Improving Access to Soil Carbon Proxy Testing:
Training Educators to Monitor Soil Health on Three Northeast Farms

Final Project Report

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Connecticut, New York, & Massachusetts Chapters

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Project Summary

Improving Access to Soil Carbon Proxy Testing: Training Educators to Monitor Soil Health on Three Northeast Farms was a multiyear project evaluating soil carbon for farmers throughout Massachusetts, Connecticut, and New York. Staff at the Massachusetts Chapter of the Northeast Organic Farming Association (NOFA/Mass) taught outreach and education staff at NOFA Chapters in New York and Connecticut the procedures for the soil Carbon Proxy Test (CPT). Farm-based adoption of healthy soils practices can lead to increased sequestration of atmospheric carbon and transition farms from carbon sources to carbon sinks for the betterment of the environment. The resultant implementation of soil health-building farm management practices can also improve crop growth and production and improve crop resiliency to the increasingly-common climate extremes such as drought, excessive rainfall, and high temperatures.

The goal of this project was to scale-up on-farm soil carbon proxy testing, increasing farmers exposure to it in Massachusetts, and teaching our NOFA counterparts in Connecticut and New York on its practices to further expand its adoption within those states. To achieve these goals, NOFA/Mass staff provided staff at CT-NOFA and NOFA-NY with soil carbon proxy training (CPT) at project commencement. NOFA/Mass also performed CPT at 21 farms over the course of the project to help farmers identify their soil carbon levels and understand the relationship between management and soil carbon. CPT were also performed at three farms annually over the duration of the project to develop a longitudinal study. The longitudinal study provided farmers with the opportunity to understand their soil carbon levels at an outset, and observe changes over time in response to soil-based management modifications. The longitudinal study was performed at Massaro Farm in Woodbridge, CT, Grindstone Farm in Pulaski, NY, and Simple Gifts Farm in Amherst, MA. This report presents observations and findings for Massaro and Simple Gifts Farms.

Soil carbon proxy testing utilizes a series of field-based tests to produce an assessment of soil carbon levels. At each farm, staff tested for: soil hardness, bulk density, infiltration rate, biological observations + earthworm counts, topsoil analysis, root depth and behavior, soil structure, soil texture, and slake test. Each of these tests play a crucial role in assessing different aspects of soil health; collectively, the findings provide a valuable snapshot of soil health and carbon content, which can be utilized to make informed decisions regarding soil management practices.

Understanding the significance of these tests is imperative to comprehending the soil's condition and its implications for agricultural productivity, ecosystem health, and environmental sustainability. Soil hardness and bulk density influence root development, water movement, and nutrient availability. Similarly, infiltration rate determines the soil's ability to absorb water, impacting draining, erosion risk, and water management strategies. From a management perspective, tillage and use of heavy equipment, particularly on wet soils, destroys soil pores and leads to runoff, erosion, slow water infiltration, and poor drainage. Most crops cannot easily send roots into soils requiring penetration pressure greater than 300 pounds/square inch (psi). Similarly, compacted soil restricts growth and mobility of beneficial mycorrhizal fungi and other soil organisms. Bulk density is another metric for compaction, identifying whether the soil pores have been compressed. Healthier soils, including those with higher carbon, support more life and tend to have lower density.

Biological observations and earthworm counts shed light on soil fertility, organic matter decomposition, and overall ecosystem functioning. Earthworm counts are correlated with soil health; their burrows improve infiltration and their casts improve aggregation and they break down larger bits of residue for use by other organisms. Soil surface biology observations track changes over time in biological diversity and the amount of bare ground, with diversity and increased soil cover generally positively correlated with soil health.

Topsoil characteristics, including color, texture, and organic matter content, assesses fertility, moisture retention, and nutrient availability. Root depth and behavior provide insights into plant water and nutrient uptake, drought tolerance, and overall plant health. Soil structure, texture, and aggregation impact water infiltration, root penetration, and nutrient retention. Aggregate stability is a primary indicator of soil carbon and is closely connected to soil biodiversity by enabling water and air retention and preserving organic matter. The slake tests evaluates soil stability and erosion resistance, which is crucial for maintaining soil integrity and preventing sediment runoff.

In a longitudinal study these tests can cumulatively inform a farmer's knowledge of the health of their soil, opening the door to recommendations for specific soil management strategies that will improve soil quality, maximize agricultural productivity, and promote sustainable land use practices.

Longitudinal Study Findings

Simple Gifts Farm

A group of north Amherst neighbors came together in 2005 and started a nonprofit to preserve the farmland formerly owned by the Dziekanowski Family. With phenomenal support from the State of Massachusetts, the Town of Amherst, and the local community, North Amherst Community Farm (NACF) was born. NACF preserves the farm as a wildlife corridor and community resource with walking trails, more equitable access to organic produce, and educational programming on the interrelation of food production/distribution and environmental health. In the middle of a densely populated neighborhood, it's uniquely positioned to cultivate connections between people and their food supply.

After purchasing the property in 2006, NACF sought a farming team to start a community-based farm here. Dave and Jeremy applied and were chosen to lease the property from NACF in an innovative shared-ownership model designed to keep the land as a community farm for generations to come. Simple Gifts Farm has been working the land since 2006, and is pleased to collaborate with NACF's lively and effective community-minded group.

Soil Hardness (by Penetrometer)

Significance: Soil hardness refers to the compactness or density of the soil. It is important because it affects root penetration, water infiltration, and nutrient availability. Hard soil can impede root growth and limit water movement, leading to poor plant growth and reduced productivity.

Table 1. Soil hardness (PSI, by penetrometer) over three years at Simple Gifts Farm at 4 different depths below the soil surface. Results are averages of three sequential readings.

Depth (inches below soil surface)	**Fall 2021**	**Fall 2022**	**Spring 2023**
3	83	160	196
6	167	213	241
9	283	263	267
12	>300	>300	>300
Depth to 300 PSI (in)	7	9	9

The changes in soil hardness at Simple Gifts Farm are found in Table 1. Interestingly, the hardness increased over the three years of testing, suggesting a potential trend of soil compaction and hardness and a potential decline in soil quality and health, with the soil becoming more compacted and less porous. The only exceptions to this are the readings at 9 inches depth, which are lower in both 2022 and 2023 than they were in 2021. In contrast to the hardness readings at all other depths, the depth to 300 PSI improved over the 3 year project duration, suggesting a deeper compaction layer than in 2021 and the potential for restricted root growth and water movement at that depth.

Overall, the data indicates a progression of soil compaction and increasing soil hardness over time. The soil profile is experiencing a significant compaction at various depths, potentially limiting root growth, water infiltration, and nutrient availability. These findings raise concerns about soil health and the need for remedial measures to address the compaction issues. One point to note, however, is the variability that can occur between spring and fall testing periods and year-to-year variability. Due to the nature of the project period, the final CPT needed to be performed in the spring, rather than fall as the other CPT had been performed. Due to seasonal variability, the value of direct comparisons between spring and fall data are limited, and a more valuable comparison would be a third year of fall-collected data, which would eliminate one additional area of variability. Similarly, year-to-year weather-related variability may account for some of the variability observed between the fall 2021 and 2022 measurements. Having a third fall data point would greater elucidate any concerns or trends to better inform management recommendations and decisions.

Bulk Density

The density of a material is its mass divided by its volume. In the case of soil, high density often means the space between soil particles for air, water, plant roots, etc. has been compressed.

Healthier soils tend to have lower density. In this protocol a tube of known volume collects soil samples at 0-4", 4-8" and 8-12" in depth. The samples are then dried out in an oven at 200ºF for a minimum of 2 hours and weight is recorded to obtain the mass. This mass is divided by the known volume to obtain density. Bulk density results from Simple Gifts Farm are shown in Table 2. Table 3 displays the relationship of bulk density values compared to the different soil types. The site at Simple Gifts Farm where these samples were collected are considered a loamy sand.

Table 2. Bulk density results at Simple Gifts Farm. Note that in 2021 bulk density measurements were collected at depths of 0-6" and 6-12", and in 2022 bulk density was collected at 4-8". All data are in g/cm^3.

Sample Depth	**0-4"**	**4-8"**	**8-12"**
Spring 2021	1.11 (0-6")		1.03 (6-12")
Spring 2022		1.23	
Spring 2023	1.15	1.38	1.12

Table 3. Plant growth conditions as related to bulk density and soil texture. Different soil textures can impact the soil's bulk density, which provides an indicator of how easily roots can penetrate the soil, impacting root and plant growth overall. Data is from the USDA, 1987.

Soil Texture	**Ideal for Plant Growth (g/cm^3)**	**Affect Root Growth (g/cm^3)**	**Restrict Root Growth (g/cm^3)**
Sands, loamy sands	< 1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.40	1.60	> 1.75
Silt loams, silty clay loams	< 1.40	1.55	> 1.65
Sandy clays, silty clays, clay loams	< 1.10	1.49	> 1.58
Clays (>45% clay)	< 1.10	1.39	> 1.47

Bulk density measures the weight of soil per unit volume. It indicates soil compaction and porosity. High bulk density restricts root growth and reduces water-holding capacity. Low bulk density may indicate poor soil structure and increased susceptibility to erosion. Optimal bulk density allows for root development and proper water and air movement in the soil.

The bulk density measurements indicate a relatively stable density across the soil profile. This suggests that the soil structure is not overly compacted, allowing for proper water infiltration and root growth.

Infiltration Rate

Infiltration rate is a measure of the capacity of soil to absorb water without puddling or running off causing erosion.

Better infiltration indicates more pores and aggregates, which means greater carbon, soil health, and water holding capacity. A ring of a known diameter is hammered into the ground and a known amount of water is added to simulate 1" of rain fall. Infiltration rate findings are shown in Table 4.

Table 4. Infiltration rate findings at Simple Gifts Farm over three years of sampling.

Year	Infiltration Rate (s)
2021	351
2022	646
2023	662

Infiltration rate measures the speed at which water enters the soil. It is crucial for water management and drainage. Slow infiltration rates can cause waterlogging and increase the risk of erosion, while high infiltration rates may lead to excessive water runoff. The infiltration rate reflects soil porosity, compaction, and overall soil health.

The recorded infiltration rates demonstrate the soil's ability to absorb water. The faster infiltration rate in Fall 2021 compared to subsequent seasons indicates a potential change in soil conditions or management practices. Monitoring infiltration rates can help identify changes in soil health and guide appropriate interventions.

Slake

The slake test observes the maturity of aggregates and resistance of aggregates in tested soil to erosion events and compare management practices on your land. This test can be performed by comparing a specific site to itself over time or it can also be used to compare an area of little to no disturbance in the same general location. A soil clod is collected at a certain depth (this is predicated upon what type of information you are gathering) and for the purposes of this report soils were collected at 4" in depth.

Image 1. Slake test performed on hedgerow/field edge and production field/area of cultivation at Simple Gifts Farm.

Image 1 shows the slake test performed on soil collected at Simple Gifts Farm. Pictures on the top display the soil clods in the mesh basket before and after being submerged for five minutes. The pictures on the bottom show the clods immediately after submergence (left) compared against the clods after being submerged for five minutes (right). Very little material was lost to the water solution.

The slake test assesses soil stability and resistance to erosion. It measures the ability of soil aggregates to maintain their structure when exposed to water. The test provides insights into the soil's susceptibility to erosion, which is crucial for maintaining soil health and preventing sediment runoff.

The slake test results indicate a relatively stable soil structure with minimal disintegration during immersion. This suggests a good level of soil stability and resistance to erosion.

Soil Type (Texture) and Aggregation (Structure)
Soil texture describes the relative proportions of sand, silt, and clay particles in the soil. It influences water-holding capacity, nutrient retention, and aeration. Different soil textures have varying drainage and fertility characteristics. Understanding soil texture helps tailor management practices and irrigation strategies to optimize plant growth.

Aggregates in soil refer to the grouping or clustering of soil particles into larger, more stable units. These aggregates are formed through various processes, including physical, chemical, and biological interactions within the soil. They range in size from microaggregates (microscopic) to macroaggregates (visible to the naked eye). Aggregates play a crucial role in maintaining healthy soil and ecosystem functions. Here are some key points highlighting their significance:

1. Soil Structure and Porosity
2. Water Infiltration and Retention
3. Nutrient Availability
4. Erosion Control
5. Root Growth and Penetration
6. Carbon Sequestration

Maintaining and improving soil aggregates is essential for sustaining soil health and productivity. Management practices that promote organic matter additions, reduced soil disturbance, proper irrigation, and balanced nutrient management contribute to the formation and stability of aggregates. By prioritizing the preservation of soil aggregates, we can enhance soil fertility, water management, erosion control, and overall ecosystem resilience.

Soil structure has several classifications and at times these descriptors are not hard values but a spectrum of the different types of classifications. The sections analyzed were from the top section (0-4") the middle section (4-8") and the lower section (8-12"). Observations of soil structure are found in Table 5.

Table 5. Soil structure observed at Simple Gifts Farm at three different depths.

Soil Section	**Aggregation, size, and prevalence**
0-4"	Granular to blocky, very fine, weak
4-8"	Blocky, medium, weak
8-12"	Blocky to platy, medium, weak

Soil structure refers to the arrangement of soil particles and the formation of aggregates. It affects water movement, root penetration, and nutrient availability. Good soil structure allows for adequate air and water circulation, root development, and microbial activity. Poor soil structure leads to compaction, reduced water infiltration, and restricted root growth.

The soil structure analysis indicates a predominance of blocky to platy aggregates throughout the observed soil sections. This structure, combined with a weak strength classification, suggests the need for management practices that promote improved aggregation and soil stability.

Soil Surface Biology Observations

Soil biology surface observations are typically performed in a single spot of land to track changes over time in biological diversity of plant and animal activity, and percentage of bare ground. More diversity and less bare ground are correlated with increasing soil health. This test involves the observation of the soil surface within a 30" diameter hoop to observe the following: estimated % of bare soil, types and amounts of various plants, types and % of mulch or duff/dead plants, types and amounts of other life and the presence of ponding or crusting. In the testing cycle of this study, we found varying degrees of soil cover and biology.

Table 6. Soil surface biology observations over three years of testing at Simple Gifts Farm.

	2021	**2022**	**2023**
% Bare Soil	65	25	40
% Living plant cover	35	30	0
% mulch cover	0	45	60
Ponding/Crusting	Not observed	Not observed	Not observed
Other	Moss, ants, grubs	Ants, moss	Ants, beetle, moss, fungi

Another observation performed is root behavior, where the average length of roots, longest root and growth habit are observed and recorded.

Table 7. Rooting behavior observed over three years of testing at Simple Gifts Farm.

	2021	**2022**	**2023**
Root depth (inches)	8	9	11
Average root depth (inches)	4	6	8
% sideways or balled up	0	0	0
Rhizosheathing	Strong	Strong	N/A

Earthworms

The earthworm count and biological observations provide insights into the soil's biological activity and health. Earthworms are indicators of soil fertility and ecosystem functioning. Their presence indicates good soil structure, organic matter decomposition, and nutrient cycling. Earthworm population may vary with site characteristics, season and species. Generally speaking, 10 earthworms per square foot is considered a good population in agricultural systems.

	2021	**2022**	**2023**
Earthworm counts (ft^2)	4	5	3
Burrows (biopores ft^2)	3	2	0

It is important to note that there are four broad ecological groups of earthworms and based on size and pigmentation the two found at this site are anecic and endogeic. The endogeic are considered soil dwelling or soil feeding, these create a network of horizontal branching burrows, while the anecic are deep vertical burrowing without branching. The latter are the most predominant type encountered at this site.

The presence of earthworms and other biological indicators suggests a favorable soil environment for microbial activity and nutrient cycling. The decrease in earthworm counts in spring 2023 may indicate changes in soil conditions that require further investigation.

Summary

In summary, it is evident that soil health management practices are essential for sustaining healthy and productive soils. Implementing soil conservation techniques, such as reducing soil compaction, incorporating organic matter, optimizing irrigation practices, and adopting erosion control measures, can contribute to maintaining and enhancing soil health. Continuous monitoring and periodic assessment of soil health parameters are crucial for identifying changes and making informed decisions regarding soil management practices. By prioritizing soil health and implementing sustainable land management practices, we can enhance soil productivity, preserve ecosystem services, and contribute to long-term agricultural and environmental sustainability.

Massaro Farm

Massaro Farm is a certified organic farm with 200+ CSA members, restaurant customers and a food donation program. The farm manager has been experimenting with tillage reduction and with methods of soil prep and weed management that minimize soil disturbance and maximize soil health while also reducing the use of disposable plastics.

This site has never been tilled to a great extent. There was minimal tillage back in 2018 and no tillage after that. The sampling site in 2021 was mostly bare due to tarping in July and August of that year. Tarp removal was postponed due to a hurricane, after which the tarp was removed and then a second hurricane hit. Consequently, little surface biology was observed in 2021. In the winter of 2021-22 cover crop was planted; the site was a chicken pasture in the spring of 2022, and a new high tunnel was installed near the testing site, which caused compaction. In the 2022 growing season winter squash was grown on the testing site.

Soil Hardness (by Penetrometer)

The changes in soil hardness at Massaro Farm are found in Table 8. It should be noted that a high tunnel, located approximately 10 ft from the carbon proxy test site, was erected during the period between sampling in 2021 and 2022. It is assumed that the activity from the installation compacted the soil at the test site (Image 2).

Table 8. Soil hardness (PSI, by penetrometer) over three years at Massaro Farm at 4 different dpeths below the soil surface. Results are averages of three sequential readings.

Depth (inches below soil surface)	Fall 2020	Fall 2021	Fall 2022
3	40	25	193
6	60	92	236
9	73	117	250
12	250	150	>300
Depth to 300 PSI (in)	15	24	12

Image 2. Soil carbon proxy test location relative to new high tunnel (background), installed between 2021 and 2022 sampling periods.

Overall, the data show low levels of soil compaction and an improvement in soil hardness at the shallowest depth in between 2020 and 2021. There was a significant increase in depth to compaction (300 PSI) between the first and second years of the project, demonstrating a potential management-related improvement. However, due to the soil disturbance that occurred prior to the 2022 sampling, it's hard to know whether the measured improvements were due to external factors, such as soil moisture, or a true representation of an improvement in soil condition. It would be valuable to revisit the site in an additional 2-3 years to observe whether the soil hardness improved following the construction-related disruptions that impacted the site in 2022.

Bulk Density

The soil at the Massaro Farm site sampled is a loamy sand, characterized by a dark brown loamy soil with coarse blocky aggregates of moderate grade in the shallower depths, and dark brown loam with fine blocky aggregates of moderate grade at deeper depths. At 8-12" the soil transitions to a marbled transition layer of light and darker soil, with medium blocky aggregates of moderate grade.

Bulk density was measured at Massaro Farm at three depths from 2020-2022 (Table 9).

Table 9. Bulk density results at Massaro Farm at three sampling depths (0-4", 4-8", 8-12"). All data are in g/cm^3.

Year	0-4"	4-8"	8-12"
2020	1.01	1.05	0.94
2021	1.16	1.14	1.03
2022	1.13	1.47	1.70

Given the site's loamy sand and loamy texture, the measured bulk densities were well within the ideal densities for plant growth (Table 3), which is < 1.40 g/cm^3 at all depths, and does not affect or restrict root growth. Bulk density results also support the findings observed through penetrometer readings, in that in 2022 the bulk density increased dramatically, particularly at the deeper depths. Interestingly, it is still within the "ideal" range except for at the 8-12" depth, where root growth may be affected. These findings support the soil hardness characteristics observed through penetrometer readings, indicating that the soil hardness is of good condition to support plant and root growth.

Infiltration Rate

As a measurement of the speed at which water enters the soil, infiltration rate is closely connected to a soil's bulk density, hardness, and overall soil health. The fast infiltration rates seen in 2020 and 2021 are a further reflection of the good soil health and condition at the site during these years. However, the infiltration rate in 2021 is slower than ideal; infiltration rates under 60 seconds is the benchmark for healthy soil function. The dramatic increase in infiltration rate, as observed in 2022, is another indicator of the impacts of the high tunnel construction on the health of the soil in the surrounding area.

Table 10. Infiltration rate findings at Massaro Farm over three years of sampling.

Year	Infiltration Rate (s)
2020	28
2021	145
2022	1408

Slake

The slake test provides farmers with a comparison of the water stable aggregates between the nearby hedgerow and the area of cultivation. Observations from the slake test are shown in Table 11), images of the soil samples during the testing process are seen in Image 3. Ideally, a well-managed field should have production area slake test observations that are nearly identical to findings in the hedgerow. The hedgerow provides a strong indication of the soil in an undisturbed condition, and reflects how much of the soil would be lost during the slake test if undisturbed. In all three years, the hedgerow slake sample lost very little of the total soil volume, indicating that the soil was well-aggregated and in good condition. Interestingly, over the three years of the study, the field-based sample closest to hedgerow findings was the sample collected in 2022. Given the known disturbance of the area, it is likely that the soil was compacted and therefore held together better during the slake test versus in previous years. This assumption would also suggest a loss of soil structure, which is supported by bulk density and penetrometer findings, and is not a good indicator of soil health alone.

Image 3. Slake test observations for field and hedgerow over three years of sampling at Massaro Farm.

Table 11. Slake test observations over 3 years of sampling at Massaro Farm. Field samples were collected from the in-field test site, whereas hedgerow samples were collected from non-production areas. The % Remaining refers to the amount of a golfball-sized sample that remained in a submerged basket after 5 minutes.

	Field Sample		**Hedgerow Sample**	
	% Remaining	**Turbidity**	**% Remaining**	**Turbidity**
2020	80%	Moderate cloudiness	98%	Extremely clear
2021	80%	Slight cloudiness	90%	Fairly clear
2022	90%	Moderate cloudiness	98%	Fairly clear

Soil Type (Texture) and Aggregation (Structure)

The soil structure observed at Massaro Farm shows good aggregation and moderate aggregate formation (Table 12), important components of structure that allows for adequate air and water circulation, root development, and microbial activity.

Table 12. Soil structure observed at Massaro Farm over three years at three different depths.

	0-4”	**4-8”**	**8-12”**
2020	Medium-coarse subangular blocky Weak grade	Coarse to very coarse blocky Moderate grade	Fine blocky Moderate grade
2021	Fine blocky Moderate grade	Coarse blocky Moderate grade	Coarse blocky Moderate grade
2022	Medium blocky/angular Moderate grade	Blocky Weaker aggregation	Blocky Weaker aggregation

Soil Surface Biology Observations

Soil biology observations from Massaro Farm are found in Table 13 and Table 14. A low amount of living cover, and a high percentage of bare soil, was observed in 2021 because the area had been tarped in July and August, 2021. Tarp removal had been delayed from its planned timing due to weather delays.

Table 13. Surface biology observations over three years of testing at Massaro Farm.

	2020	2021	2022
% Bare Soil	20	95	25
% Living plant cover	80	4	75
% mulch cover	0	1	0
Ponding/Crusting	Not observed	Not observed	Not observed
Other			Pill bug, millipedes (2), wireworm, earwig, earwig larvae, grub, earthworms

Root behavior, including deepest root, average root depth, and rhizosheathing (Table 14) all support the soil health findings observed in other metrics. The absence of balled or sideways roots supports a lack of compaction, and the rooting depth increased over the project duration, indicating improvements in overall soil health.

Table 14. Rooting behavior observed over three years of testing at Massaro Farm.

	2020	2021	2022
Root depth (inches)	8.5	9	13
Average root depth (inches)	6.5	6	7
% sideways or balled up	0	0	0
Rhizosheathing	Strong	N/A	Strong

Earthworms

The earthworm count and biological observations support observations in other metrics regarding soil structure, organic matter decomposition, and nutrient cycling. The increase in earthworms over time suggests soil improvements, despite the known disturbances in 2022 (Table 15). It is likely that the soil improvements that had been building over time were still supportive of earthworm communities despite the surface-level disruption that occurred during high tunnel construction.

Table 15. Earthworm observations over three years of testing at Massaro Farm.

	2020	2021	2022
Earthworm counts (ft^2)	0	1	9
Burrows (biopores ft^2)	0	0	0

Summary
Overall the soil health proxies indicate that health is improving over time. There are some outliers noted to 2022; which the famer, Steve Munno, confirmed were caused by disturbance when the high tunnel was built nearby the test site. The negative impacts were measured below the top 4" soil layer, with the greatest impact occurring around 8-12". The infiltration test shows us that there is compaction and less pore spaces for water to be held, and also a sign of weaker aggregation, which was also observed during the 2022 testing. Bulk density measurements in 2022 confirm the compaction of the soil, especially between 4 – 12". Over the three year longitudinal study, Massaro Farm showed generally improved soil health, as indicated through improvements in water infiltration, penetrometer resistance, and topsoil depth.

In conversation with Steve it was clear that the longitudinal carbon proxy testing informed his decision making and management. As previously stated, Massaro Farm generally uses minimal tillage and regenerative farming practices, including an intermixed 2-4 species cover crop, which is flail mowed and allowed to regrow 2-3 times, depending upon the planting schedule and crop. They terminate their cover crops with tarping, which can also help warm the soil in the spring.

Despite having other types of soil tests performed (namely, chemical test), Steve had never looked at soil carbon proxy-type tests prior to enrolling in this study. He found it interesting to learn more about their soil through physical tests such as water infiltration, bulk density, and penetrometer readings. Looking at the physical quality of the soil was very meaningful to them, and gave them confidence that their low-till methods and regenerative practices were paying off.

Massaro Farm has been reduced-till with regenerative practices since 2010, and have been cover cropping for more than a decade. A challenge with reduced tillage is trying to maintain raised beds without reforming them every year; they also try to maintain the same walking paths to avoid compaction. In spring 2020 they needed to reshape some beds that had gotten messy from growing potatoes, and wondered whether that impacted their overall compaction readings. When asked if they would change any management practices in response to the CPT results, Steve indicated that they hadn't made any management changes, but that the results also support what they've been doing for the past 13 years. Finally, Steve emphasized he found the CPT valuable, and appreciated having other people look at and test his fields. He feels as though more information is better to help with their management practices, and appreciated that participating in the CPT did not require a large amount of his time.

Grindstone Farm
Summary
Due to a variety of unanticipated factors, Grindstone Farm was only sampled in 2020. Upon reviewing his CPT results, Grindstone farmer Dick DeGraff expressed surprise at the difference between his soil health indicators on his tilled annual vegetable fields and his 10-year asparagus beds. The infiltration test in particular helped to increase his awareness of soil health indicators,

as his tilled, non-cover cropped annual vegetable field took 104 seconds for 1 inch of water to infiltrate, compared to 27 seconds in his asparagus beds in the same field, about 10 yards away. Data for 2021 and 2022, yet it would have been valuable to see the effects of any management changes in response to the initial CPT in 2020.

Conclusions

Regular CPT provides a great service to farmers by helping them understand the effects of their management practices and production on their soil's physical characteristics. While chemical testing is commonly done by farmers to help them understand the amount of nutrients they should apply to their fields, physical analysis is done far less frequently yet is of equal importance. A soil's physical composition plays an essential role in either facilitating or inhibiting plant and root growth, productivity, and capacity to withstand extreme weather events, such as drought or heavy rainfall. As extreme weather is occurring with increased frequency due to climate change, shifting management practices in support of soil health will benefit farmers over time.

Massaro and Simple Gifts Farms, which participated in the longitudinal study, both had been performing soil-building and regenerative farming practices prior to their participation in the study. Utilizing this information and the metrics evaluated as a part of the CPT, farmers can identify areas that can be potentially improved upon and approaches for doing so. For instance, issues of compaction could be addressed through changes in tillage, adoption of cover crops or use of alternative cover crop termination strategies, or use of cover crops specially designed to address compaction issues, such as tillage radish. These findings can support soil carbon-building practices to benefit the environment, production, and sustainability of production systems. In conclusion, CPTs are a valuable and simple tool for farmers to learn more about their farms and the relationship between their management, production, and soil health.