Northern New York Agricultural Development Program
2018-2019 Project Report

Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability

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Background:
Soil health is a concern for farmers in Northern New York (NNY). NNY fields in conventionally managed, row crop rotations are often compacted, both at the surface and subsurface, and consequently are occasionally subject to surface crusting, slow infiltration, and runoff. Fields are most commonly tilled before planting row crops and forage seedings, which can alleviate compaction but reduces soil organic matter and biological activity over time. These conditions limit

soil function and are associated with reduced soil health. Soil health on these same fields may also be improved with perennial forages in the rotation and with manure application, which would be expected to improve soil organic matter and microbial communities. Farmers and land managers are motivated to manage soils toward improved health and function, making feedback on efficacy of their methods valuable.

The Cornell Soil Health Assessment is a useful tool, available to commercial farmers of any scale, for monitoring progress toward improved soil health. The Cornell assessment provides a comprehensive soil health score by combining multiple outcomes across multiple soil chemical, physical and biological measurements conducted on each sample. However, sampling protocols for farm-scale fields must permit detection of small and slow changes in soil health parameters over a few years. An appropriate sampling intensity to adequately assess soil health on commercial farm-scale fields using this method must be developed because results can vary from location to location within a field.

This project aimed to investigate and identify the appropriate sampling intensity required to accurately assess soil health on commercial farm-scale fields, such that subtle improvements over 3-4 years may be detected. A simultaneous goal of this project is to train outreach educators in all 6 NNY counties to correctly sample soils for soil health assessment. This skill will carry forward with their respective work with farms in their counties.

Methods:

Soils were sampled in 9 fields on 8 different farms across five NNY counties during spring and fall of 2018. Fields of interest for this study were those typical of NNY cropping systems, in row-crop or row-crop-perennial forage rotations using largely conventional tillage methods. All fields in this study were in a row crop during the year preceding sampling. Fields and descriptions are listed in Table 1.

Surface (0 to 6-8" depth) soil samples were collected using a spade and a bucket, following the procedure outlined in the Cornell Comprehensive Assessment of Soil Health (3rd edition) handbook. Samples were air-dried at ambient temperature, coarsely sieved (1/4" screen), mixed and subsampled. Samples were submitted to the University of Maine Soil Testing Lab for modified Morgan analysis and also to the Cornell Soil Health Lab for the Comprehensive Assessment. To avoid any 'batch' effect in each lab, samples from each field were randomly assigned to one of 4 batches with original identifications concealed before submission. Soil chemical data were received and forwarded to the Soil Health Lab for inclusion in overall soil health assessment.

Within each field, sampling points were identified in one of two ways. For larger fields, where GPS 1-acre grid sampling points were available from the Ketterings Lab's corn yield stability project at Cornell, those grid points were used as sampling locations to permit subsequent analysis and mapping beyond this study. Because only 36 points were needed in these fields, grid points along headlands or the field boundary, or near mapped soil type changes or atypical features, were avoided. Up to 12 points were identified in other fields, using no more than one sample per acre to avoid spatial autocorrelation of results.

Sampling points were selected from aerial soil maps to represent dominant soil types in the field and to avoid headlands, field edges and other atypical features.

Table 1. Descriptions of 9 fields sampled for soil health assessments in spring and fall of 2018, Using the Cornell Soil Health Test on Commercial Farms in NNY:Identifying Within-Field Variability Project, NNYADP.

County	Field	Acres	Dominant Soil Type(s)		Sample Points N	
Clinton	CL	53	Malone / Hogansburg	loam	12	
Clinton	GM	11	Hogansburg	loam	12	
Essex	G3	9	Windsor / Cosad	loamy sand / loamy fine sand	9	
Essex	SWT	19	Howard	gravelly loam	12	
Franklin	CF1	26	Salmon	very fine sandy loam	12	
Franklin	MT	6	Covington	silty clay	6	
Jefferson	RM	80	Kingsbury / Vergennes	silty clay / clay	36	Grid
St. Lawrence	BW3	65	Stockholm	loamy fine sand	36	Grid
St. Lawrence	BW4	40	Muskellunge	silty clay loam	36	Grid

Figure 1 is an example of the CL field and 12 sampling points in this study. At each sampling point, 5 subsamples were collected using the sampling pattern depicted in Figure 2. Five subsamples were mixed and subsampled for subsequent analyses and 5 soil penetrometer readings were collected using the same spatial scheme for each sampling point within each field. A total of 171 soil samples were collected and analyzed in this study. Soil penetrometer (Dickey-John, Auburn, IL, USA) readings for surface (0 to 6" depth) and subsurface (6 to 18" depth) were recorded at approximately field capacity soil moisture using a standard ½" tip. Soil penetrometer readings beyond 300 psi were recorded as 300 psi because plant roots are not expected to penetrate beyond this resistance.

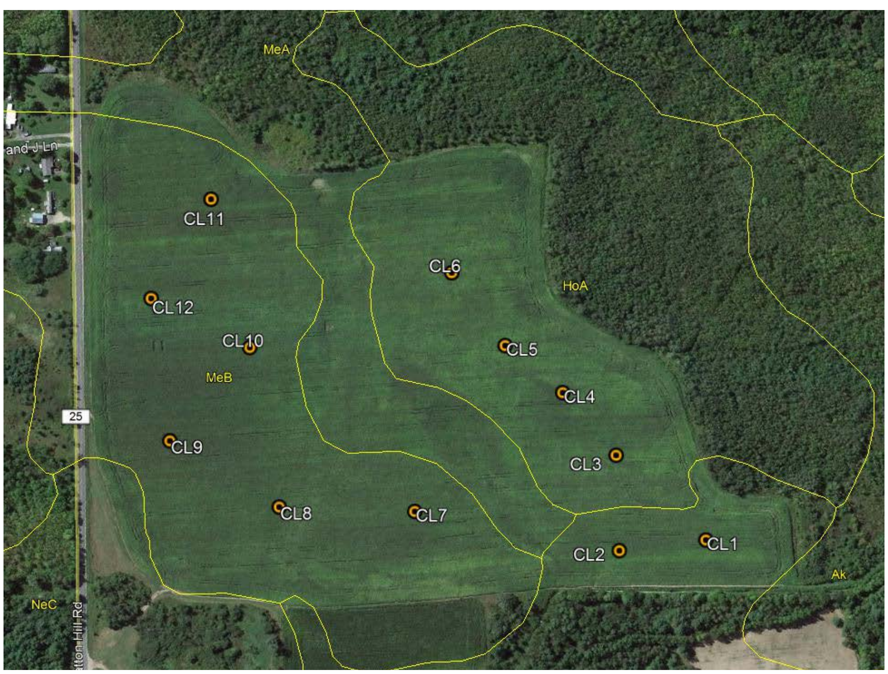

Figure 1. Sample location selection for a non-grid-sampled field. Twelve sampling locations were identified while avoiding headlands, field boundaries, atypical features and expected transitions between soil types; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability, NNYADP, 2018.

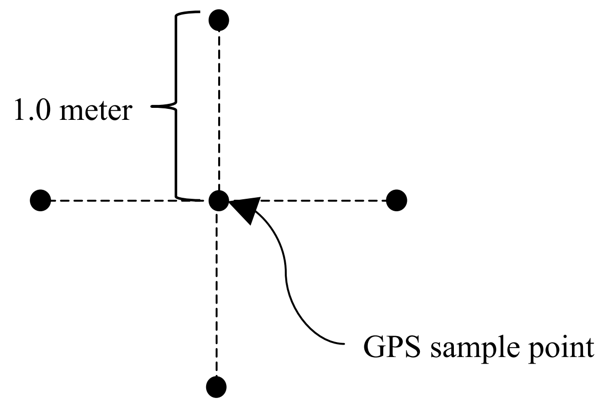

Figure 2.
Subsampling scheme for each GPS sampling point used across all fields. Black dots (•) represent 5 subsamples collected and 5 soil penetrometer readings recorded at 2 depths for each GPS sampling point; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability, NNYADP, 2018.

Statistical analysis of the data was performed using JMP statistical software to calculate and express within-field variation in both overall soil health assessment scores and individual soil health indicators for each field. Additional estimates of sampling intensity required to detect reasonable future changes of 10% in soil health indicators and overall health score were also calculated. For example, a 10% change in soil organic matter would be an increase from 3.0% to 3.3%, which is a reasonable expectation over 4 to 10 years with significant management changes.

Results:

Soil chemical and health assessment results are summarized in Tables 3 and 4 and Figures 2-9. Data Tables 3 and 4 list mean and standard deviations for 7 measured parameters within each field and the overall soil health score for each field, calculated by averaging scores for all these parameters. Exact analysis and calculation methods are described in the Comprehensive Assessment of Soil Health manual published by the Cornell Soil Health Lab.

Considerable variation was observed within fields for many parameters in this study. **Surface soil penetration resistance or hardness**, for example, ranged from a mean of 35 to 238 PSI for the 9 fields as listed in Table 3. The variability within each field is important too. The standard deviations (SD) for those surface hardness measurements ranged from 11.5 to 35.8, or from 11% to 42% of the field hardness means. Figure 3 depicts this within-field variation surface hardness measurements for each field. Two fields, CF1 and RM had relatively consistent surface hardness measurements while the other 7 fields varied widely. To detect a 10% improvement in surface hardness, or a reduction of 14.3 PSI, as many as 164 samples per field would be needed for the most variable fields, or 77 samples per average field at each of 2 different time points for the comparison.

Subsurface hardness observations were the most consistent parameter in this study; however, the reason for that consistency is somewhat artificial. See Table 3 and Figure 4. Subsurface compaction was quite serious in all fields studied, so a ceiling of 300 PSI was chosen as a maximum reading. Readings above 300 PSI were recorded as 300, which compressed the readings into the upper range of measurements. In two fields, G3 and SWT, we measured ≥300 PSI at every sample location, so SDs are 0. In two additional fields, BW4 and CF1, all subsurface PSI measurements except one were ≥300 PSI. This lack of variability causes the box-and-whisker plots in Figure 4 to appear as only a median line with a couple of outliers for these 4 fields. Only one field in the study, RM, had a subsurface hardness mean that was notably lower than 300 PSI, the subsurface resistance pressure known to limit root penetration, cause poor drainage and poor deep water storage. Only 9 samples locations per field would be sufficient to detect a 10% improvement in subsurface hardness for an average field in this study, however 80 sample locations per field would be needed to find this same difference in a highly variable field such as RM in 2018. If a ceiling of 300 PSI were not used, more samples would undoubtedly be required.

Table 3. Mean and standard deviation (SD) for soil hardness, pH and phosphorus results in 9 NNY row crop fields in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability, NNYADP, 2018.

	Surface Hardness, PSI, 0 to 6"		Subsurface Hardness, PSI, 6 to 18"		Soil pH		Soil P, lb / acre	
Field	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
CL	109	17.8	294	10.5	7.12	0.41	54.3	42.6
GM	238	33.3	295	8.1	6.53	0.55	6.3	2.6
G3	213	26.1	300	0.0	5.81	0.23	4.0	1.2
SWT	172	35.8	300	0.0	6.63	0.80	124.8	99.7
CF1	35	14.6	299	2.9	6.04	0.14	19.9	2.8
MT	122	18.3	285	20.7	5.54	0.23	3.9	0.9
RM	100	11.5	190	48.9	5.69	0.17	4.4	1.5
BW3	129	27.4	277	32.6	6.68	0.29	8.2	5.3
BW4	167	34.5	298	9.2	6.82	0.26	13.0	6.0
10% of Average[1]	14.28		28.20		0.63		2.7	
Maximum SD[2]		35.8		48.9		0.80		99.7
Average SD[3]		24.4		14.8		0.34		18.1
No. Samples needed to detect 10% change, max. SD[4]	164		80		43		36774	
No. Samples needed to detect 10% change, average SD[5]	77		9		9		1207	

[1] Average of field means, multiplied by 0.1.
[2] Maximum standard deviation within column.
[3] Average standard deviation within column.
[4] Number of samples required, at each of two time points, to detect a 10% change in that parameter calculated using the maximum standard deviation in that column with 95% confidence.
[5] Number of samples required, at each of two time points, to detect a 10% change in that parameter calculated using the average standard deviation in that column with 95% confidence.

Soil pH was the least variable soil health measurement included in this project, as shown in Table 3 and Figure 5. Field averages ranged from a low of 5.54 to a high of 7.12 and SDs ranged from 3% to 12% of field means. Three fields had pH averages below the recommended minimum pH for corn of 6.0. Because pH was not as highly variable within-field, just 9 sampling locations would be needed to detect a 10% change for an average field in this investigation, while 43 samples would be needed in a more variable field such as SWT.

Table 4. Mean and standard deviation (SD) for soil organic matter, aggregate stability, respiration and overall soil health score results in 9 NNY row crop fields in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability, NNYADP, 2018.

	Soil Organic Matter, %		**Aggregate Stability, %**		**Respiration, mg CO_2 / g soil**		**Overall Score**	
Field	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean[6]**	**SD**
CL	3.5	0.9	47.1	9.2	1.08	0.32	81.8 a	12.9
GM	3.7	0.8	68.0	2.6	0.90	0.12	80.0 a	6.3
G3	2.8	0.6	59.1	4.3	0.36	0.10	66.2 bc	7.2
SWT	2.6	0.9	48.5	9.4	0.49	0.16	60.8 c	14.3
CF1	2.8	0.2	41.6	3.2	0.46	0.08	75.5 ab	3.9
MT	2.5	0.4	47.8	8.9	0.35	0.05	53.4 c	3.7
RM	4.8	1.0	51.8	6.5	1.25	0.22	80.2 a	6.1
BW3	3.5	1.0	46.2	7.6	0.56	0.16	80.4 a	8.0
BW4	3.5	0.8	44.1	7.3	0.58	0.14	82.8 a	6.5
10% of Average[1]	0.3		5.1		0.07		7.35	
Maximum SD[2]		1.0		9.4	0.07	0.32		14.3
Average SD[3]		0.7		6.5		0.15		7.6
No. Samples needed to detect 10% change, max. SD[4]	265		92		545		99	
No. Samples needed to detect 10% change, average SD[5]	132		45		121		30	

[1] Average of field means, multiplied by 0.1.
[2] Maximum standard deviation within column.
[3] Average standard deviation within column.
[4] Number of samples required, at each of two time points, to detect a 10% change in that parameter calculated using the maximum standard deviation in that column with 95% confidence.
[5] Number of samples required, at each of two time points, to detect a 10% change in that parameter calculated using the average standard deviation in that column with 95% confidence.
[6] Means within a column with different letters are statistically different.

Soil phosphorus was the most variable soil health indicator included in this study. Mean field P measurements ranged from 3.9 to 124.8 lbs/acre and SDs ranged from 14% to 80% of those within-field means. Fields CL and SWT had SDs that were 79% and 80% of their respective means. Box plots depicted in Figure 6 show this wide variation in soil P within these 2 fields which contributed greatly to the overall average variation across fields. The other 7 fields had low P, averaging 8.5 lbs P/acre and with an average SD of 2.9 or 34%. Because of this high variability in measured within-field P, many more samples would be needed to detect a 10% change in soil P across 2 points in time within a field. For the most variable fields, almost 37,000 sample locations would be needed. About 1200 sample locations would be needed for an average field in this study and 607 samples would be needed in the 7 least variable fields in this study.

Soil organic matter means and SD for each field are listed in Table 4 and within-field data distributions are depicted in Figure 7. The 9 fields included in this study contained an average of

3.3% soil organic matter, typical of NNY row crop fields. Organic matter field means ranged from of 2.5% to 4.8% with SDs of 7% to 36% of those respective means. Figure 6 shows similar data distributions across fields with CF1, GM and MT being slightly more consistent than the average.

Soil organic matter is one of the soil health indicators farmers may be most familiar with and a measure many are taking steps to improve with practices like no- or reduced-tillage planting methods and cover crops. To detect a 10% improvement in soil organic matter, a change from 3.3 to 3.6%, which may require 4-8 years with effective management changes, 132 sampling locations would be required in a field typical of this study, or 265 sampling points in the most variable field.

Aggregate stability is a measure of the strength of a soil's structure and how well it resists breakage from raindrop impacts and from swelling due to water absorption. Weak aggregates fall apart easily upon wetting and can cause surface crusting, while stronger aggregates will remain intact under stress. Aggregate stability field means ranged from 41.6 to 68.0 in the 9 fields included in this study and corresponding SDs were moderate, ranging from 4% to 19% of those means. See Table 4 and Figure 8. Because of this lower within-field variability, fewer samples would be needed to detect a 10% improvement in aggregate stability than for some other indicators in this study. Forty-five samples would be needed for an average field while 92 sampling points would be needed for a field as variable as SWT in this study.

Soil respiration, or the amount of CO_2 given off by a soil upon rewetting, is a measure of biological activity of a soil. More CO_2 respired indicates a larger, more active microbial community. Soil respiration field means in this study ranged 4-fold, from 0.35 to 1.25 mg CO_2/g soil as shown in Table 4 and Figure 9. Variability across and within-fields was substantial, with SDs ranging from 14% to 33% of field means. This variability is reflected in the estimated number of samples needed to detect a 10% change in soil respiration. An average field should be sampled at 45 points while a highly variable field, such as CL in this study, would require 545 sampling locations.

The overall soil health score, calculated for each sample, is a combination of several soil health indicators into one comprehensive score. In this calculation, individual parameters, such as soil organic matter or P, are measured and then scored using a cumulative normal distribution curve. Those scores are then averaged to yield the overall soil health score, on a scale from 0 to 100 with 100 signifying the healthiest or least constrained score, and 0 representing the least healthy or most limited end of the range. Each soil health indicator is given equal weight in the overall score.

As listed in Table 4 and depicted in Figure 10, field mean overall scores ranged from 53.4 to 82.8 with SDs ranging from 5% to 23% of those means. Despite the overall score being an aggregate of all other indicator measurements, its inherent variation, in this study, is not a sum of all its components' variability. To detect a 10% change in overall score, for example an improvement from 65 to 75, 30 sample locations per field typical of these 9 fields would be sufficient. For the most variable fields in this group, SWT or CL, 99 sample locations would be needed to detect a change of that magnitude.

A quick summary of the sampling needed to detect a 10% improvement in the soil health parameters evaluated in this study follows.

The following estimations are based on the fields studied for this project:

Surface Hardness: as many as 164 samples per field for the most variable fields, or 77 samples per average field at each of 2 different time points

Subsurface Hardness*: 9 sample locations per field for an average field
80 sample locations per field to find same difference in a highly variable field

**If a ceiling of 300 PSI were not used, more samples would undoubtedly be required*

pH*: 9 sampling locations for an average field
43 samples for more variable field

** pH was not as highly variable within-field in this study*

Within-Field Soil P: ~37,000 sample locations for the most variable fields,
~1200 sample locations for an average field
607 samples in the 7 least variable fields in this study

Soil Organic Matter*: 132 sample locations for fields typical in this study
265 sample locations for more variable fields

**A change from 3.3 to 3.6% may require 4-8 years with effective management changes*

Aggregate Stability: 45 sample locations for an average field
92 sample locations for higher variable fields

Soil Respiration: 45 sample locations for an average field
545 sample locations for more variable field

Overall Score: 30 sample locations for fields typical in this study
99 sample locations for more variable fields

Conclusions/Outcomes/Impacts:

Considerable and important variation was observed within fields for most parameters in this study. The overall Cornell soil health score, the integration of many soil health indicators, was one of the least variable measures reported, however, more sampling locations than currently recommended will be needed to reliably detect changes of a magnitude of just 10% of field means in this study. Sample size calculations using the measured standard deviations in this study indicate that 9 to 1207 samples would be needed to detect 10% improvements in reported soil health indicators while 43 to 36774 sampling locations would be needed to detect these same changes in the most variable fields in this study.

Outreach:

We will immediately recommend and implement a minimum of 40-50 sampling locations per field for farms wishing to begin monitoring soil health status and improvements over time on their farms using a similar sampling scheme. More sample locations would be needed for some component indicators. For example, if soil compaction comparisons are desired, a minimum of 75-80 measurements per field per point in time would be the recommendation. The indicators that many farms view as the most important soil health indicators: compaction, soil organic matter and aggregate stability, could drive this sampling intensity decision. To reliably detect 10% changes in those parameters, farmers, landowners and crop consultants could target 80-120 samples per field using a similar scheme. Current recommendations are for 5-10 sampling locations per field for the complete soil health assessment. Information and recommendations will be shared with County Extension offices and County Soil and Water Conservation District offices across the region that often use soil health testing as part of their farm impact and environmental conservation work. A factsheet will be written summarizing this study as rationale for these recommendations.

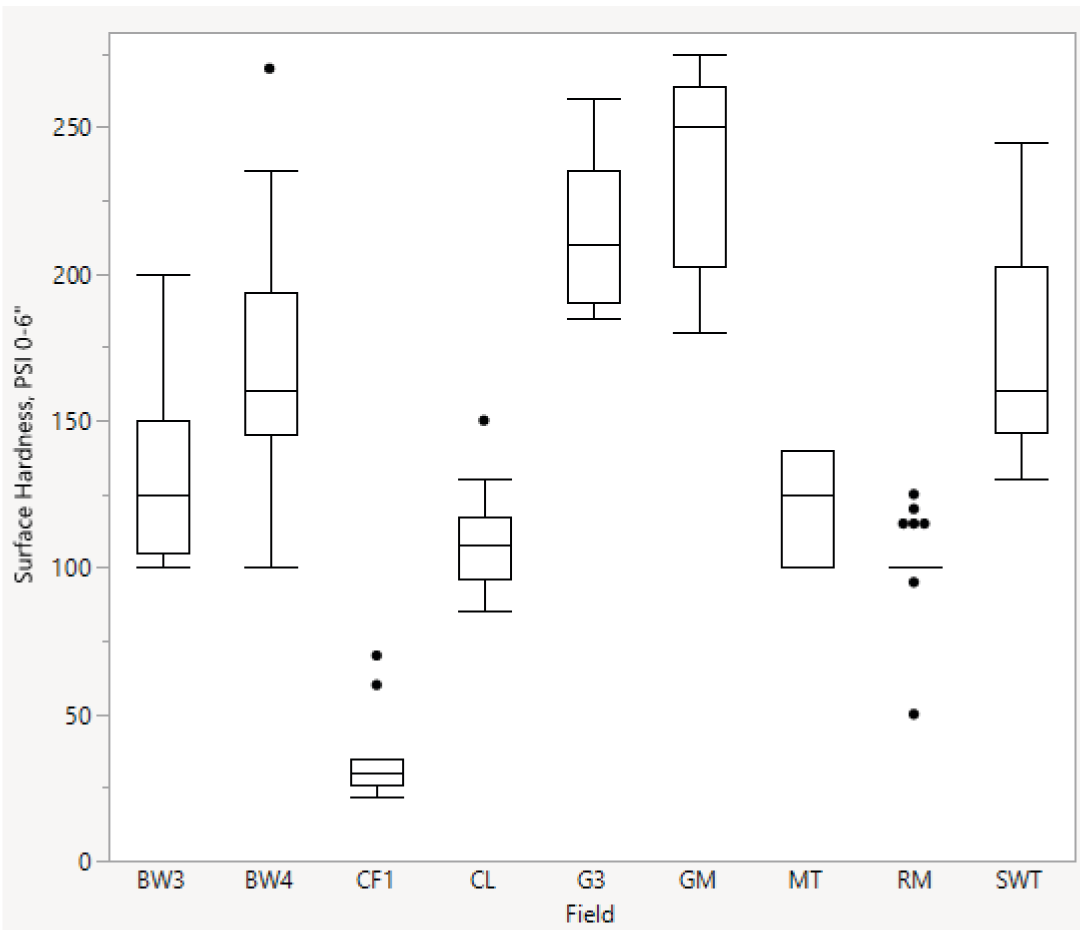

Figure 3. Box-and-whisker plot[1] of surface hardness (0 to 6" depth) data distributions in pounds per square inch (PSI) for 9 fields measured in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

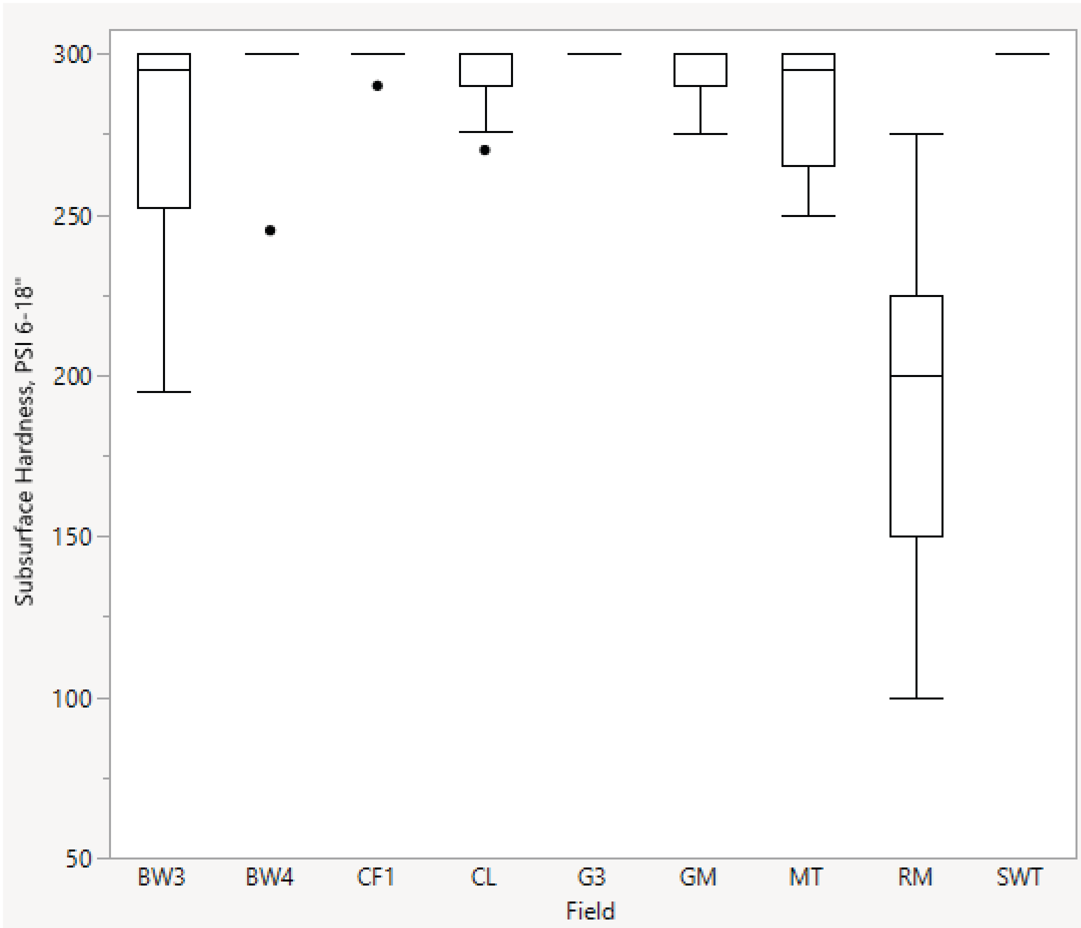

Figure 4. Box-and-whisker plot[1] of subsurface hardness (6 to 18" depth) data distributions in pounds per square inch (PSI) for 9 fields measured in 2018. Soil penetrometer readings beyond 300 PSI were recorded as 300 PSI; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

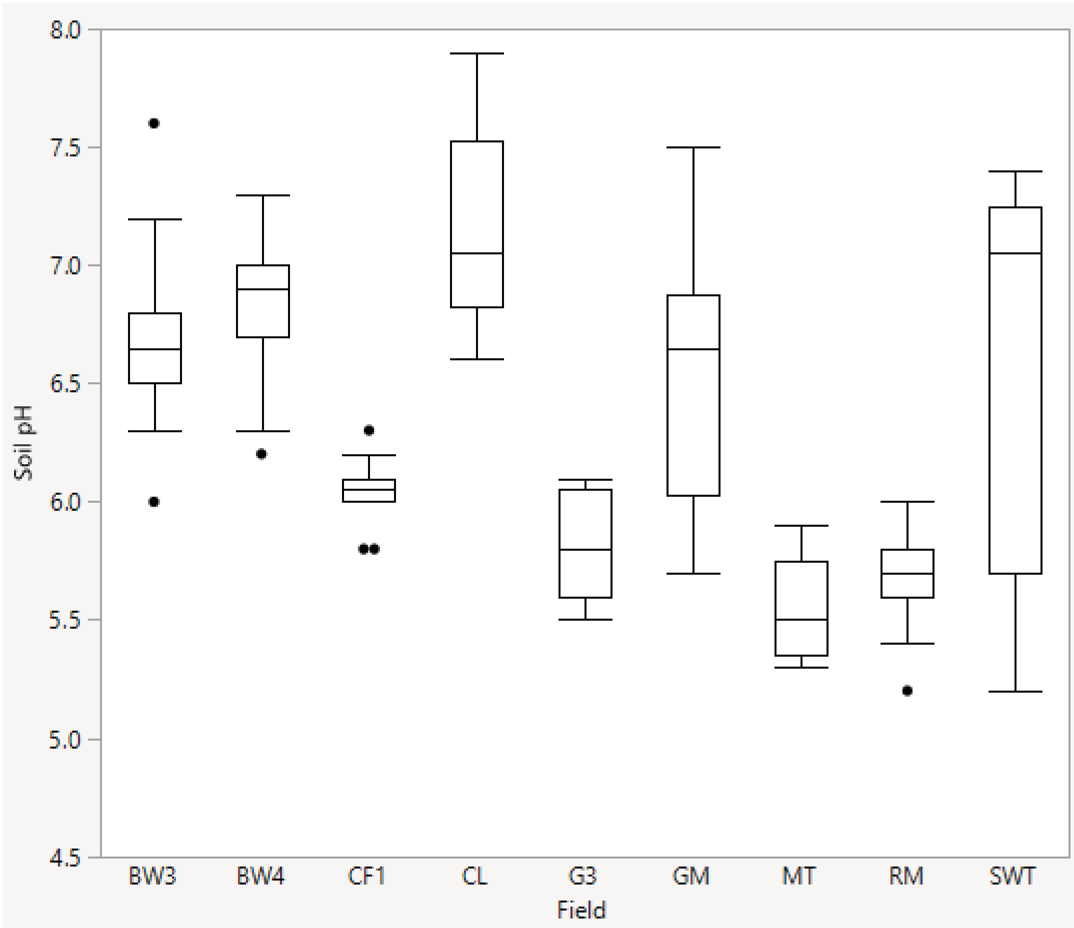

Figure 5. Box-and-whisker plot[1] of soil pH data distributions measured in 9 fields in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

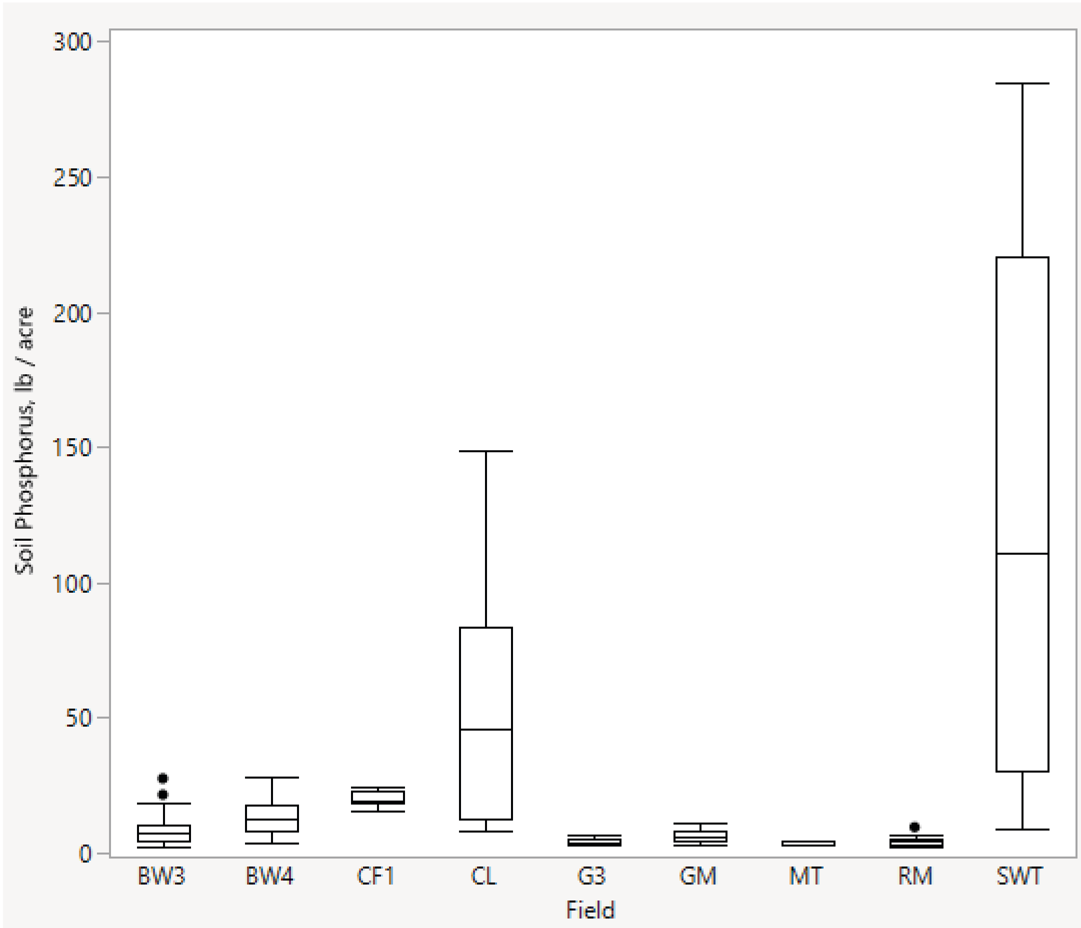

Figure 6. Box-and-whisker plot[1] of soil phosphorus (lbs / acre) data distributions measured in 9 fields in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

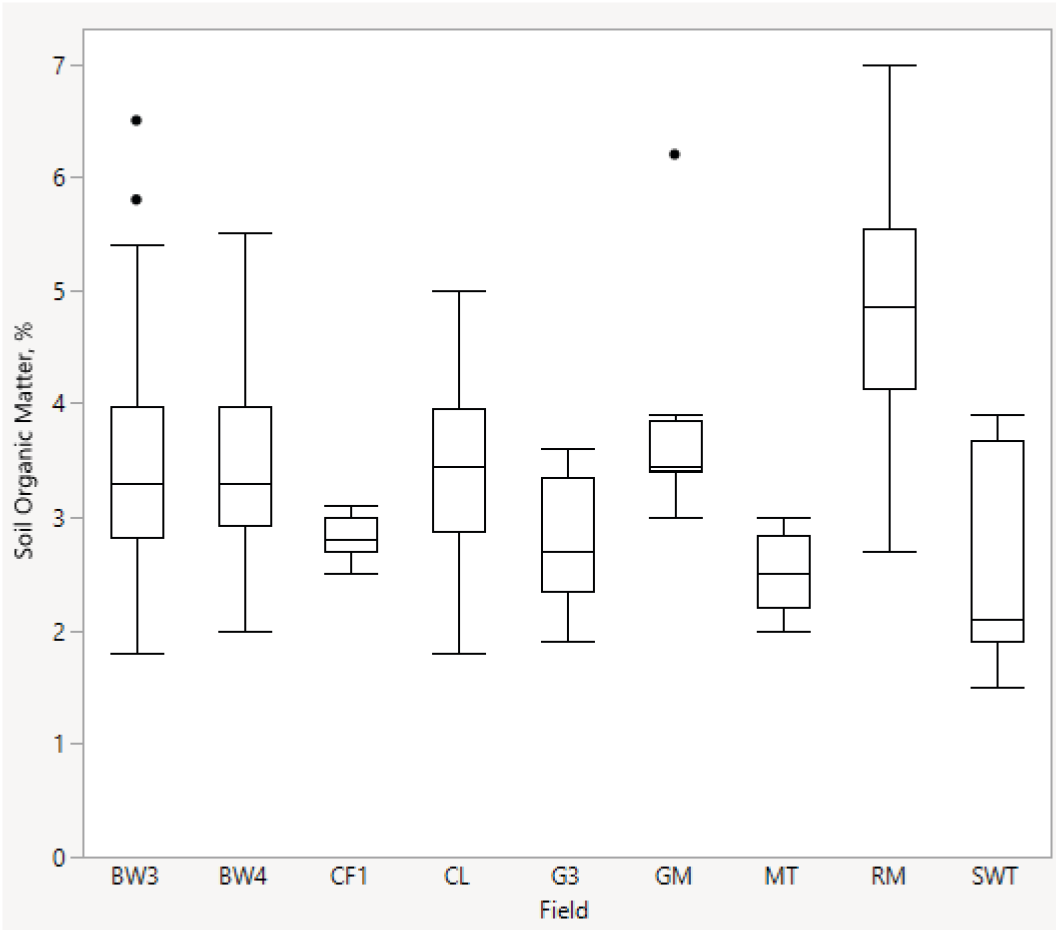

Figure 7. Box-and-whisker plot[1] of soil organic matter (%) data distributions measured in 9 fields in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

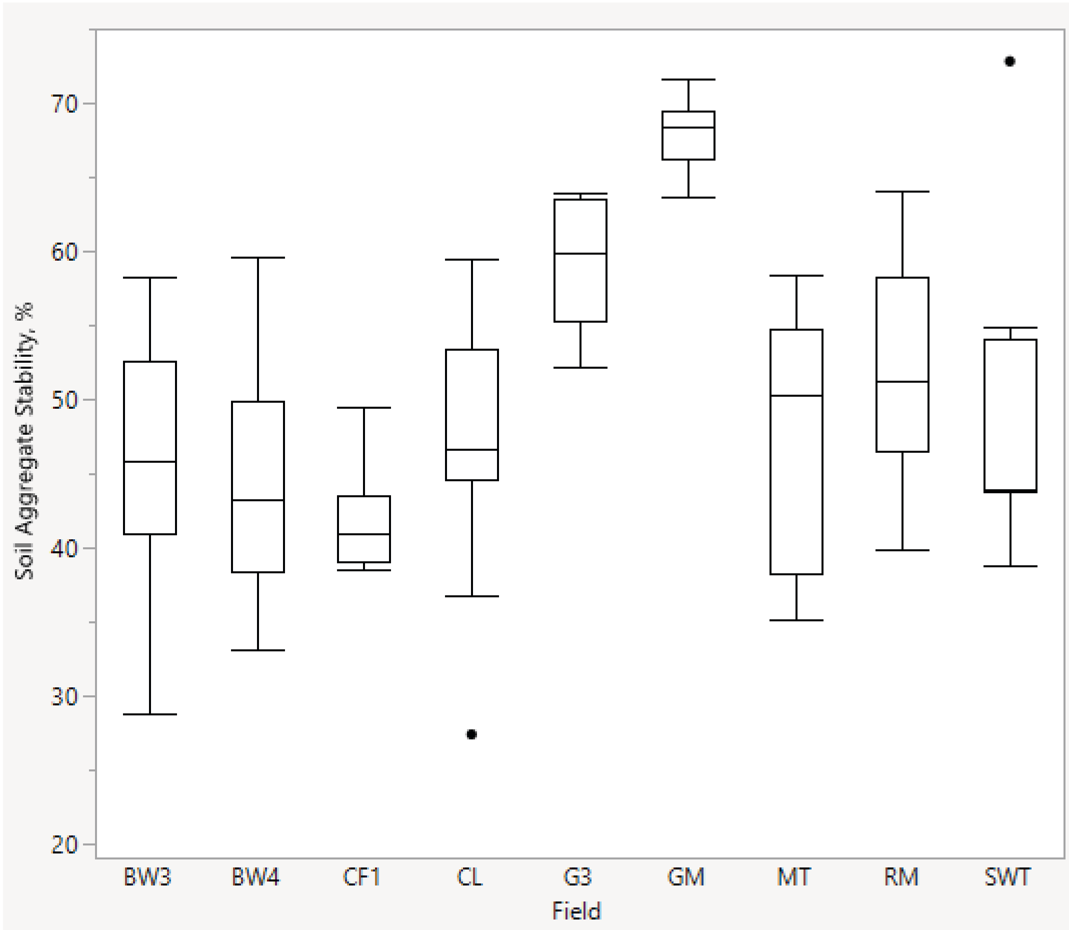

Figure 8. Box-and-whisker plot[1] of soil aggregate stability (%) data distributions measured in 9 fields in 2018; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

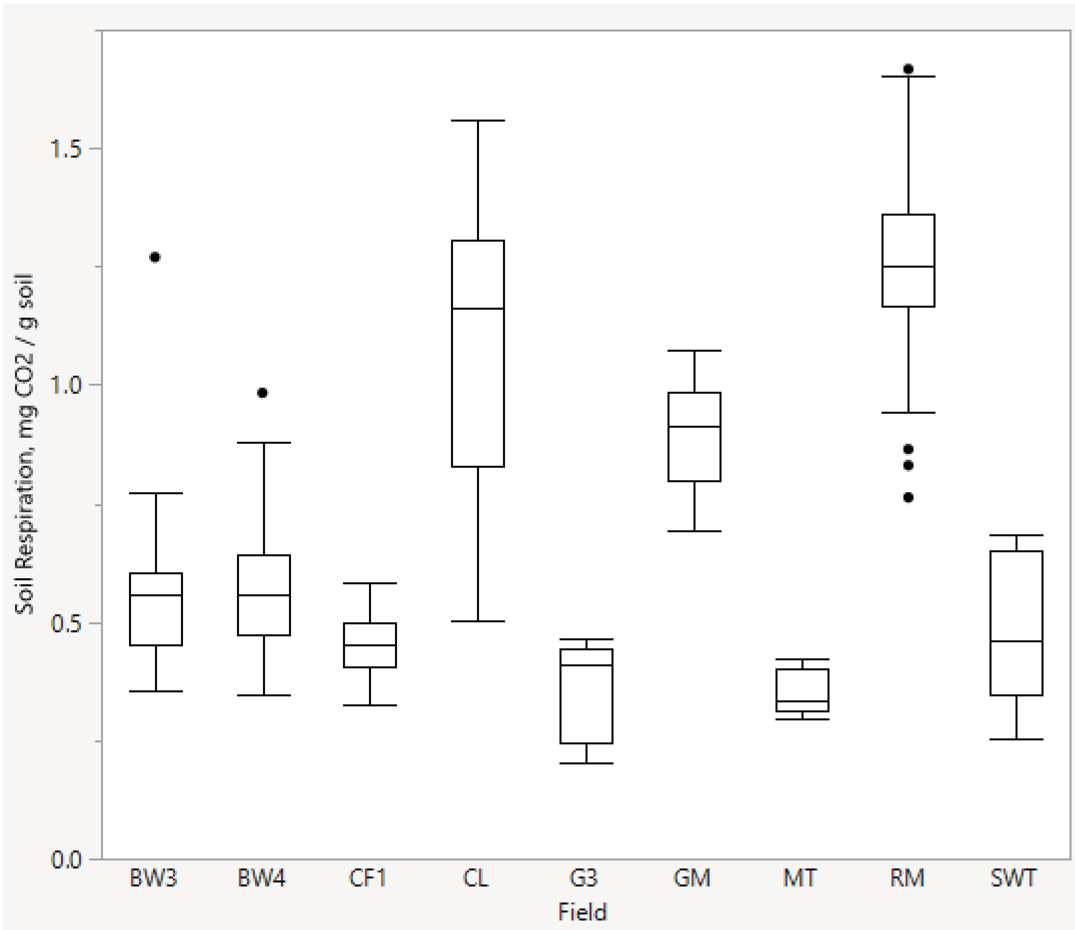

Figure 9. Box-and-whisker plot[1] of soil respiration (mg CO_2 respired per g soil in 4 days) data distributions measured in 9 fields in 2018.; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

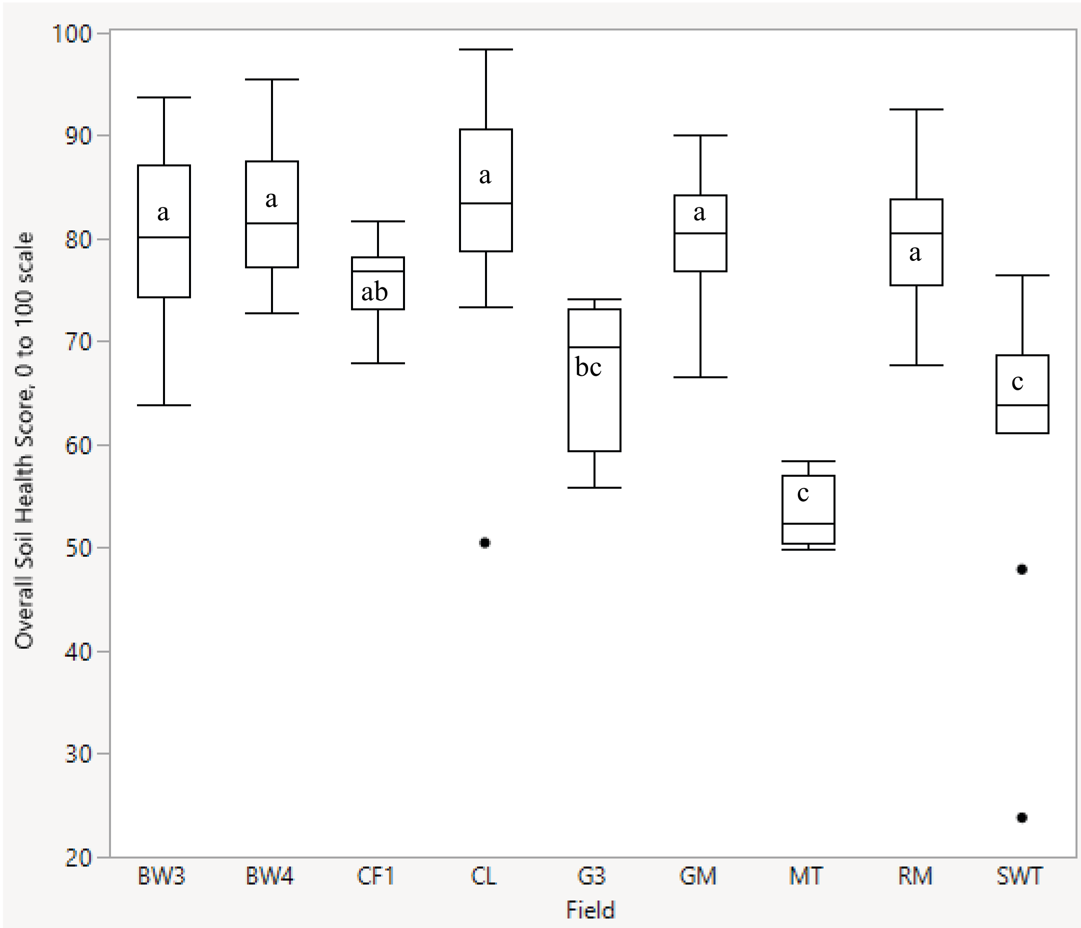

Figure 10. Box-and-whisker plot[1] of overall soil health score (average of individual indicator scores) distributions measured in 9 fields in 2018. Means for fields with different letters are statistically different; Using the Cornell Soil Health Test on Commercial Farms in NNY: Identifying Within-Field Variability Project, NNYADP.

[1] The boxes represent from the 25th to 75th percentiles of the data distribution observed within each field, with whisker lines extending below to the 1st percentile and upward to the 100th percentile for each field. A horizontal line inside each box represents the median and points outside the whisker lines represent outliers.

References:

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