of soil health indicators sampled in June of 2020 and 2021 comparing BMP treatments applied in the autumn of 2020. Lettering indicates where significant differences exist between BMP treatments.*

These results at Site 14 show that the organic amendments had the highest values for all four soil health indicators, however, no statistical difference was observed between the poultry manure treatment and the control (nor the combination). While the cover crop treatment showed slightly lower values on average for each indicator, it only showed a statistical difference for active carbon compared to the untreated check. The results from a single year of BMP testing at this site are preliminary but may indicate that organic amendments have the potential to show a faster response over additional years of implementation and may be of value for targeting short-term soil health improvements. The cover crop treatment from Site 4 demonstrates that some indicators may be reduced in the short term and show a lag in response before soil conditions improve over time.

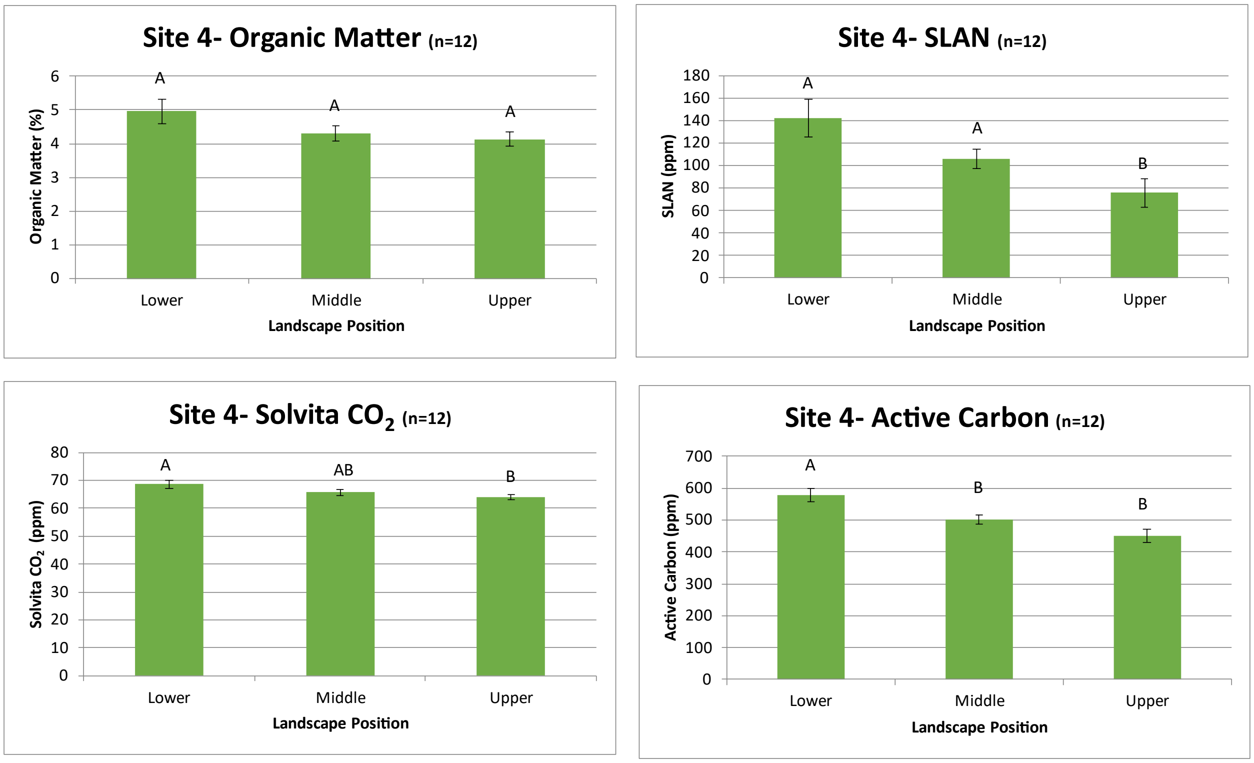

Figure 15. *Mean values and standard deviations of soil health indicators sampled in June of 2020 and 2021 comparing landscape position differences along a hillslope. Lettering indicates where significant differences exist between landscape positions.*

Figure 15 shows the importance of considering landscape position when sampling these indicators. Using SLAN concentration as an example, the cover crop and organic amendment treatments showed a significant difference of approximately 30 ppm, while landscape position showed a much larger difference by approximately 60 ppm. The range in the measurements taken at different landscape positions illustrates the variability that can be found in a field and the need to target sampling areas. These results are presented after one year of cover crop implementation at one site; as ONFARM continues into the third field season, results from repeated cover crop treatments on multiple sites will be analyzed to better understand these implications.

Another difference between organic matter and the other three soil indicators shown in Figure 15 is that organic matter, though trending similarly, is the only indicator to not show a statistically significant difference across landscape positions. Significant differences were observed in corn yield in 2021 between lower and upper slope positions, suggesting this group of soil health indicators may be more responsive to differences in soil health that relate to yield potential than organic matter alone.

The correlations shown in Table 5 from Site 4 reflect two different years of correlations between various soil health indicators and yield data. Differences can be seen between the two years in both the number of significant correlations observed and the strength of those correlations. This change from 2020 to 2021 is likely driven by the combination of BMP treatments (not implemented until after the June sampling period in 2020) and differences in crop requirements between winter wheat and corn, grown in 2020 and 2021 respectively. For the winter wheat crop, there was less variability in the soil health indicator values and yield, which may be explained by the density of the crop in the sampling areas and the growth stage of the crop during the sample timing. In 2021, the crop was corn which was at a relatively earlier growth stage during the June soil health sampling. The variability in the soil health and yield measurements result in more meaningful correlations between parameters. Notably, this analysis shows only correlations between these parameters and does not confirm any causal relationships. This analysis will be extended as ONFARM continues to collect data on these soil health indicators spread over more crops and BMP treatments.

3.0 Priority Subwatersheds and Edge of Field Sites

3.1 Priority Subwatershed Project Overview

In addition to the 25 BMP soil health research sites, eight EOF monitoring sites have been established in six Priority Subwatersheds (PSPs) of the Lake Erie, St Clair, and Huron basins (Figure 1). A map of each PSP's geographic location is shown in Figure 16. As with the soil health BMP sites, the EOF sites examine key soil health indicators while also monitoring different BMPs and agricultural practices' impacts on nutrient loading and water quality. These sites are supported by five CAs, and include:

- Garvey-Glenn (MVCA)
- Huronview Demonstration Farm (ABCA)
- Gully Creek (ABCA)
- Upper Medway (UTRCA/AAFC)
- Kettle Creek (UTRCA)
- Jeannettes Creek (LTVCA)
- Wigle Creek (ERCA)

Each PSP has established a network of monitoring stations to collect water quality samples, particularly during peak flow events (i.e. when peak nutrient loading is anticipated). Data is captured at subwatershed outlet stations, upstream subwatershed stations and EOF stations. This data will be used to calculate nutrient loads, evaluate the effectiveness of BMPs, and calibrate subwatershed models. Each CA is conducting assessments and farmer surveys to capture land-use and land management data within the watershed. The goals of the ONFARM PSP component are to better understand phosphorus movement throughout the agricultural landscape, model the water quality impact of agricultural BMPs at a subwatershed scale, and continue the soil health investigations outlined in Section 2.0.

Table 5. *Correlation statistics between various soil health indicators and yield data from 2020 and 2021 for Site 4, where the number of samples was 36 for each parameter. Each cell shows Pearson's r, indicating the strength of the correlation (top); Prob > |r| under H0: Rho=0, indicating the statistical significance of the relationship when less than 0.05 (bottom). Bolded values indicate moderate to strong correlations.*

Site 4 2020 Correlation Coefficients							
	OM	**ActiveC**	**Solvita**	**SLAN**	**BD**	**Moisture**	**Yield**
OM		**0.70754** **<.0001**	**0.5842** **0.0002**	0.35801 0.032	**-0.52338** **0.0011**	**0.57136** **0.0003**	-0.06857 0.6911
ActiveC	**0.70754** **<.0001**		**0.52632** **0.001**	0.30083 0.0746	**-0.63067** **<0.001**	**0.61184** **<0.001**	-0.02732 0.8743
Solvita	**0.5842** **0.0002**	**0.5232** **0.001**		0.3001 0.0754	-0.33666 0.0447	0.28819 0.0883	0.08425 0.6252
SLAN	0.35801 0.032	0.30083 0.0746	0.3001 0.0754		-0.15674 0.3613	0.29742 0.0781	0.24764 0.1453
BD	**-0.52338** **0.0011**	**-0.63067** **<.0001**	-0.33666 0.0447	-0.15674 0.3613		**-0.5649** **0.0003**	-0.01976 0.9089
Moisture	**0.57136** **0.0003**	**0.61184** **<.0001**	0.28819 0.0883	0.29742 0.0781	**-0.5649** **0.0003**		-0.21084 0.2171
Yield	-0.06857 0.6911	-0.02732 0.8743	0.08425 0.6252	0.24764 0.1453	-0.01976 0.9089	-0.21084 0.2171	
Site 4 2021 Correlation Coefficients							
	OM	**ActiveC**	**Solvita**	**SLAN**	**BD**	**Moisture**	**Yield**
OM		**0.73626** **<.0001**	**0.66688** **<.0001**	**0.78117** **<.0001**	-0.29109 0.085	**0.54887** **0.0005**	**0.51646** **0.0013**
ActiveC	**0.73626** **<.0001**		**0.58531** **0.0002**	**0.85786** **<.0001**	**-0.5254** **0.001**	**0.67006** **<.0001**	**0.59614** **0.0001**
Solvita	**0.66688** **<.0001**	**0.58531** **0.0002**		**0.71708** **<.0001**	-0.40392 0.0146	0.49848 0.002	**0.71928** **<.0001**
SLAN	**0.78117** **<.0001**	**0.85786** **<.0001**	**0.71708** **<.0001**		**-0.597** **0.0001**	**0.66185** **<.0001**	**0.69989** **<.0001**
BD	-0.29109 0.085	**-0.5254** **0.001**	-0.40392 0.0146	**-0.597** **0.0001**		**-0.48595** **0.0027**	-0.23561 0.1666
Moisture	**0.54887** **0.0005**	**0.67006** **<.0001**	0.49848 0.002	**0.66185** **<.0001**	**-0.48595** **0.0027**		**0.55032** **0.0005**
Yield	**0.51646** **0.0013**	**0.59614** **0.0001**	**0.71928** **<.0001**	**0.64842** **<.0001**	-0.23561 0.1666	**0.55595** **0.004**	

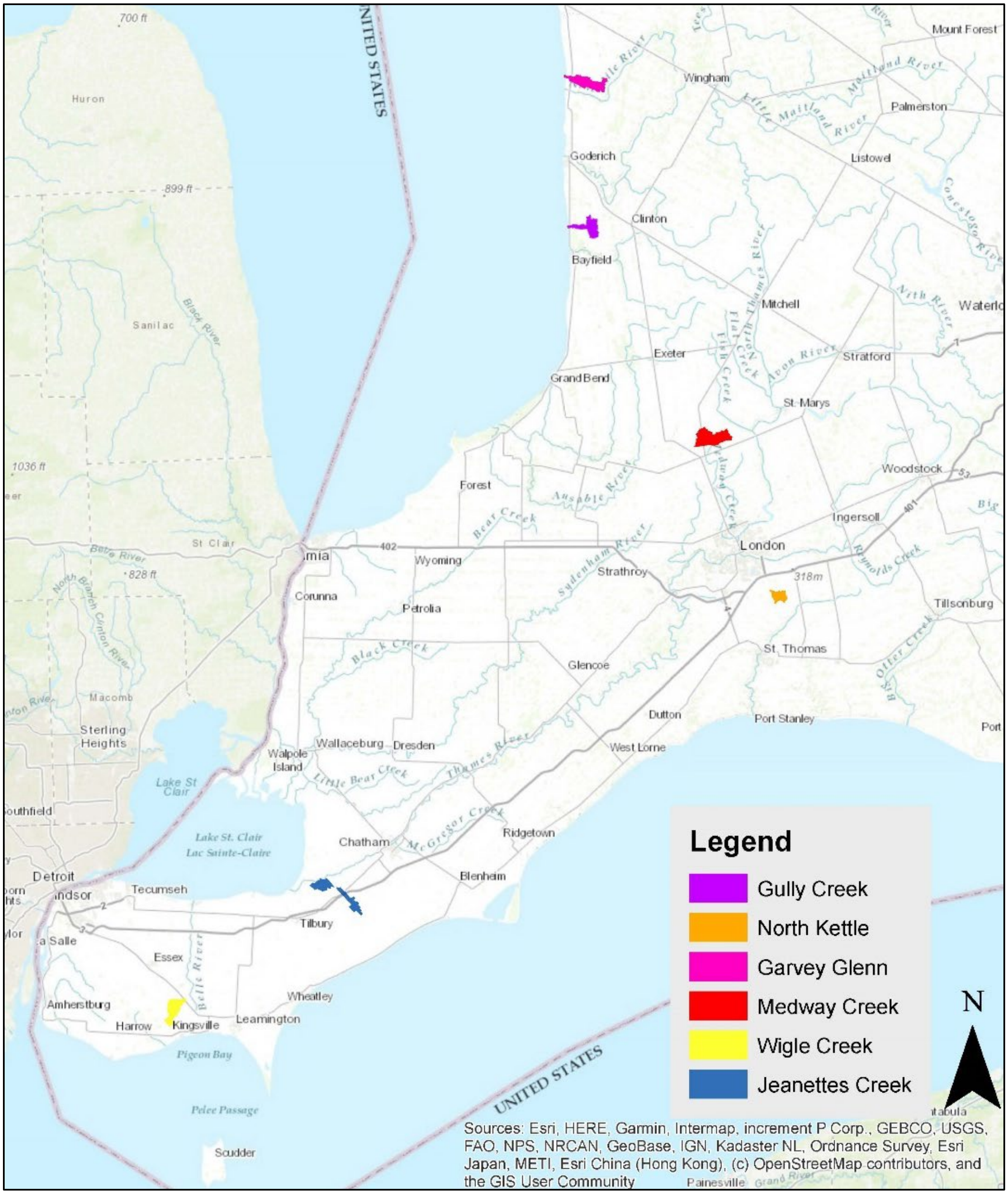

Figure 16. *Locations of ONFARM Priority Subwatersheds (PSP).*

3.2 Priority Subwatershed Data Collection

Data collection within the PSPs, specifically at the EOF monitoring stations, began in 2019 and continued throughout the 2021 ONFARM program year. Data was collected from various sources, and examples of the types of data collected are shown in Table 6. Water data is collected with a combination of automatic sampling equipment and manual sampling methods. Figure 17 shows staff from UTRCA collecting stream flow data downstream of an EOF station, and Figure 18 shows an automated EOF station collecting water at high flow. Figure 19 shows a conceptual diagram of an EOF station where sensor data are captured, and physical samples are collected. Following the [ONFARM Data Management Plan](), CA staff have input data into the Kisters Water Information System (WISKI) database for long-term storage. The WISKI database enhances the collection, management, reporting and advanced development of water networks. In 2022, the CAs are continuing their work on quality control, data management, and analysis.

Figure 17. *UTRCA staff monitoring flow in the Upper Medway Creek with an Acoustic Doppler Current Profiler boat. High-tech sampling equipment enabled them to capture accurate data for a 75 mm storm event in Sept 2021.*

In addition to water quantity and quality monitoring, each EOF site was sampled by SRG for the full suite of soil assessments described in Section 2.0; however, the treatment design differed slightly from the BMP trial sites. Cover crop, tillage, and organic amendment BMPs were explored at EOF sites, but benchmark locations were chosen to complement the pre-existing EOF water quality sampling infrastructure. Sample collection methodology from the soil health component was applied at all EOF sites.

Table 6. *Examples of data collected at each EOF location and within PSPs.*

Data Collected	Examples
Weather	Rainfall, snowfall, snowpack, relative humidity, ground temperature (5 cm, 15 cm, 30 cm), ground water level
Hydrologic layers	Stream/water body layer, municipal drainage layer (open and closed), tile surface inlet locations, subsurface tile drainage layer
Land use layers	Non-agricultural land use boundaries, land-based BMP layer (WASCoB, buffer, etc.), field boundaries, agricultural land use by field
Farmstead characteristics	Nutrient storages, livestock housing capacity/actual livestock numbers
Field/soil characteristics	Soil phosphorus (P) and potassium (K) test (0-6”), potentially mineralizable nitrogen (N) (0-6”), soil organic carbon (0-6”), soil aggregate stability, bulk density, infiltration
Field activities information	Fertilizer application, manure application, tillage, surface residue cover, planting, point discharges
Water quantity	Stream flow
Stream water quality	Total suspended solids, total P, total dissolved P, total organic P, total N, nitrate-N, ammonia-N, organic-N

Figure 18. *The inside of an automated sampling station produced by UTRCA, featuring equipment used to collect water samples at EOF sites (left), and an EOF station monitoring high flows (right).*

Runoff events were continuously monitored throughout the entire year. In 2020 and 2021 and across all PSPs, 33 runoff-generating events were sampled in spring, 35 events in summer, 83 events in fall, and 56 events in winter. The total number of events captured from the program’s start is 207 (Figure 20).

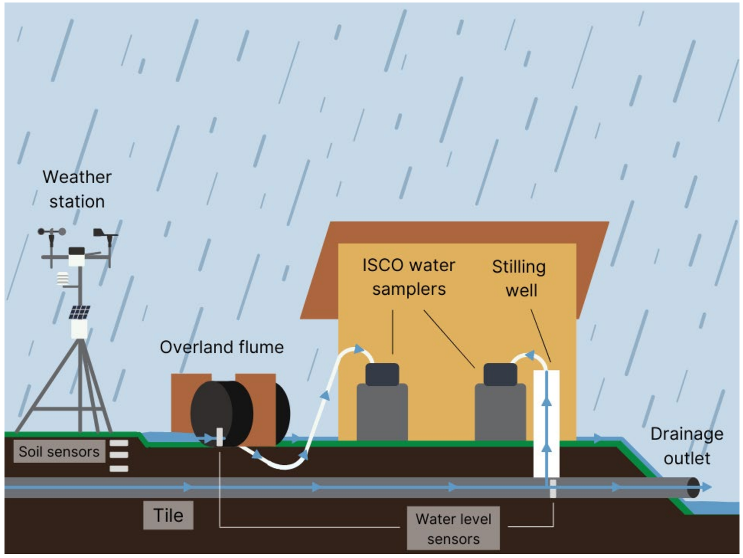

Figure 19. *Conceptual diagram of an Edge of Field (EOF) monitoring station in the Garvey-Glenn PSP (MVCA). Sensors capture weather, soil, and water level data, and water movement triggers automatic collection of water samples from overland flow or tile drains.*

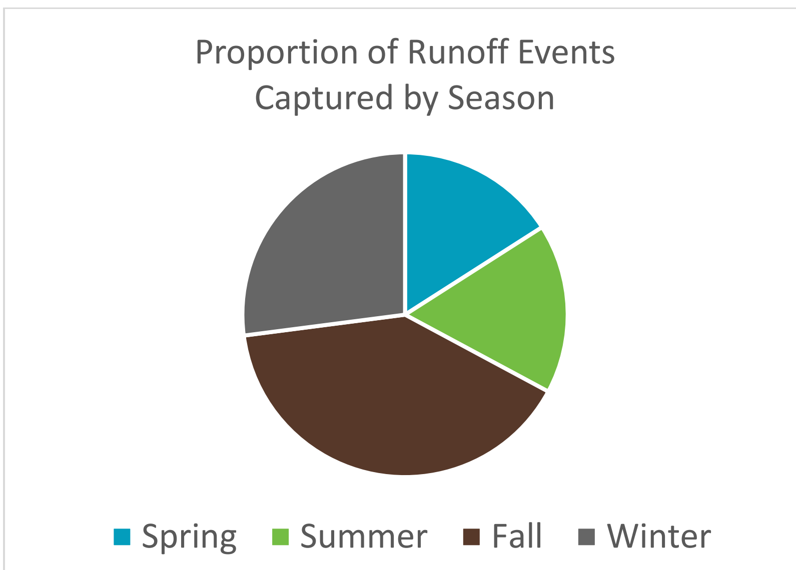

Figure 20. *Seasonal distribution of all 207 runoff events sampled under the ONFARM program across all subwatersheds. 33 events were sampled in spring, 35 events in summer, 83 events in fall, and 56 events in winter.*

As of March 2022, 3177 water samples were collected between all PSPs for laboratory analysis. Evaluating water quality and comparing results between systems requires a great deal of mathematical work beyond the sample collection and laboratory analysis. Water quality parameters, such as dissolved phosphorus or suspended solids, are presented as concentrations (i.e., mg/L) which identify how much of each parameter was contained in a sample. Concentrations are typically used to discuss nutrient levels in lakes or streams;

for example, Ontario's interim Provincial Water Objective standard for Total Phosphorus suggests excessive plant growth in surface waters should be eliminated at concentrations below 30 µg/L, or 0.03 mg/L. However, for EOF monitoring, researchers also consider the amount of water flowing exactly when each sample was taken; by overlaying nutrient concentrations sampled throughout an event with a hydrograph (as shown in Figures 23, 24, and 25), the total amount of a specified nutrient lost can be calculated. ONFARM researchers have determined the catchment area draining each EOF monitoring station and by dividing the amount of nutrients lost during an event by the catchment area they can determine the nutrient load (shown in kg/ha). Using nutrient loads enables strong comparisons between sites of varying sizes that may receive different weather patterns. Water quality data continues to be compiled from ONFARM EOF sites, and CA staff continue to analyze water quality data, which will be used to inform the modelling activities detailed in Section 3.4 and inform agricultural BMPs in Ontario.

In 2021, water quality monitoring from the EOF sites showed similar patterns between PSPs, with variability driven mostly by the time of year and weather patterns. In general, 2021 was drier than average through the spring (shown in Figure 21) with drought conditions occurring in some locations. Though some runoff events were sampled in the summer, most runoff occurred through the autumn. Larger runoff events during the non-growing season resulted in the majority of the observed nutrient losses.

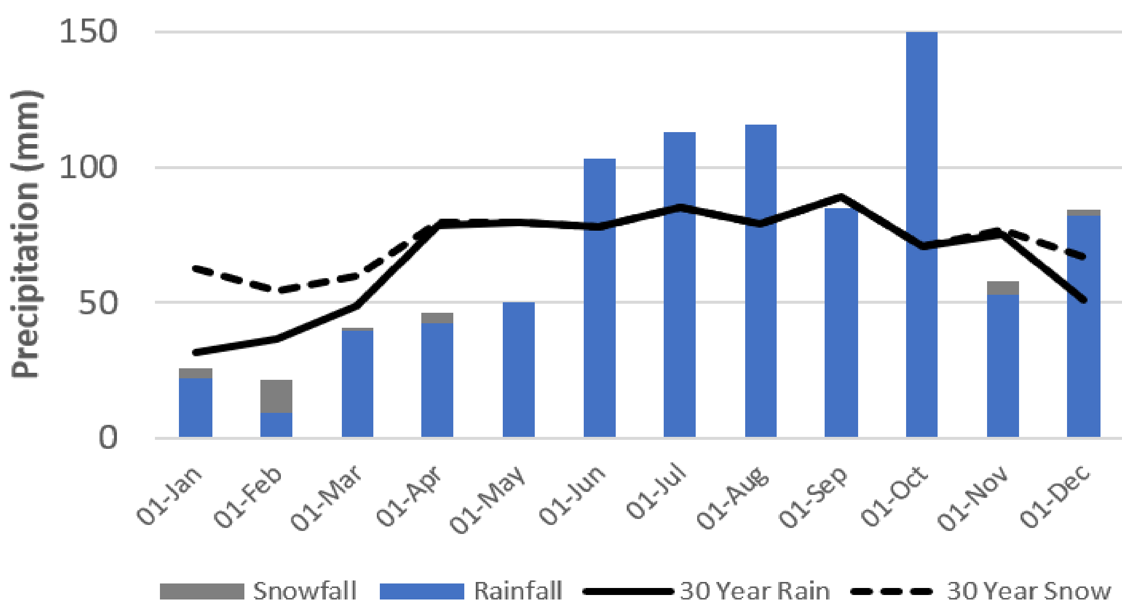

Figure 21. *Monthly precipitation received at Edge of Field sites 2 and 3 (LTVCA) comparing 2021 to the 30-year average data (Environment and Climate Change Canada).*

These seasonal trends have been observed in previous monitoring years as well; Figures 24 and 25 compare differences between a typical growing season and non-growing season event from 2020 from the Garvey-Glenn watershed. Peak flows from the winter event reached over 5,000 L/s and resulted in a phosphorus load over 70 times higher compared to the summer. LTVCA has observed similar trends consistent with historical data in their watershed; several runoff events in the fall and winter of 2021 were driven by heavy rainfall and resulted in the highest level of turbidity observed at the EOF site, shown in Figure 22.

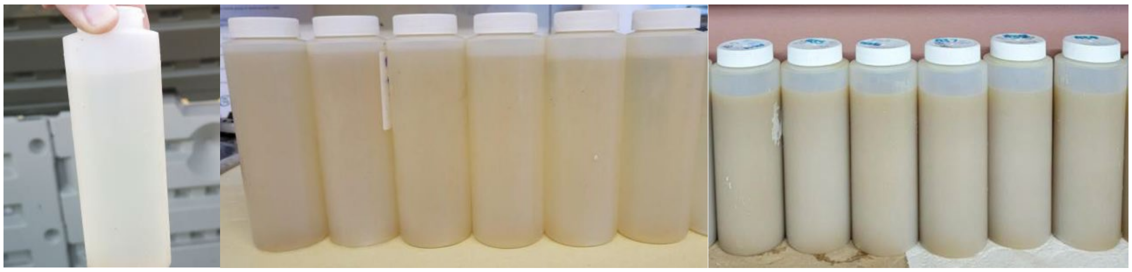

Figure 22. *Water samples collected by LTVCA in 2021 from July 14, Oct 15, and Dec 11 (left to right). Turbidity in the samples was greatest in December and indicates soil erosion has resulted in sediment-associated nutrients moving from the field to the creek.*

The particularly high turbidity observed in the December sample may have resulted from greater antecedent moisture conditions in the field compared to summer and fall events, and from difference in soil coverage with more exposure in bare wheat and soybean fields. However, heavy phosphorus loss still occurred during the October event; nutrient loads were measured at 0.48 and 0.72 kg/ha of dissolved reactive phosphorus and total phosphorus, respectively, from LTVCA's EOF site's tile drain system. Turbid samples similar to this are commonly observed in the watershed, related to the inherent characteristics of Brookston clay soils found in the region, such as slow infiltration and consequently more suspended soil in runoff. Differences in soil, regional climate, and resulting nutrient loading levels observed between ONFARM sites demonstrate the need for continued water quality monitoring to provide regionally based guidance for BMPs.

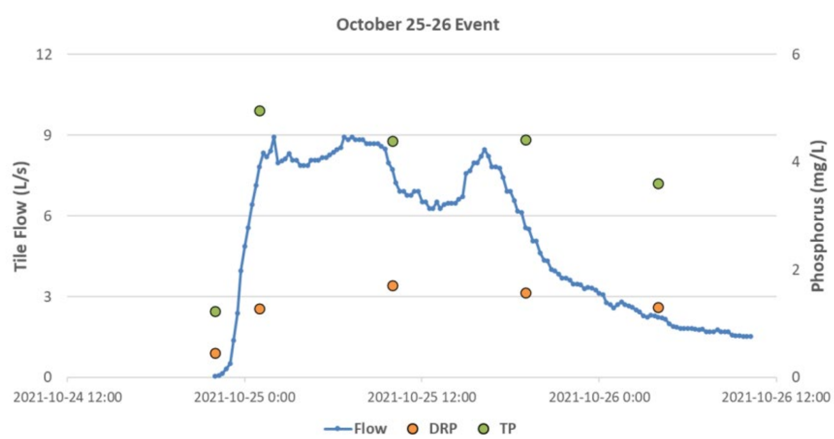

Figure 23. *Runoff event flow monitoring and associated phosphorus concentrations from October 25-26, 2021 (LTVCA).*

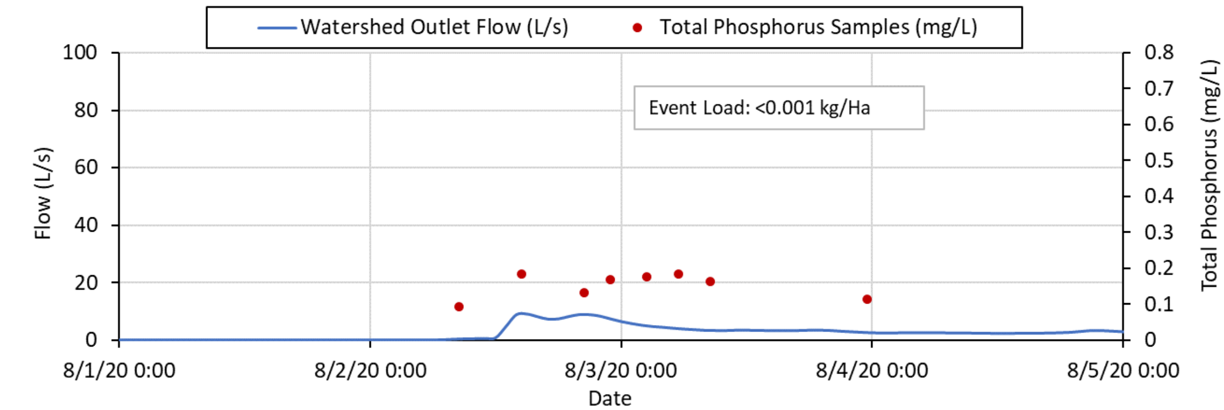

Figure 24. *Watershed outlet flow from the Garvey-Glenn Watershed and total phosphorus concentrations resulting from a rain event in the growing season of 2020 (MVCA).*

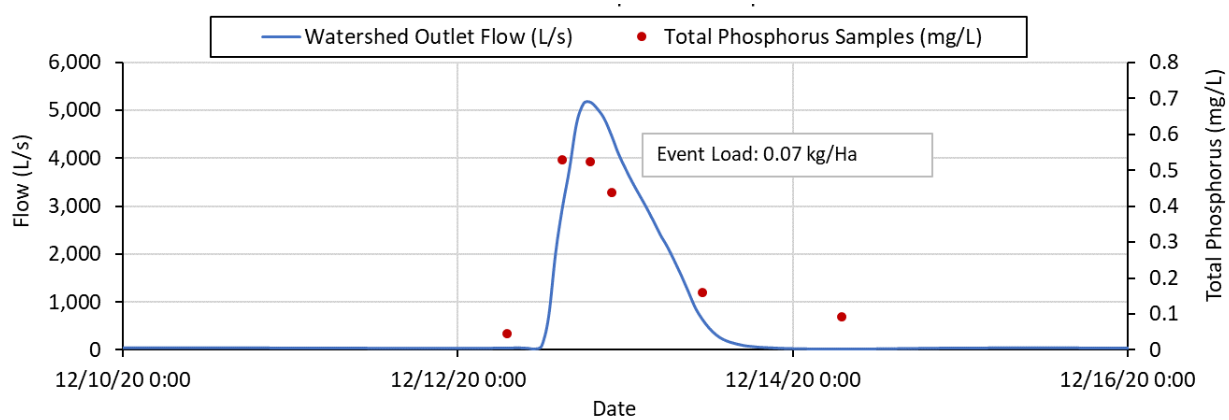

Figure 25. *Watershed outlet flow from the Garvey-Glenn Watershed and total phosphorus concentrations resulting from a rain event in the non-growing season of 2020 (MVCA).*

3.3 Land Management and Cost Benefit Surveys

Within each PSP soil, water quantity, and water quality measurements will also be complemented with three additional assessments: windshield surveys, the Land Management Survey, and the Cost-Benefit Survey, to describe the land-use practices within each PSP to inform the subwatershed models described in Section 3.4 of this report. Windshield surveys were conducted in 2020 and 2021 by CA staff throughout each PSP to visually identify the types of crops and land management practices occurring within each watershed. These visual assessments are completed yearly and complemented with detailed Land Management Surveys conducted with farmers operating in the PSP areas. In 2021, the Land Management Survey strategy was finalized, and delivery began with volunteer farmers. The Land Management Survey collects information on acreage, livestock, cropping history, BMP implementation, soil testing, fertilizer rates, nutrient management planning, and BMP implementation. Farmers are also asked to note BMPs they were previously unfamiliar with or if they intend to implement specific BMPs in the future, and if they have perceived shifts within their farming communities over time that have affected the way they farm.

Land Management Surveys are delivered by the CAs through the ESRI Survey123 platform, pictured in Figure 26. Survey123 was chosen as the best option for integrating spatial data with both quantitative and qualitative data received from farmers, and to maximize quality assurance processes for data input. Centralizing survey data entry and storage into Survey123 enables all five CAs to standardize response formatting easily and minimizes data cleaning required for the modelling team.

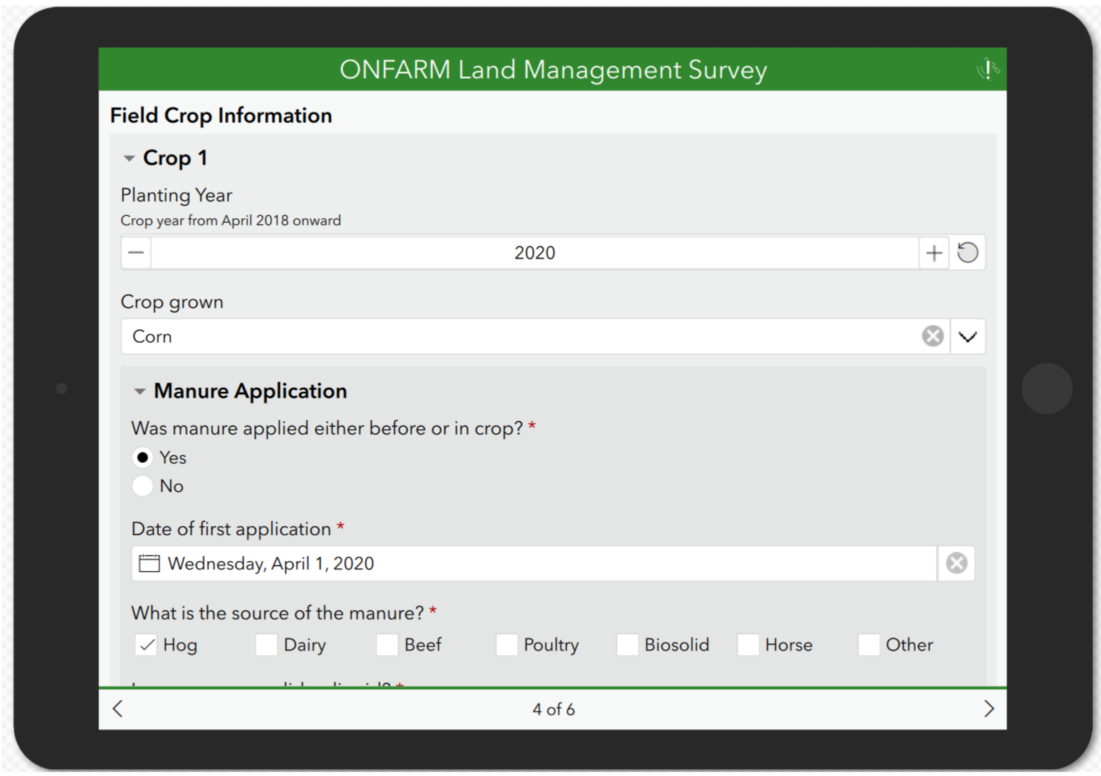

Figure 26. *Sample of Land Management Survey data collected using the Survey123 platform (provided by UTRCA).*

CAs will deliver a voluntary Cost-Benefit Survey following or in conjunction with the Land Management Survey. A version of the survey will be completed for each BMP on a farm to differentiate between the impact of individual BMPs. Questions track the timeline of BMP implementation and expected lifetime for use, the area affected and cost implications, including equipment purchase price, ongoing or maintenance costs, loss of cropland, labour, impact on crop inputs, and yield. Delivery of the Cost-Benefit Surveys is slated to begin in 2022, and data will be incorporated into final model deployments as described in Section 3.4.

3.4 Modelling and Cost-Benefit Analysis

ONFARM will utilize data collected by CAs and SRG to develop water quality models for each of the PSPs, recognizing that it can take many years to understand the downstream impacts of field-scale changes and modifications to agricultural practices on water quality. ONFARM's modelling component was designed to iterate on work completed through GLASI, which showed encouraging results but demonstrated a need for long-term data. The data collected by ONFARM partners from Land Management Surveys, and soil and water analysis will be used to configure, update, and calibrate PSP models. Integrating financial information within the models will enable CAs to better assess the cost-efficacy of implementing phosphorus-reducing BMPs.

In 2021, the Watershed Evaluation Group at the University of Guelph joined ONFARM to complete the modelling component and serve on the Technical Working Group. The ONFARM modelling deliverables will be provided using two tools: Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) and Ecosystem Services Assessment Tool (ESAT).

IMWEBs is a hydrological model that uses a cell-based spatial structure to partition landscape features, such as agricultural fields, forests, wetlands, and riparian buffers out into a fine resolution grid, an example of which is shown in Figure 27. The model integrates these landscape features with processes shown in Table 7, including: climate, water balance, crop growth, soil, and nutrients, to model the movement of water and associated nutrient loading. A key strength of the IMWEBs model is its functionality across varying spatial scales. IMWEBs can be applied from the field or farm level to an entire watershed (which is well suited for the monitoring data setup) and pairs high-resolution EOF monitoring and site characterization with monitoring stations throughout the PSPs.

As more than just a hydrological model, IMWEBS was designed to model the effects of agricultural BMPs. ONFARM's modelling work will be targeted toward BMPs being employed and evaluated at the 25 soil health research sites and is focussed on cover crops, organic amendments, and reduced tillage. Other BMPs may also be included in the modelling in areas where high quality data is available.

ESAT works as a web-based GIS tool that conservation land managers will use to translate results from the IMWEBs modelling into more actionable plans for their Conservation Authorities. The ESAT tool explores watershed conditions and allows researchers to pinpoint localized hot spots for potential phosphorus loss. The tool is economically focussed and will assess both the efficacy of existing BMPs maintained in the watershed and target future BMP implementation based on the cost-effectiveness. This will allow future conservation funding to be well-targeted and achieve more a cost-effective reduction in nutrient loading.

To manage the development of IMWEBs and ESAT occurring concurrently with ONFARM water quality monitoring, model development is set to occur in two phases. Initial development of models will use historical data collected through the GLASI program for calibration of BMP effectiveness coefficients across all PSP. The first preliminary model is planned for completion in Spring of 2022 and finalized upgrades will be completed by February of 2023 to incorporate the water monitoring completed by September 2022.

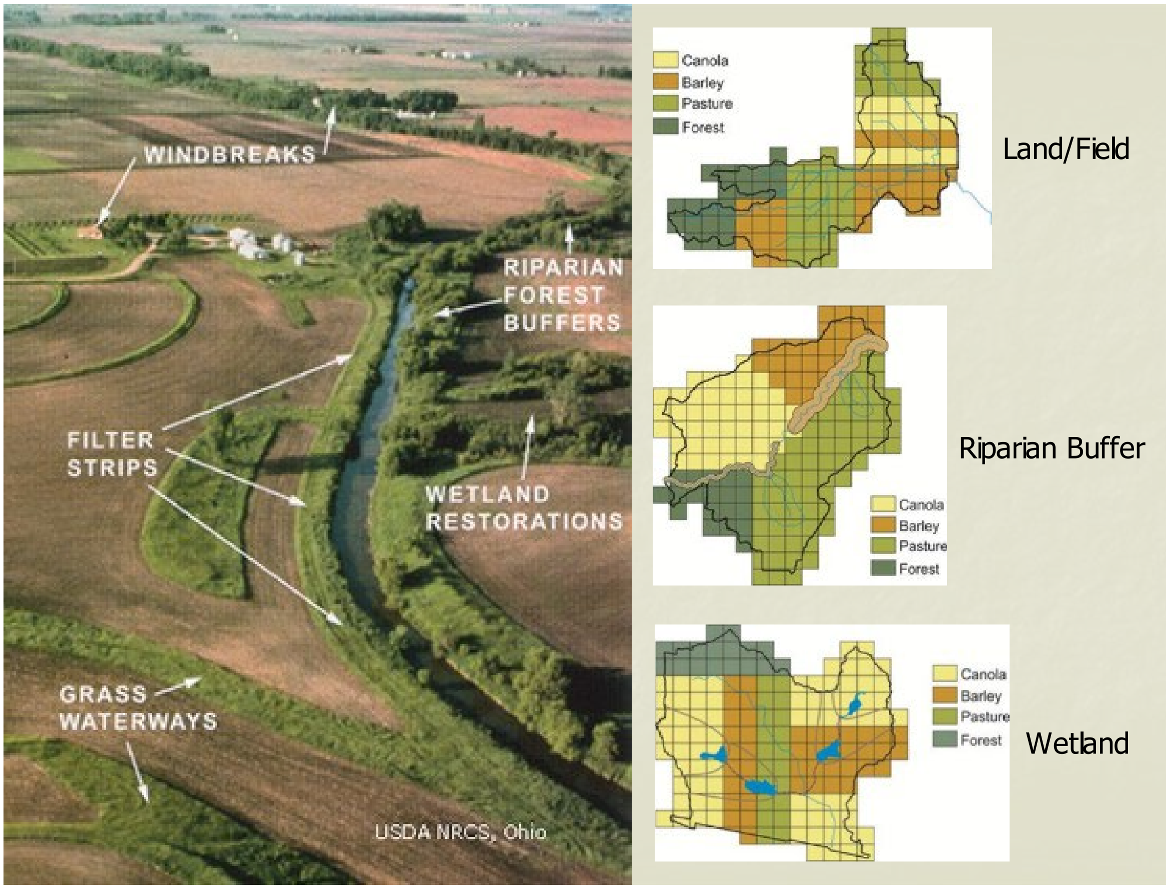

Figure 27. *Comparison of a sample agricultural landscape demonstrating various landscape features and BMPs (left; photo taken from of USDA NRCS) and the IMWEBs cell-based categorization of landscape features within watersheds (right; Watershed Evaluation Group).*

Table 7. *List of input data types for IMWEBs modelling.*

Data Collected	Examples
Climate	Daily temperature and precipitation, wind speed and direction, solar radiation, evaporation, relative air moisture
Spatial Boundaries	Watershed boundary, stream network, farm and field boundaries
Topography	LiDAR DEM level topography
Land-use	Farmland, forest, wetland, or buffer characterization
Soil	Texture and nutrient analysis from soil sampling
Water	Flow and nutrient analysis
Farm Management	Livestock management, cropping, fertilizer and manure application details
Wetland and Buffers	Inventory of wetlands and characterization of riparian buffers, ongoing management practices
BMPs	Cover crops, nutrient management, reduced tillage, etc.

4.0 Future ONFARM Milestones

As ONFARM enters the third field season, soil and agronomic monitoring will continue at all 25 BMP trial sites. Early results have indicated the potential for BMP treatments to impact soil health and yield but predominantly have demonstrated the need for long-term research to capture these impacts fully. In 2022, OSCIA released the first ONFARM Data Dashboard to present 2020 soil testing results. The platform will continue to be updated to feature new results from the program as they become available. As data analysis continues, results from ONFARM's soil health BMP trials will continue to be shared in various formats, including technical reports, dashboard updates, field days, and through the annual ONFARM Forum.

In 2021 modelling work began to assess the water quality data captured by ONFARM's eight EOF monitoring sites. In 2022, preliminary modelling will be completed and delivered to watershed managers. Water quality monitoring will continue through the ONFARM program through September 2022. As final results are compiled, the ONFARM modelling team will finalize IMWEBs modelling for the PSPs and ESAT systems by February 2023 to enable watershed managers to optimize the economic and environmental benefits for BMPs implemented in their regions.

To learn more about how ONFARM plans to share results and engage the agricultural community, please visit the ONFARM website and see the 2022 Outreach and Engagement Strategy. Please also visit our news page or OSCIA's twitter to stay up to date on project information and future activities.