RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

2023 Soil Health Program Report

Zach Dickhausen, *Natural Resources Coordinator* **rpbcwd.org**

INTRODUCTION

Riley Purgatory Bluff Creek Watershed District and Barr Engineering staff are working to establish and develop the Soil Health Program as a branch of the Ecosystem Health Action Plan (EHAP). Through this plan, staff are identifying a set of soil health indicators to sample within the District. The goal of the sampling is to establish baseline soil conditions across a variety of landscape-use types and to characterize what constitutes healthy/unhealthy soil in the District. This data will be used to inform future District actions and management practices. Soil assessment and sampling results are a major tool for developing the Soil Health Program.

WHAT IS SOIL HEALTH?

Soil health can be seen as "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans" (NRCS 2023). Soil health and soil quality are considered synonymous, although many professionals will make one distinction between the two, that soil quality includes both inherent and dynamic quality (Moebieus-Clune 2017). Inherent quality is the makeup and properties of soil, shaped by long-term geological processes; Dynamic qualities, more of the "soil health" qualities, are the properties of the soil which are influenced by use and changes on a human time scale (Cornell University 2017). It is important to manage and strive for good soil health and function, as it is its own ecosystem, working as a vital part of broader ecosystems. Properly functioning soil will allow for nutrient cycling and retention, support healthy vegetation communities, sequester carbon, allow for greater water infiltration and storage, etc. For more information on soil health and healthy soil characteristics, refer to Cornell University's "What is Soil Health?" Soil Health Manual Series, Fact sheet number 16-02 found in Appendix A, or the Cornell University Comprehensive Assessment of Soil Health Training Manual, Edition 3.2, 2017. Extensive research exists on soil health and its effectiveness on improving water quality and water conservation. Staff have started the process of reviewing literature on the subject to compile research findings and to identify best practices for soil improvement and soil guidance/policies that can result in water conservation improvements in the District.

The following is a summary of the soil assessment efforts staff undertook during late 2022 through the 2023 field season. This includes methods of assessment, as well as data collected pertaining to infiltration/hydraulic conductivity, and soil physical, biological, and chemical characteristics data collected. Apparent trends in said data across different landscape-use types and soil types is also discussed.

Soil sample collection

SAMPLE METRICS

The following table (Table 1) contains the current list of sampling metrics being collected during a typical site assessment. These metrics may change/be-added-to upon further literature review and reassessment of data/needs. Metrics to be analyzed by Cornell University's Soils lab as a part of their standard soil health analysis package are noted in the following table.

Table 1. List of current RPBCWD Soil Health Program sampling metrics.

Metric	Assessment
Infiltration rates (MPD infiltrometer)	On-site
Compaction (field penetrometer)	On-site
Soil respiration	Cornell University Soils Lab
pH	Cornell University Soils Lab
Modified Morgan Extractable P	Cornell University Soils Lab
K, Mg, Fe, Mn, Zn, Al, Ca, Cu, S, B	Cornell University Soils Lab
Soil texture	On-site *and* Cornell University Soils Lab
Active carbon	Cornell University Soils Lab
Wet aggregate stability	Cornell University Soils Lab
Soil organic carbon	Cornell University Soils Lab
Predicted Autoclave-citrate Extractable (ACE) protein*	Cornell University Soils Lab
Available water capacity	Cornell University Soils Lab
Surface/sub-surface hardness interpretation (based off field penetrometer readings)	Cornell University Soils Lab
Soil profile/horizon assessment (texture, color, thickness, matrix makeup, redoximorphic features, presence of wetland soils and/or hydrology, etc.)	On-site
Soil moisture	On-site
Vegetation	On-site
Presence of earthworms	On-site

*Autoclave-citrate extractable (ACE) protein and available water capacity are predicted based on other indicators measured.

SAMPLE SITES/POINTS

Sample points were based on identification of representative sites and landscape/ecosystem types (disturbed woodland, old field, wet prairie wetland, field/mowed lawn, etc.), and soil textures/types (sand *vs.* clay/USDA mapped soils). Figure 1 shows sites sampled in the fall of 2022 and during the 2023 field season. At least one composite sample, consisting of at least two sub-samples taken across the site, was taken within each identified landscape type. Samples taken at smaller areas (small scale rain gardens/bee lawns, sites adjacent to BMPs such as the Rice Marsh Lake Kraken unit, etc.) usually consisted of only two subsamples. If multiple mapped soils occurred within these identified landscape types, a separate composite sample was taken within each mapped soil unit. Subsamples were usually taken adjacent to (within 10 feet) of the corresponding infiltration measurement (two subsamples taken 15 feet apart; if more than two subsamples were needed, they were taken at other points within the landscape type).

Sampling was conducted when there was no precipitation and had not been any for the previous 24 hours. Clear, sunny days were needed to properly evaluate the soil profile. In instances where it was too overcast to properly assess soil horizon colors, soil profiles were conducted at a later date during sunny conditions.

Figure 1. Map of soil assessment areas in RPBCWD.
The red dots indicate area where soil assessments were conducted. Thirty-nine sites were identified and assessed within these areas.

INFILTRATION

Infiltration testing was conducted to measure the hydraulic conductivity of the soil (Ksat) at each site using a Modified Philip Dunne infiltrometer (MPD). For each site tested three, four-inch diameter graduated cylinders were pounded into the soil at a three-foot radius around a center point. They were each filled with 30 centimeters of water. Once filled, the MPD sensor heads were placed onto the cylinders and the test was started immediately (each individual cylinder constituted one test). Each test ran until all the water had drained from the tube. If no water drainage was detected after four hours, the test was concluded. Once the sensor head is in place and turned on, the MPD automatically records data for each test.

SAMPLES

Each composite sample consisted of at least two subsamples. Each pair of subsamples were taken 15 feet apart (if taken at an MPD sample point, the same center point was used for both the sampling and infiltration testing). For each subsample, surface debris was removed before digging. With a tile spade, an 8-inch deep hole was dug. From the side of the hole (two inches below surface), a six-by-two-inch sample, the width of the shovel blade, was removed. Any extra soil was removed from the sample so as to make it as uniform as possible. Subsamples were placed together in a clean, five-gallon bucket, mixed thoroughly, and five cups were measured out and double bagged in gallon freezer bags. Samples were labeled with site information, refrigerated and sent to the Cornell University Soils Lab for analysis (all samples sent by end of day, the day after sampling to ensure freshness of the soil). A penetrometer was used to measure surface and subsurface compaction at each subsample site. Penetrometer readings were included with the soil samples to be analyzed by the soils lab.

RESULTS

INFILTRATION DATA

Thirty-nine sites were assessed for infiltration/hydraulic conductivity from fall 2022 through the 2023 field season. Across these sites, 129 individual infiltration tests (one MPD graduated cylinder constitutes one test) were conducted using the MPD infiltrometer (at least one set of three tests at each site; some sites had repeat or extra tests). Of these sites, 18 tests had some sort of error occur and produced a “NULL” result (this is in-part why some sites had multiple tests). Sites were chosen to look at soil conditions at BMP/project sites, as well as collect data on different types of landscape/land-use types. Of the 111 successful tests, 17 were done in rain gardens, 41 across maintained lawns/parkland/bare soil, 19 on restored prairie, six on bee lawns, 11 in restored wet meadow, two in restored shallow marsh, three in stormwater basins, five in restored woodland, and seven in woodland (Table 2). Of the sites planned for assessment across the 2024 field season, the majority will be sites containing landscape use types which are currently lacking in data (woodlands, wet meadows, prairie, old field that has reverted to prairie, restoration sites, etc.) as well as project-specific sites.

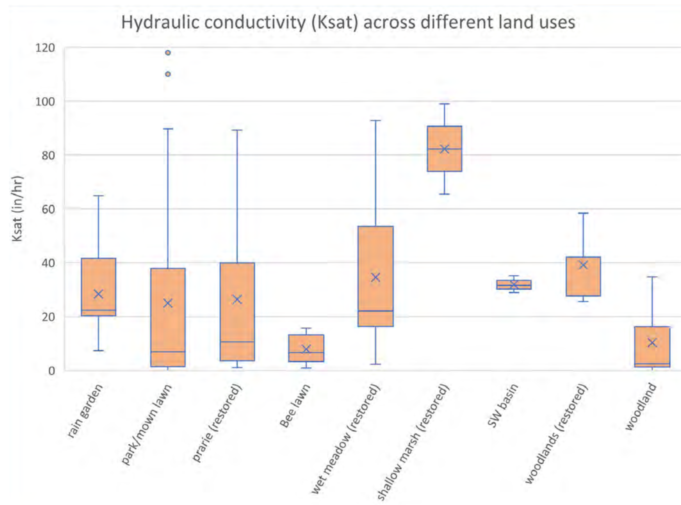
Table 2. Number of successful infiltration tests conducted in 2022-2023 and their associated landscape type.

Landscape use	Number of tests
Field/park/mowed lawn	41
Prairie (restored)	19
Rain garden	17
Wet meadow (restored)	11
Woodland (not restored)	7
Bee lawn	6
Woodland (restored)	5
Stormwater basin	3
Shallow marsh (restored)	2
Total	**111**

Infiltration varied across the different landscape uses (Figure 2). One thing to note across several of the BMP and restored sites, some of these projects were recently finished and vegetation had been recently planted. Many of these sites will be re-assessed in the future to see how conditions and soil structure/health have changed. Restored landscape types tended to have the greater mean Ksat (prairie: 26.38 inch/hour over 19 tests; wet meadow: 34.60 inch/hour over 11 tests; shallow marsh: 82.25 inch/hour over two tests; restored woodlands: 39.16 over five tests). The bee lawn tests and woodland tests produced the lowest mean Ksat (7.92 inch/hour at the bee lawns over six tests, and 10.34 inch/hour over seven woodland tests). The bee lawn contained mostly native vegetation (planted in spring of 2022) which was seemingly not fully grown in at the time of sampling. The woodland tests took place adjacent to wooded ravines and upland draining to Lotus Lake.

Park/mowed lawn areas consisted mainly of mowed Kentucky Bluegrass (*Poa pratensis*) used for recreation and sports fields. There were some areas within this landscape type sampled that had bare ground as well. Test results from these areas had the greatest range. The mean Ksat was 25.03 in/hr across 41 tests. The lowest value was 0.006 in/hr, and the highest was 118 in/hr (which was plotted with a measurement of 110 in/hr as outliers). At most of the lawn/park land sites, soil profiles showed mixed soil layers and clear evidence of soil disturbance. Most of these sites are moderately-to-heavily traveled/used. All these park/lawn sites specifically scored either low functioning/quality or very low functioning/quality (constraining) scores for surface hardness and sub surface hardness (these scores are provided by Cornell University Soils lab based on site compaction readings taken during sampling, Appendix A and Appendix B). Of all the MPD sites where penetrometer readings were taken and compaction was assessed, only one of the wooded sites (Kerber Ravine, penetrometer readings were not taken at the other two wooded sites: LL_7 and LL_8) and two of the rain garden sites (Rice Marsh Lake and St Hubert's) had a sub-surface hardness score above low (all three scored very high). Only the Kerber ravine site and the Rice Marsh Lake raingarden had a surface hardness score above low (high and very high function scores, respectively, Appendix A).

Figure 2. Hydraulic conductivity measured over 111 successful infiltration tests.
"X" indicates the mean hydraulic conductivity (Ksat) value across all the tests within that particular landscape type. The lines intersecting each box plot indicate the median Ksat value of the tests conducted for that particular landscape type.



SAMPLE DATA

From fall 2022 through the 2023 field season, 29 site samples were mailed to the Cornell lab for testing/analysis. Each site sample was a composite, consisting of at least two sub-samples from within the site. Samples were collected from the upper eight inches of soil. Lab results and assessment of the samples included a comprehensive analysis of soil health, including physical, biological, and chemical metrics (Table 3). The Cornell soils lab also provided a comprehensive assessment of soil health, along with functional ratings for each soil sample submitted. (Figure 3 is the results of a sample assessment report for one of three samples taken at North Lotus Lake Park. This site is labeled as "NLLP2" on all the figures displaying functional ratings in this report. The full comprehensive assessment of this site is included in Appendix C). This assessment is based off the Cornell Comprehensive Assessment of Soil Health (CASH) Training Manual/framework (Moebius-Clune 2017). The assessment for each sample also includes soil texture composition (sand/silt/clay), as well as management suggestions to correct indicators which scored poorly. It is important to note that the CASH framework assessment and soil health focus around agricultural settings.

Most samples had an overall quality score of medium or higher. Samples taken from maintained lawn/park landscapes tended to have more mid-to-lower scores overall than other landscape types (six of the 15 field/lawn sites had an overall score of medium, and one had a low score). The undisturbed wooded areas (all located just west of Lotus Lake) had the highest scores (two of three had very high overall scores). Outside of surface hardness ratings, and aggregate stability at one of the sites, these two undisturbed wooded sites scored high – very high across all indicators sampled for. The one undisturbed wooded site that scored lower was observed to have similar understory and herbaceous vegetation growing to those the other two wooded sites. The one stormwater basin sampled so far had the lowest overall score of 29/low. It also tended to have lower, if not the lowest scores across most of the indicators sampled for. This basin was dry at the time of sampling. As far as the restored sites and BMPs were concerned, their scores varied across the indicators sampled for. The Scenic Heights Forest Restoration sites samples (including samples: Sc Ht Woods, Sc Ht Prairie, Sc Ht wet meadow) tended to score higher, more consistently across the indicators sampled for. This is the oldest restored area sampled thus far, and vegetation was well established across the site. Outside of hardness ratings, the Scenic Heights wet meadow and woods scored a medium rating or better across all the indicators, and outside of hardness and soil respiration, these two sites scored a high – very high rating across the board.

Most of the sites sampled to date were on landscapes that had a higher amount of recent disturbance and/or compaction: field/park/mowed lawn (11 sites), landscapes that had been recently restored (prairie, wet meadows, woodland, seven sites), recent BMPs (one stormwater basin, two rain gardens, one bee lawn).

The majority of sites scored low-very low for surface hardness and sub-surface hardness (23 of 25 and 22 of 25, respectively). As stated before, most of these sites have regular foot traffic or have recently in the last few years been restored and had some level of soil disturbance and/or compaction.

Most sites scored high–very high for nutrient content (presence of extractable P and K, and presence of additional nutrients: Mg, Fe, Mn, Zn, Al, Ca, Cu, S, B). Three of the field/park/mowed lawn sites with somewhat lower scores for extractable P (compared to the other sites, three with high and two with medium scores) also had the lowest scores for presence of additional nutrients (all three still having high scores). However, soil pH tended to be lower across most of the field/mowed lawn sites, the SW basin, and a couple of the restored sites (including three of four sites/BMPs located at the NW side of Rice Marsh Lake near the Kraken unit). Six of the 15 sampled field/mowed lawn sites had medium-low pH scores, indicating that the nutrients in the soil may be less available for plant use.

Table 3. Soil Health Indicators - Cornell Framework

PHYSICAL	**Predicted Available Water Capacity:** reflects the quantity of water that a disturbed sample of soil can store for plant use. It is the difference between water stored at field capacity and at the wilting point, and is measured using pressure chambers.
	Surface Hardness: is a measure of the maximum soil surface (0 to 6 inch depth) penetration resistance (psi), or compaction, determined using a field penetrometer.
	Subsurface Hardness: is a measure of the maximum resistance (psi) encountered in the soil between 6 to 18 inch depths using a field penetrometer.
	Aggregate Stability: is a measure of how well soil aggregates resist disintegration when hit by rain drops. It is measured using a standardized simulated rainfall event on a sieve containing soil aggregates between 0.25 and 2.0 mm. The fraction of soil that remains on the sieve determines the percent aggregate stability.
BIOLOGICAL	**Organic Matter:** is a measure of all carbonaceous material that is derived from living organisms. The percent organic matter is determined by the mass of oven dried soil lost on combustion in a 500º C furnace.
	Predicted Soil Protein: is a measure of the fraction of the soil organic matter which contains much of the organically bound N. Microbial activity can mineralize this N and make it available for plant uptake. This is measured by extraction with a citrate buffer under high temperature and pressure.
	Soil Respiration: is a measure of the metabolic activity of the soil microbial community. It is measured by re-wetting air dried soil, and capturing and quantifying carbon dioxide (CO_2) produced.
	Active Carbon: is a measure of the small portion of the organic matter that can serve as an easily available food source for soil microbes, thus helping fuel and maintain a healthy soil food web. It is measured by quantifying potassium permanganate oxidation with a spectrophotometer.
CHEMICAL	**Soil Chemical Composition:** is a standard soil test analysis package measures levels of pH and plant nutrients. Measured levels are interpreted in this assessment's framework of sufficiency and excess but no crop specific recommendations are provided. Nutrients measured include extractable phosphorus, extractable potassium, calcium, magnesium, iron, zinc, aluminum, boron, copper, manganese, and sulfur.

Figure 3. Sample comprehensive assessment of soil health from Cornell University Soils Lab.

The assessment gives functional ratings for each sampled indicator, as well as an overall soil health quality score (the overall score is the mean value of indicator functional ratings). In the rating column, dark green indicates a "very high quality" functional rate, light green indicates "high quality," yellow indicates "medium quality," orange indicates "low quality," and red indicates "very low quality."

Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences
School of Integrative Plant Science, Cornell University, Ithaca, NY 14853
https://soilhealthlab.cals.cornell.edu

Grower:
Zach Dickhausen
18681 Lake Drive East
Chanhussen, MN 55317
zdickhausen@rpbcwd.org

Sample ID:	WW2424
Field ID:	N. Lotus Lake Park 2
Date Sampled:	05/09/2023
Given Soil Type:	Lester-Kilkenny
Crops Grown:	PRK/PRK/PRK
Tillage:	no till
Coordinates:	Latitude: 44.884027000000 Longitude: -93.526559000000

Measured Soil Textural Class: **sandy loam**

Sand: **59%** - Silt: **23%** - Clay: **16%**

Group	Indicator	Value	Rating	Constraints
physical	Predicted Available Water Capacity	**0.18**	**76**	
physical	Surface Hardness	**325**	**2**	Rooting, Water Transmission
physical	Subsurface Hardness	**600**	**0**	Subsurface Pan/Deep Compaction, Deep Rooting, Water and Nutrient Access
physical	Aggregate Stability	**39.0**	**48**	
biological	Organic Matter Soil Organic Carbon: 1.73 / Total Carbon: 1.80 / Total Nitrogen: 0.16	**2.8**	**82**	
biological	Predicted Soil Protein	**4.70**	**22**	
biological	Soil Respiration	**0.5**	**34**	
biological	Active Carbon	**359**	**32**	
chemical	Soil pH	**7.4**	**96**	
chemical	Extractable Phosphorus	**2.5**	**72**	
chemical	Extractable Potassium	**62.5**	**87**	
chemical	Additional Nutrients Ca: 2770.2 / Mg: 398.8 / **S: 2.0** Al: 3.2 / B: 0.26 / Cu: 0.03 Fe: 0.6 / Mn: 2.3 / **Zn: 0.1**		**77**	

Overall Quality Score: **52** / Medium

Table 4 has a list of all the sample site IDs, their corresponding landscape type, and their soil texture composition. These site IDs correspond to the IDs used in all 13 of the figures which display the functional ratings for each soil health indicator (Appendix A). Figure 4 shows the overall soil quality score for each site. Each of these scores is an average of the 12 soil health indicator functional ratings. Figures for the results of each of those 12 indicators can be found in Appendix A. Figures showing average scores for the 12 soil indicators within the eight different landscape types can be found in Appendix B. The CASH manual does note that the overall score should be taken as a general summary rather than the main focus of the soil health assessment.

Most samples had an overall quality score of medium or higher. Samples taken from maintained lawn/park landscapes tended to have more mid-to-lower scores overall than other landscape types (six of the 15 field/lawn sites had an overall score of medium, and one had a low score). The undisturbed wooded areas (all located just west of Lotus Lake) had the highest scores (two of three had very high overall scores). Outside of surface

Figure 4. Sample site IDs with corresponding location description, Landscape type and soil texture composition.

Site ID	Location description	Landscape	Texture ratio (sand/silt/clay)
NLLP1	N. Lotus Lake Park, northern field area	Field/park/mowed lawn	44/36/18
NLLP2	N. Lotus Lake Park, middle of field area	Field/park/mowed lawn	59/23/16
NLLP3	N. Lotus Lake Park, southern field area	Field/park/mowed lawn	47/28/23
LSP outfield	Lake Susan Park, ball fields	Field/park/mowed lawn	45/30/24
St hub field	St Hubert's ball field	Field/park/mowed lawn	38/35/26
RML outfield	Ball field near Kraken unit, NW side of Rice Marsh Lake	Field/park/mowed lawn	41/37/20
ChanDTSW1	Chanhassen city center park, ball fields north of school	Field/park/mowed lawn	41/35/22
ChanDTSW2	Chanhassen city center park, ball fields north of school	Field/park/mowed lawn	38/38/22
ChanDTSW3	Chanhassen city center park, ball fields north of school	Field/park/mowed lawn	38/37/24
ChanDTSW4	Chanhassen city center park, ball field south of school	Field/park/mowed lawn	37/36/25
ChanDTSW5	Chanhassen Elementary School ball fields west of school	Field/park/mowed lawn	38/36/24
ChanDTSW6	Chanhassen Elementary School ball fields west of school	Field/park/mowed lawn	39/36/23
ChanDTSW7	Chanhassen Elementary School ball fields west of school	Field/park/mowed lawn	40/35/23
ChanDTSW8	Chanhassen Elementary School ball fields west of school	Field/park/mowed lawn	33/40/26
LL_3	Meadow Green Park, south end near wooded area	Field/park/mowed lawn	8/56/35
LL_7	Wooded area between Meadow Green Park and Lotus Lake	Woodland	38/36/24
LL_8	Wooded area, just west of Lotus Lake, south end	Woodland	41/34/23
Kerber rav	Ravine downstream of Kerber Pond	Woodland	44/33/21
LSP FE sand	Lake Susan Park, prairie area buffering Iron (FE) sand filter	Prairie (restored)	48/28/22
Sc HT Prairie	Scenic Heights School Forest Restoration, prairie area	Prairie (restored)	81/8/9
St Hub m prairie	St Hubert's restored prairie	Prairie (restored)	41/30/28
RML prairie	Rice Marsh Lake restored prairie near Kraken unit	Prairie (restored)	43/34/21
Sc Ht wet meadow	Scenic Heights School Forest Restoration, wet meadow area	Wet meadow (restored)	70/14/14
St Hub basin	St Hubert's restored basin	Wet meadow (restored)	46/32/21
Sc Ht woods	Scenic Heights School Forest Restoration, wooded area	Woodland (restored)	65/20/14
FH s basin	Stormwater pond, SW of Fawn Hill Rd, across from Bentz Ct	SW basin	90/1/9
St Hub rain garden	St Hubert's rain garden	Rain garden	91/3/4
RML rain garden	Rice Marsh Lake Rain Garden near Kraken unit	Rain garden	91/3/5
RML bee lawn	Rice Marsh Lake Bee Lawn near Kraken unit	Bee lawn	38/24/36

hardness ratings, and aggregate stability at one of the sites, these two undisturbed wooded sites scored high–very high across all indicators sampled for. The one undisturbed wooded site that scored lower was observed to have similar understory and herbaceous vegetation growing to those the other two wooded sites. The one stormwater basin sampled so far had the lowest overall score of 29/low. It also tended to have low, if not the lowest, scores across most of the indicators sampled for. This basin was dry at the time of sampling. As far as the restored sites and BMPs were concerned, their scores varied across the indicators sampled for. The Scenic Heights Forest Restoration sites samples (including samples: Sc Ht Woods, Sc Ht Prairie, Sc Ht wet meadow) tended to score higher, more consistently across the indicators sampled for. This is the oldest restored area sampled thus far, and vegetation was well established across the site. Outside of hardness ratings, the Scenic Heights wet meadow and woods scored a medium rating or better across all the indicators, and outside of hardness and soil respiration, these two sites scored a high–very high rating across the board.

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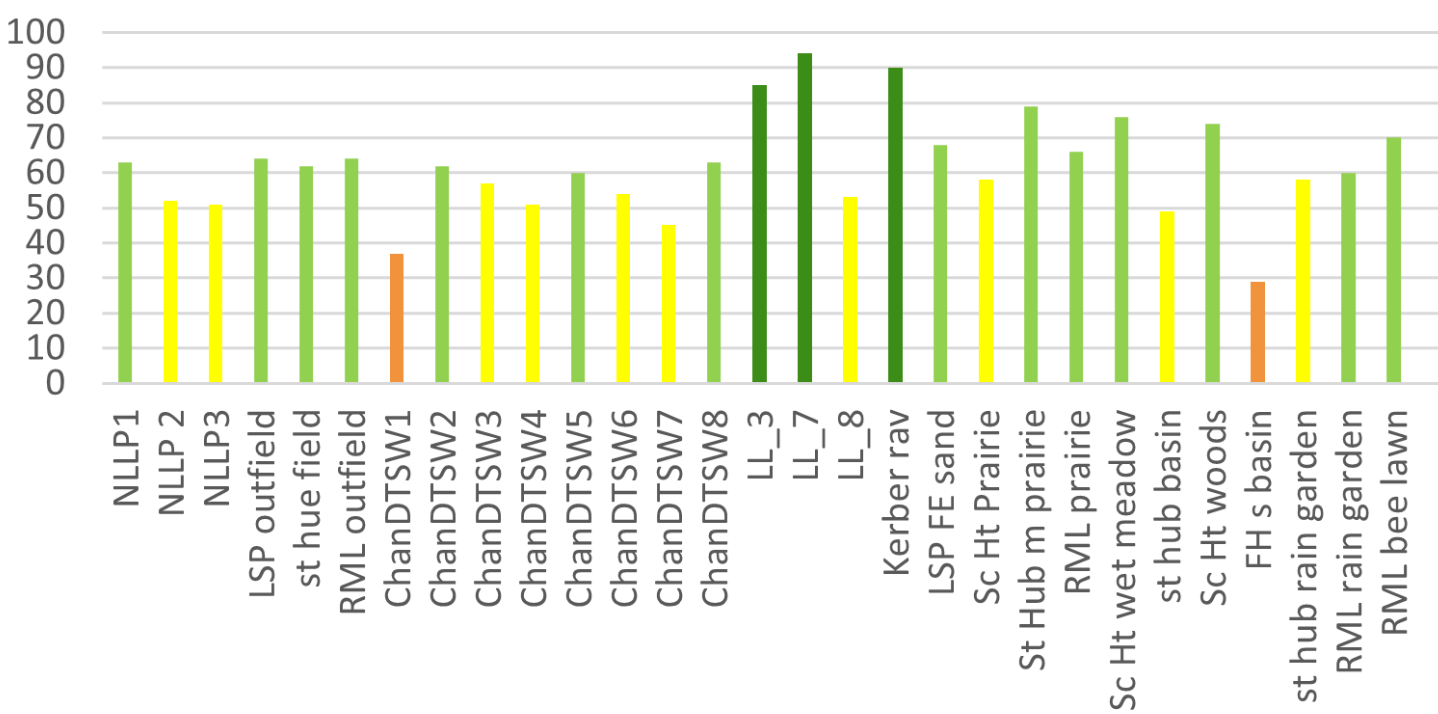
Most sites scored high–very high for nutrient content (presence of extractable P and K, and presence of additional nutrients: Mg, Fe, Mn, Zn, Al, Ca, Cu, S, B). Three of the field/park/mowed lawn sites with somewhat lower scores for extractable P (two high and one medium scores) also had the lowest scores for presence of additional nutrients (all three still having high additional nutrient scores). However, soil pH scores tended to be lower across almost half of the field/mowed lawn sites, the

Figure 5. Overall quality score of soil samples taken.

Dark green bars indicate a "very high quality" functional rating (score ≥ 80), light green indicates "high quality" (60 – 80), yellow indicates "medium quality" (40 – 60), orange indicates "low quality" (20 – 40), and red indicates "very low quality" (< 20). This score was determined by the Cornell University Soils Lab based on guidelines developed for the Cornell Comprehensive Assessment of Soil Health manual.



SW basin, and a couple of the restored sites (including three of four sites/BMPs located at the NW side of Rice Marsh Lake near the Kraken unit). Six of the 15 sampled field/mowed lawn sites had medium-low pH scores, indicating that the nutrients in the soil may be less available for plant use.

REFERENCES

Moebius-Clune, B.N., D.J Moebius-Clune, B.K. Gugino, O.J. Idowu, Et al. 2017. Comprehensive Assessment of Soil Health, The Cornell Framework. Cornell University. Ithaca, New York. Available at: soilhealth.ca ls.cornell.edu/manual

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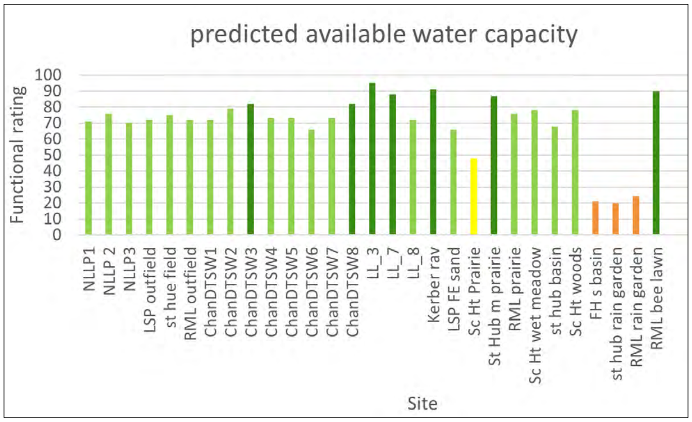
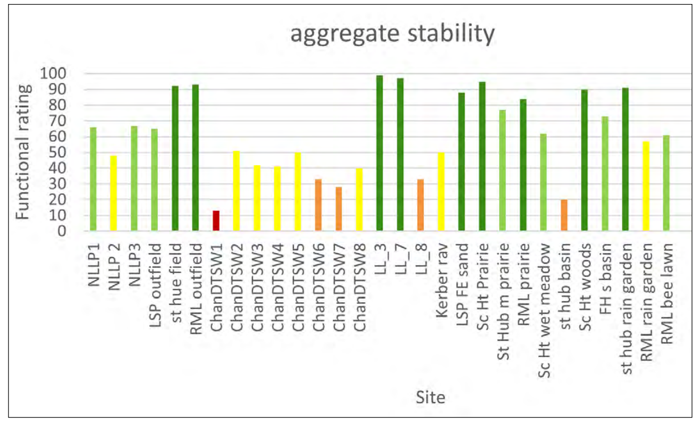
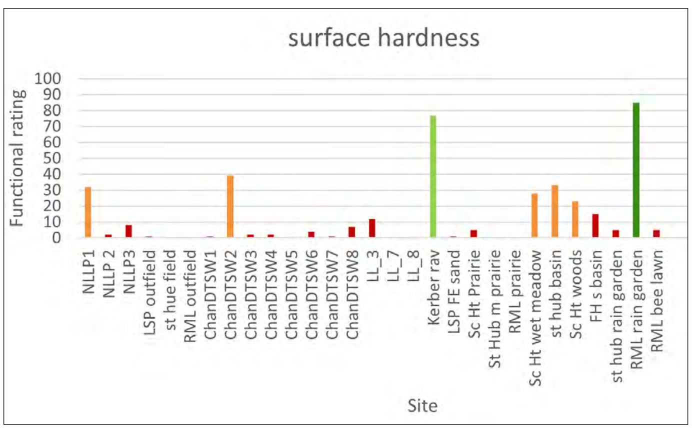
APPENDICES

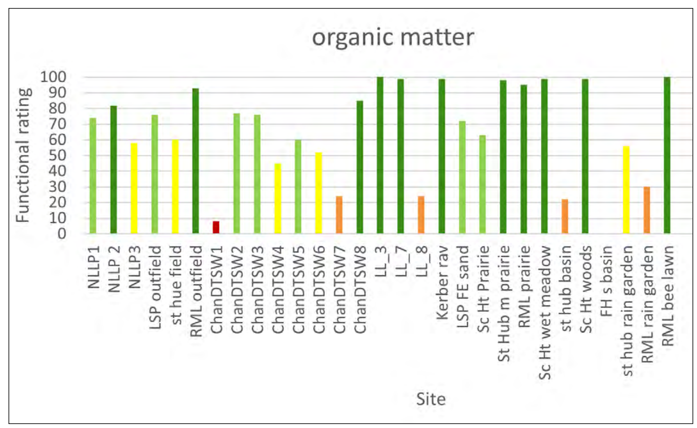
APPENDIX A

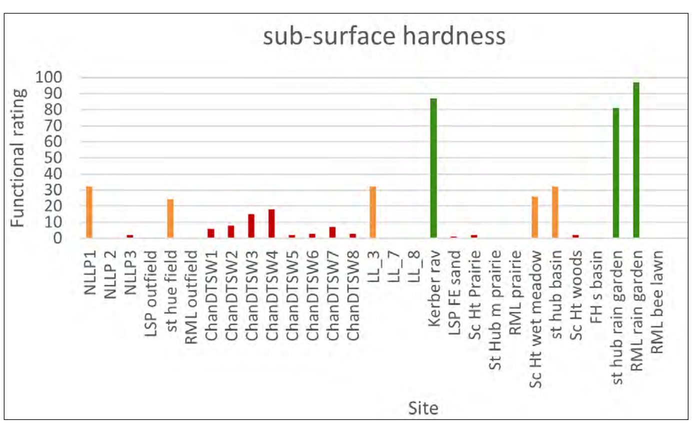
Comprehensive assessment of soil health indicator function/health ratings across all sites sampled.

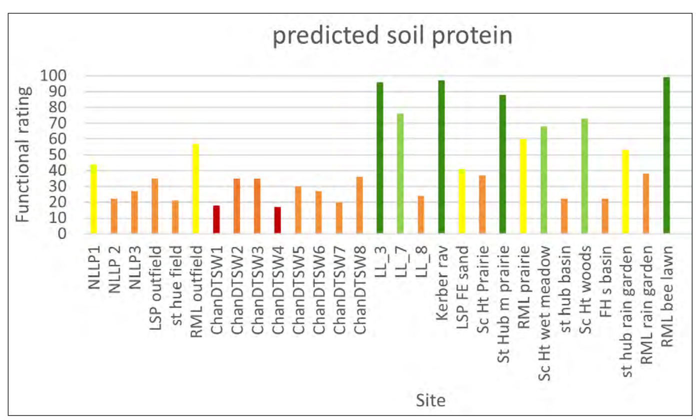


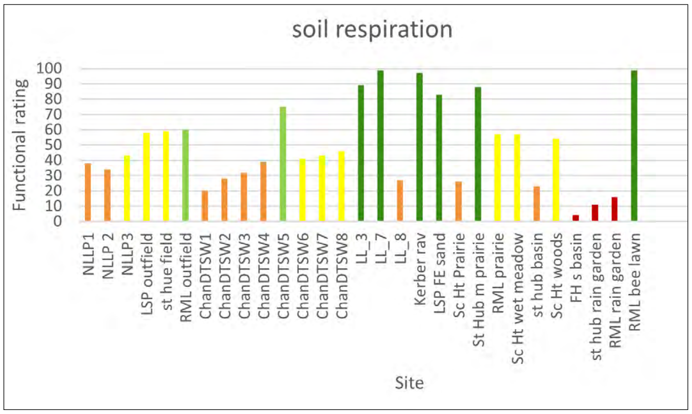











soil respiration
Functional rating
Site
NLLP1
NLLP 2
NLLP3
LSP outfield
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RML outfield
ChanDTSW1
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ChanDTSW3
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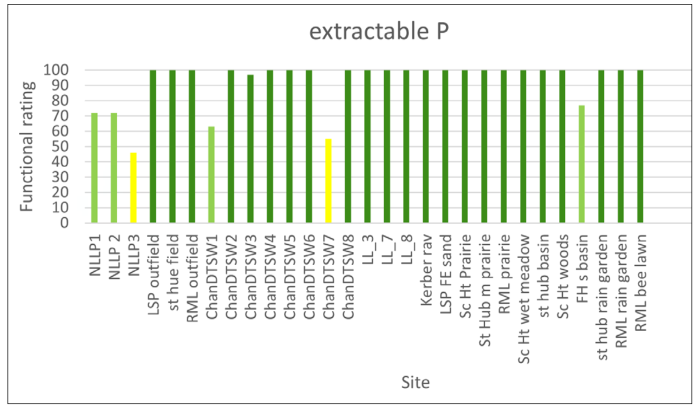
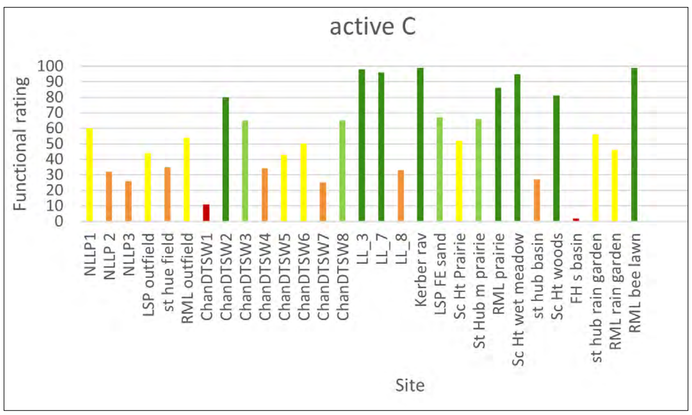
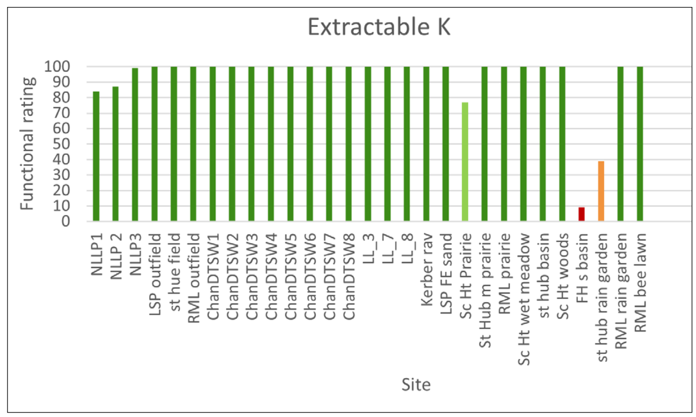
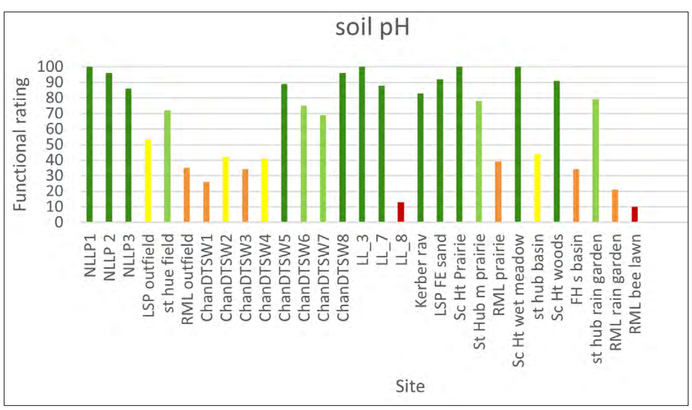
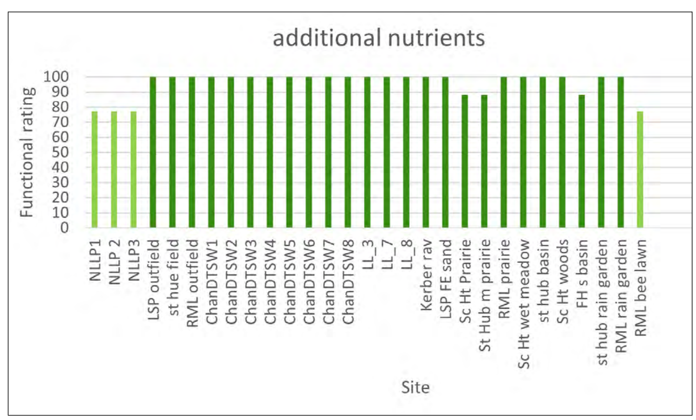
FH s basin
st hub rain garden
RML rain garden
RML bee lawn


extractable P
Functional rating
Site


active C
Functional rating
Site

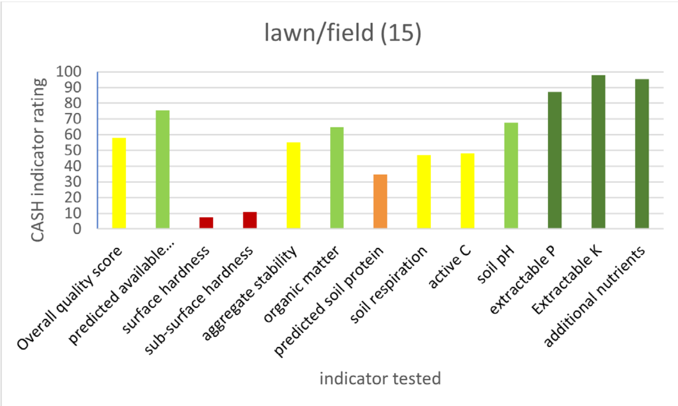

Extractable K
Functional rating
Site

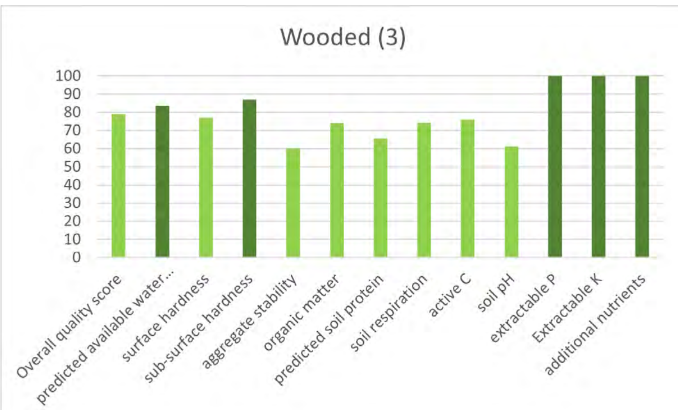

soil pH
Functional rating
Site

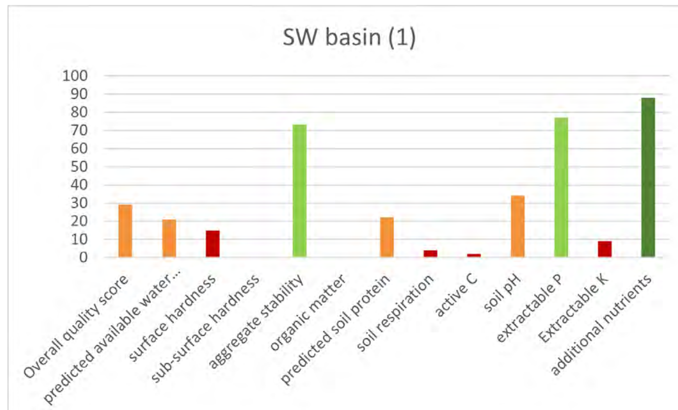

additional nutrients
Functional rating
Site

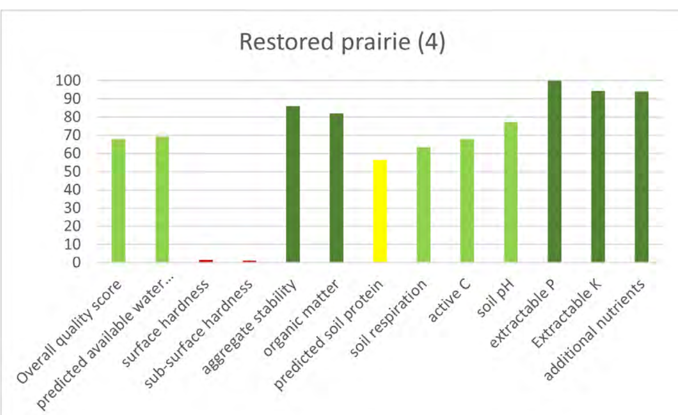
APPENDIX B

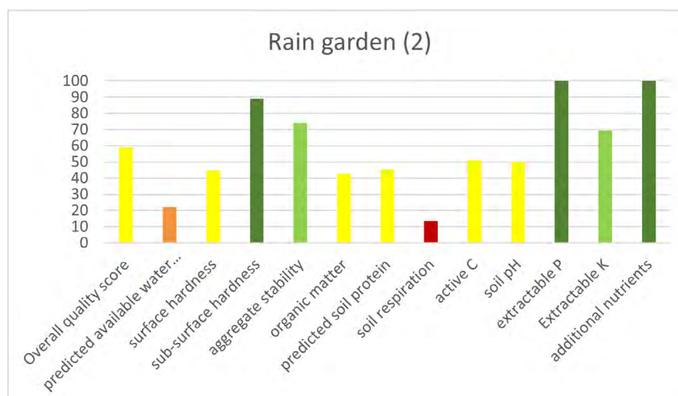
Comprehensive assessment of soil health indicator function/health: average ratings across landscape types. Number of total sites sampled per landscape type denoted in parentheses.

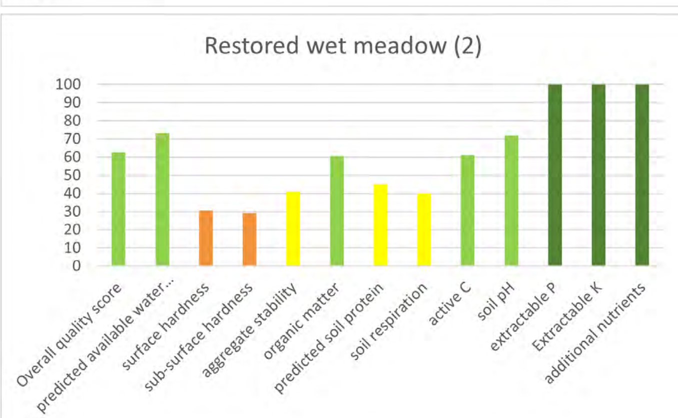


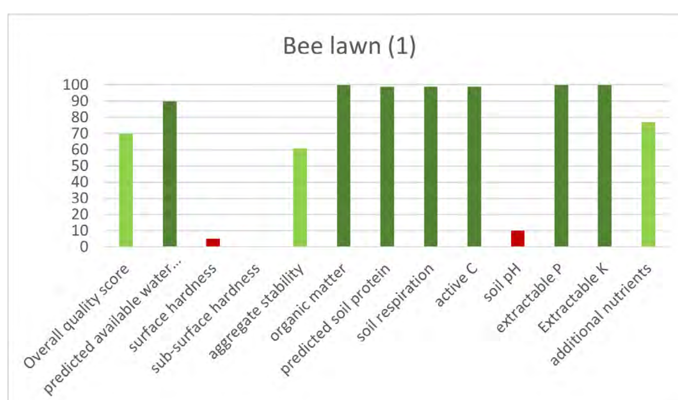












APPENDIX C

Sample Cornell University Comprehensive Assessment of Soil Health Report: one of three samples taken from North Lotus Lake Park (NLLP2)

Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences
School of Integrative Plant Science, Cornell University, Ithaca, NY 14853
https://soilhealthlab.cals.cornell.edu

Grower:
Zach Dickhausen
18681 Lake Drive East
Chanhussen, MN 55317
zdickhausen@rpbcwd.org

Sample ID:	WW2424
Field ID:	N. Lotus Lake Park 2
Date Sampled:	05/09/2023
Given Soil Type:	Lester-Kilkenny
Crops Grown:	PRK/PRK/PRK
Tillage:	no till
Coordinates:	Latitude: 44.884027000000 Longitude: -93.526559000000

Measured Soil Textural Class: **sandy loam**

Sand: **59%** - Silt: **23%** - Clay: **16%**

Group	Indicator	Value	Rating	Constraints
physical	Predicted Available Water Capacity	**0.18**	**76**	
physical	Surface Hardness	**325**	**2**	Rooting, Water Transmission
physical	Subsurface Hardness	**600**	**0**	Subsurface Pan/Deep Compaction, Deep Rooting, Water and Nutrient Access
physical	Aggregate Stability	**39.0**	**48**	
biological	Organic Matter Soil Organic Carbon: 1.73 / Total Carbon: 1.80 / Total Nitrogen: 0.16	**2.8**	**82**	
biological	Predicted Soil Protein	**4.70**	**22**	
biological	Soil Respiration	**0.5**	**34**	
biological	Active Carbon	**359**	**32**	
chemical	Soil pH	**7.4**	**96**	
chemical	Extractable Phosphorus	**2.5**	**72**	
chemical	Extractable Potassium	**62.5**	**87**	
chemical	Additional Nutrients Ca: 2770.2 / Mg: 398.8 / **S: 2.0** Al: 3.2 / B: 0.26 / Cu: 0.03 Fe: 0.6 / Mn: 2.3 / **Zn: 0.1**		**77**	

Overall Quality Score: **52** / Medium

Measured Soil Health Indicators

The Cornell Soil Health Test measures several indicators of soil physical, biological and chemical health. These are listed on the left side of the report summary, on the first page. The "value" column shows each result as a value, measured in the laboratory or in the field, in units of measure as described in the indicator summaries below. The "rating" column interprets that measured value on a scale of 0 to 100, where higher scores are better. Ratings in red are particularly important to take note of, but any in yellow, particularly those that are close to a rating of 30 are also important in addressing soil health problems.

- **A rating below 20 indicates *Very Low (constraining)* functioning and is color-coded red.** This indicates a problem that is likely limiting yields, crop quality, and long-term sustainability of the agroecosystem. In several cases this indicates risks of environmental loss as well. The "constraint" column provides a short list of soil processes that are not functioning optimally when an indicator rating is red. It is particularly important to take advantage of any opportunities to improve management that will address these constraints.
- **A rating between 20 and 40 indicates *Low* functioning and is color-coded orange.** This indicates that a soil process is functioning somewhat poorly and addressing this should be considered in the field management plan. The Management Suggestions Table at the end of the Soil Health Assessment Report provides linkages to field management practices that are useful in addressing each soil indicator process.
- **A rating between 40 and 60 indicates *Medium* functioning and is color-coded yellow.** This indicates that soil health could be better, and yield and sustainability could decrease over time if this is not addressed. This is especially so if the condition is being caused, or not being alleviated, by current management. Pay attention particularly to those indicators rated in yellow and close to 40.
- **A rating between 60 and 80 indicates *High* functioning and is color-coded light green.** This indicates that this soil process is functioning at a non-limiting level. Field soil management approaches should be maintained at the current intensity or improved.
- **A rating of 80 or greater indicates *Very High* functioning and is color-coded dark green.** Past management has been effective at maintaining soil health. It can be useful to note which particular aspects of management have likely maintained soil health, so that such management can be continued. Note that soil health is often high, when first converting from a permanent sod or forest. In these situations, intensive management quickly damages soil health when it includes intensive tillage, low organic matter inputs, bare soils for significant parts of the year, or excessive traffic, especially during wet times.
- **The Overall Quality Score** at the bottom of the report is an average of all ratings, and provides an indication of the soil's overall health status. However, the important part is to know which particular soil processes are constrained or suboptimal so that these issues can be addressed through appropriate management. Therefore the ratings for each indicator are more important information.

The Indicators measured in the Cornell Soil Health Assessment are important soil properties and characteristics in themselves, but also are representative of key soil processes, necessary for the proper functioning of the soil. The following is a summary of the indicators measured, what each of these indicates about your soil's health status, and what may influence the relevant properties and processes described.

A Management Suggestions Table follows, at the end of the report, with short and long term suggestions for addressing constraints or maintaining a well-functioning system. This table will indicate constraints identified in this assessment for your soil sample by the same yellow and red color coding described above. Please also find further useful information by following the links to relevant publications and web resources that follow this section.

Texture is an inherent property of soil, meaning that it is rarely changed by management. It is thus not a soil health indicator per se, but is helpful both in interpreting the measured values of indicators (see the Cornell Soil Health Assessment Training Manual), and for deciding on appropriate management strategies that will work for that soil.

Your soil's measured textural class and composition: sandy loam

Sand: 59% Silt: 23% Clay: 16%

Predicted Available Water Capacity (AWC) is not a directly measured soil property but is modeled from a suite of measured soil health indicators including the percent sand, silt, clay and organic matter. By using a decision tree approach, the developed Random Forest model can predict the laboratory measured AWC value with no more error than that encountered in the raw laboratory analysis. Details of this modeling effort can be found in our Soil Health Management Series Fact Sheet Number 19-05b.

https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/f/5772/files/2016/12/05b_Soil_Health_Fact_Sheet_Available_Water_Capacity-Predicted-2019-002-132f3th.pdf

The Soil Health Lab continues to offer the laboratory measured AWC test as an add-on to the soil health package analyses.

The Predicted AWC value is presented as grams of water per gram of soil. This value is scored against an observed distribution in regional soils with similar texture. A physical soil characteristic, AWC is an indicator of the amount of plant-available water the soil can store, and therefore how crops will fare in droughty conditions. Soils with lower storage capacity will cause greater risk of drought stress. AWC is generally lower when total organic matter and/or aggregation is low. It can be improved by reducing tillage, long-term cover cropping, and adding large amounts of well-decomposed organic matter such as compost. Coarse textured (sandy) soils inherently store less water than finer textured soils, so that managing for relatively high water storage capacity is particularly important in coarse textured soils. While the textural effect cannot be influenced by management, management decisions can be in part based on an understanding of inherent soil characteristics.

Your Predicted Available Water Capacity value is **0.18 g/g**, corresponding with a score of **76**. This score is in the **High** range, relative to soils with similar texture. **This suggests that this soil process is enhancing overall soil resilience. Soil management should aim at maintaining this functionality while addressing any other measured soil constraints as identified in the Soil Health Assessment Report.** Please refer to the management suggestions table at the end of this document.

Surface Hardness is a measure of compaction that develops when large pores are lost in the surface soil (0-6 inches). Compaction is measured in the field using a penetrometer, and the resultant value is expressed in pounds per square inch (p.s.i.), representing the localized pressure necessary to break forward through soil. It is scored by comparison with a distribution observed in regional soils, with lower hardness values rating higher scores. A strongly physical characteristic of soils, surface hardness is an indicator of both physical and biological health of the soil, as growing roots and fungal hyphae must be able to grow through soil, and may be severely restricted by excessively hard soil. Compaction also influences water movement through soil. When surface soils are compacted, runoff, erosion, and slow infiltration can result. Soil compaction is influenced by management, particularly in timing and degree of traffic and plowing disturbance, being worst when the soil is worked wet.

> **Your measured Surface Hardness value** is **325 p.s.i.**, corresponding with a score of **2**. This score is in the **Very Low (constraining)** range, relative to soils with similar texture. **Surface Hardness level should be given a high priority in management decisions based on this assessment, as it is likely to be an important constraint to proper soil functioning and sustainability of management at this time.** Please refer to the management suggestions table at the end of this document.

Subsurface Hardness is a measure of compaction that develops when large pores are lost in the subsurface soil (6-18 inches). Subsurface hardness is measured and scored similarly to surface hardness, but deeper in the profile, and scored against an observed distribution in regional soils with similar texture. Large pores are necessary for water and air movement and to allow roots to explorethe soil. Subsurface hardness prevents deep rooting and thus deep water and nutrient uptake by plants, and can increase disease pressure by stressing plants. It also causes poor drainage and poor deep water storage. After heavy rain events, water can build up over a hard pan causing poor aeration both at depth and at the surface, as well as ponding, poor infiltration, runoff and erosion. Impaired water movement and storage create greater risk during heavy rainfall events, as well as greater risk of drought stress. Compaction occurs very rapidly when the soil is worked or trafficked while it is too wet, and compaction can be transferred deep into the soil even from surface pressure. Subsoil compaction in the form of a plow pan is usually found beneath the plow layer, and is caused by smearing and pressure exerted on the undisturbed soil just beneath the deepest tillage operation, especially when wet.

> **Your measured Subsurface Hardness value** is **600 p.s.i.**, corresponding with a score of . This score is in the **Very Low (constraining)** range, relative to soils with similar texture. **Subsurface Hardness level should be given a high priority in management decisions based on this assessment, as it is likely to be an important constraint to proper soil functioning and sustainability of management at this time.** Please refer to the management suggestions table at the end of this document.

Aggregate Stability is a measure of how well soil aggregates or crumbs hold together under rainfall or other rapid wetting stresses. Measured by the fraction of dried aggregates that disintegrate under a controlled, simulated rainfall event similar in energy delivery to a hard spring rain, the value is presented as a percent, and scored against a distribution observed in regional soils with similar textural characteristics. A physical characteristic of soil, Aggregate Stability is a good indicator of soil biological and physical health. Good aggregate stability helps prevent crusting, runoff, and erosion, and facilitates aeration, infiltration, and water storage, along with improving seed germination and root and microbial health. Aggregate stability is influenced by microbial activity, as aggregates are largely held together by microbial colonies and exudates, and is impacted by management practices, particularly tillage, cover cropping, and fresh organic matter additions.

Your measured Aggregate Stability value is **39.0 %**, corresponding with a score of **48**. This score is in the **Medium** range, relative to soils with similar texture. **This suggests that, while Aggregate Stability is functioning at an average level, management practices should be geared toward improving this condition, as it currently indicates suboptimal functioning. Soil management should aim at improving this functionality while addressing any other measured soil constraints as identified in the Soil Health Assessment Report.** Please refer to the management suggestions table at the end of this document.

Organic Matter (OM) is a measure of the carbonaceous material in the soil that is biomass or biomass-derived. Measured by the mass lost on combustion of oven-dried soil, the value is presented as a percent of the total soil mass. This is scored against an observed distribution of OM in regional soils with similar texture. A soil characteristic that measures a physical substance of biological origin, OM is a key or central indicator of the physical, biological, and chemical health of the soil. OM content is an important influence on soil aggregate stabilization, water retention, nutrient cycling, and ion exchange capacity. Soils with low organic matter tend to require higher inputs, and be less resilient to drought and extreme rainfall. The retention and accumulation of OM is influenced by management practices such as tillage and cover cropping, as well as by microbial community growth. Intensive tillage and lack of organic matter biomass additions from various sources (amendments, residues, active crop or cover crop growth) will decrease organic matter content and overall soil health with time.

Total Carbon (Tot C) is an indicator for the OM in soil, with carbon comprising 48-58% of the total weight of OM. The Tot C analysis measures all of the carbon in a sample using complete oxidation of carbon to CO2 using high temperature combustion (1100C). The measured Tot C includes ***organic*** forms of carbon (Soil Organic Carbon SOC), comprised of available carbon as well as relatively inert carbon in stable organic materials. Carbon can also be found in ***inorganic*** form (Soil Inorganic Carbon SIC) as carbonate minerals such as calcium carbonate (lime).

Soil Organic Carbon (SOC) is equivalent to Tot C when there are no carbonate minerals. However, soils above pH 6.5 may contain high levels of carbonates. These carbonates are measured as SIC and subtracted from the Tot C: **SOC = Tot C - SIC**.

Total Nitrogen (Tot N) includes the organic (living and non-living) and inorganic (or mineral) forms of nitrogen. About half of the Tot N found in soil is in relatively stable organic compounds. Inorganic nitrogen is liberated from organic nitrogen sources in the soil, particularly proteins and amino acids through the action of soil microorganisms. Ammonium (NH4+) and nitrate (NO3-) are the inorganic forms of nitrogen found in soil that are plant available. The Tot N is determined following the combustion methodology known as DUMAS.

Your measured Organic Matter value is **2.8 %**, corresponding with a score of **82**. This score is in the **Very High** range, relative to soils with similar texture. **This suggests that management practices should be geared toward maintaining this condition, as it currently indicates ideal soil functioning.** Please refer to the management suggestions table at the end of this document. The **SOC** level is **1.73%**, the **Tot C** level is **1.80%**, the **Tot N** level is **0.16%**.

Predicted Soil Protein is not a directly measured soil property but is modeled from a suite of measured soil health indicators including the percent sand, silt, clay and organic matter. By using a decision tree approach, the developed Random Forest model can predict the laboratory measured soil protein value with a tolerable small error. Details of this modeling effort can be found in our Soil Health Management Series Fact Sheet 20-09b.

https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/f/5772/files/2020/05/09b-Predicted-Protein.pdf

The Soil Health Lab continues to offer the laboratory measured Soil Protein test as an add-on to the Standard soil health package analyses.

The Predicted Soil Protein is presented as mg per gram of soil. This indicator represents the fraction of the soil organic matter that is present as protein or protein-like substances. Protein content, as organically bound N, influences the ability of the soil to make N available by mineralization, and has been associated with soil aggregation and water movement. Protein content can be influenced by biomass additions, the presence of roots and soil microbes, and tends to decrease with increasing soil disturbance such as tillage.

> **Your measured Predicted Soil Protein value** is **4.70** , corresponding with a score of **22**. This score is in the **Low** range, relative to soils with similar texture. **This suggests that, while Predicted Soil Protein does not currently register as a strong constraint, management practices should be geared toward improving this condition, as it currently indicates suboptimal functioning.** Please refer to the management suggestions table at the end of this document.

Soil Respiration is a measure of the metabolic activity of the soil microbial community. Measured by capturing and quantifying carbon dioxide (CO_2) produced by this activity, the value is expressed as total CO_2 released (in mg) per gram of soil over a 4 day incubation period. Respiration is scored against an observed distribution in regional soils, taking texture into account. A direct biological activity measurement, respiration is an indicator of the biological status of the soil community, integrating abundance and activity of microbial life. Soil biological activity accomplishes numerous important functions, such as cycling of nutrients into and out of soil OM pools, transformations of N between its several forms, and decomposition of incorporated residues. Soil biological activity influences key physical characteristics like OM accumulation, and aggregate formation and stabilization. Microbial activity is influenced by management practices such as tillage, cover cropping, manure or green manure incorporation, and biocide (pesticide, fungicide, herbicide) use.

> **Your measured Soil Respiration value** is **0.5 mg**, corresponding with a score of **34**. This score is in the **Low** range, relative to soils with similar texture. **This suggests that, while Soil Respiration does not currently register as a strong constraint, management practices should be geared toward improving this condition, as it currently indicates suboptimal functioning.** Please refer to the management suggestions table at the end of this document.

Active Carbon is a measure of the small portion of the organic matter that can serve as an easily available food source for soil microbes, thus helping maintain a healthy soil food web. Measured by potassium permanganate oxidation, the value is presented in parts per million (ppm), and scored against an observed distribution in regional soils with similar texture. While a measure of a class of physical substances, active carbon is a good leading indicator of biological soil health and tends to respond to changes in management earlier than total organic matter content, because when a large population of soil microbes is fed plentifully with enough organic matter over an extended period of time, well-decomposed organic matter builds up. A healthy and diverse microbial community is essential to maintain disease resistance, nutrient cycling, aggregation, and many other important functions. Intensive tillage and lack of organic matter additions from various sources (amendments, residues, active crop or cover crop growth) will decrease active carbon, and thus will over the longer term decrease total organic matter.

> **Your measured Active Carbon value** is **359 ppm**, corresponding with a score of **32**. This score is in the **Low** range, relative to soils with similar texture. **This suggests that, while Active Carbon does not currently register as a strong constraint, management practices should be geared toward improving this condition, as it currently indicates suboptimal functioning.** Please refer to the management suggestions table at the end of this document.

Soil pH is a measure of how acidic the soil is, which controls how available nutrients are to crops. A physico-chemical characteristic of soils, pH is an indicator of the chemical or nutrient status of the soil. Measured with an electrode in a 1:1 soil:water suspension, the value is presented in standard pH units, and scored using an optimality curve. Optimum pH is around 6.2-6.8 for most crops (exceptions include potatoes and blueberries, which grow best in more acidic soil – this is not accounted for in the report interpretation). If pH is too high, nutrients such as phosphorus, iron, manganese, copper and boron become unavailable to the crop. If pH is too low, calcium, magnesium, phosphorus, potassium and molybdenum become unavailable. Lack of nutrient availability will limit crop yields and quality. Aluminum toxicity can also be a concern in low pH soils, which can severely decrease root growth and yield, and in some cases lead to accumulation of aluminum and other metals in crop tissue. In general, as soil OM increases, crops can tolerate lower soil pH. Soil pH also influences the ability of certain pathogens to thrive, and of beneficial organisms to effectively colonize roots. Raising the pH through lime or wood ash applications, and organic matter additions, will help immobilize aluminum andheavy metals, and maintain proper nutrient availability.

> **Your measured Soil pH value** is **7.4** , corresponding with a score of **96**. This score is in the **Very High** range, relative to soils with similar texture. **This suggests that management practices should be geared toward maintaining this condition, as it currently indicates ideal soil functioning.** Please refer to the management suggestions table at the end of this document.

Extractable Phosphorus is a measure of phosphorus (P) availability to a crop. Measured on a modified Morgan's extract using an ICP Spectrometer, the value is presented in parts per million (ppm), and scored against an optimality curve for sufficiency or excess. P is an essential plant macronutrient, and its availability varies with soil pH and mineral composition. Low P values indicate poor P availability to plants, and excessively high P values indicates a risk of adverse environmental impact through runoff and contamination of surface waters. Most soils in the Northeast store unavailable P from the soil’s mineral make up or from previously applied fertilizer or manure. This becomes more available to plants as soils warm up. Therefore, incorporating or banding 10-25 lbs/acre of soluble ‘starter’ P fertilizer at planting can be useful even when soil levels are optimum. Some cover crops, such as buckwheat, are good at mining otherwise unavailable P so that it becomes more available to the following crop. When plants associate with mycorrhizal fungi, these can also help make P (and other nutrients and water) more available to the crop. P is an environmental contaminant and runoff of P into fresh surface water will cause damage through eutrophication, so over-application is strongly discouraged, especially close to surface water, on slopes, and on large scales.

> **Your measured Extractable Phosphorus value** is **2.5 ppm**, corresponding with a

score of **72**. This score is in the **High** range, relative to soils with similar texture. **This suggests that this soil process is enhancing overall soil resilience. Soil management should aim at maintaining this functionality while addressing any other measured soil constraints as identified in the Soil Health Assessment Report.** Please refer to the management suggestions table at the end of this document.

Extractable Potassium is a measure of potassium (K) availability to the crop. Measured on a modified Morgan's extract using an ICP Spectrometer, the value is presented in parts per million (ppm), and scored against an optimality curve for sufficiency. K is an indicator of soil nutrient status, as it is an essential plant macronutrient. Plants with higher potassium tend to be more tolerant of frost and cold. Thus good potassium levels may help with season extension. While soil pH only marginally affects K availability, K is easily leached from sandy soils and is only weakly held by increased organic matter, so that applications of the amount removed by the specific crop being grown are generally necessary in such soils.

Your measured Extractable Potassium value is **62.5 ppm**, corresponding with a score of **87**. This score is in the **Very High** range, relative to soils with similar texture. **This suggests that management practices should be geared toward maintaining this condition, as it currently indicates ideal soil functioning.** Please refer to the management suggestions table at the end of this document.

Additional Nutrients including (calcium (Ca), magnesium (Mg) and sulfur (S)) with micronutrients (aluminum (Al), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn), etc.) are essential plant nutrients taken up by plants in smaller quantities than the macronutrients N, P and K. Note that some leafy vegetables can require significant amounts of these nutrients. If any of these nutrients are deficient, this will decrease yield and crop quality, but toxicities can also occur when concentrations are too high. While Al is not technically a plant nutrient, it can become toxic to crop plants at pH below 5.5. The solubility and availability of all of the elements are strongly influenced by pH and organic matter. High pH favors the availability of magnesium and calcium whereas low pH increases the availability of most micronutrients. High OM and microbial activity tend to increase micronutrient availability. The ratings indicate whether these measured nutrients are deficient or excessive.

Your measured Additional Nutrients Rating is **77**. This score is in the **High** range. Magnesium (398.8 ppm) is sufficient, Iron (0.6 ppm) is sufficient, Manganese (2.3 ppm) is sufficient, Zinc (0.1 ppm) is deficient, Aluminum (3.2 ppm) is sufficient, Calcium (2770.2 ppm) is sufficient, Copper (0.03 ppm) is sufficient, Sulfur (2.0 ppm) is deficient, Boron (0.26 ppm) is sufficient. **This suggests that this soil process is enhancing overall soil resilience. Soil management should aim at maintaining this functionality while addressing any other measured soil constraints as identified in the Soil Health Assessment Report.** Please refer to the management suggestions table at the end of this document.

Overall Quality Score: an overall quality score is computed from the individual indicator scores. This score is further rated as follows: less than 20% is regarded as very low, 20-40% is low, 40-60% is medium, 60-80% is high, and greater than 80% is very high. The highest possible quality score is 100 and the least score is 0, thus it is a relative overall soil health status indicator. However, of greater importance than a single overall metric is identification of constrained or suboptimally functioning soil processes, so that these issues can be addressed through appropriate management. The overall soil quality score should be taken as a general summary rather than the main focus.

Your Overall Quality Score is **52**, which is in the **Medium** range.

Management Suggestions for Physical and Biological Constraints

Constraint	Short Term Management Suggestions	Long Term Management Suggestions
Predicted Available Water Capacity Low	• Add stable organic materials, mulch • Add compost or biochar • Incorporate high biomass cover crop	• Reduce tillage • Rotate with sod crops • Incorporate high biomass cover crop
Surface Hardness High	• Perform some mechanical soil loosening (strip till, aerators, broadfork, spader) • Use shallow-rooted cover crops • Use a living mulch or interseed cover crop	• Shallow-rooted cover/rotation crops • Avoid traffic on wet soils, monitor • Avoid excessive traffic/tillage/loads • Use controlled traffic patterns/lanes
Subsurface Hardness High	• Use targeted deep tillage (subsoiler, yeomans plow, chisel plow, spader.) • Plant deep rooted cover crops/radish	• Avoid plows/disks that create pans • Avoid heavy loads • Reduce traffic when subsoil is wet
Aggregate Stability Low	• Incorporate fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch	• Reduce tillage • Use a surface mulch • Rotate with sod crops and mycorrhizal hosts
Organic Matter Low	• Add stable organic materials, mulch • Add compost and biochar • Incorporate high biomass cover crop	• Reduce tillage/mechanical cultivation • Rotate with sod crop • Incorporate high biomass cover crop
Predicted Soil Protein Low	• Add N-rich organic matter (low C:N source like manure, high N well-finished compost) • Incorporate young, green, cover crop biomass • Plant legumes and grass-legume mixtures • Inoculate legume seed with Rhizobia & check for nodulation	• Reduce tillage • Rotate with forage legume sod crop • Cover crop and add fresh manure • Keep pH at 6.2-6.5 (helps N fixation) • Monitor C:N ratio of inputs
Soil Respiration Low	• Maintain plant cover throughout season • Add fresh organic materials • Add manure, green manure • Consider reducing biocide usage	• Reduce tillage/mechanical cultivation • Increase rotational diversity • Maintain plant cover throughout season • Cover crop with symbiotic host plants
Active Carbon Low	• Add fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch	• Reduce tillage/mechanical cultivation • Rotate with sod crop • Cover crop whenever possible

Management Suggestions for Chemical Constraints

Constraint	Short Term Management Suggestions	Long Term Management Suggestions
Soil pH Low	• Add lime or wood ash per soil test recommendations • Add calcium sulfate (gypsum) in addition to lime if aluminum is high • Use less ammonium or urea	• Test soil annually & add "maintenance" lime per soil test recommendations to keep pH in range • Raise organic matter to improve buffering capacity
Soil pH High	• Stop adding lime or wood ash • Add elemental sulfur per soil test recommendations	• Test soil annually • Use higher % ammonium or urea
Extractable Phosphorus Low	• Add P amendments per soil test recommendations • Use cover crops to recycle fixed P • Adjust pH to 6.2-6.5 to free up fixed P	• Promote mycorrhizal populations • Maintain a pH of 6.2-6.5 • Use cover crops to recycle fixed P
Extractable Phosphorus High	• Stop adding manure and compost • Choose low or no-P fertilizer blend • Apply only 20 lbs/ac starter P if needed • Apply P at or below crop removal rates	• Use cover crops that accumulate P and export to low P fields or offsite • Consider low P rations for livestock • Consider phytase for non-ruminants
Extractable Potassium Low	• Add wood ash, fertilizer, manure, or compost per soil test recommendations • Use cover crops to recycle K • Choose a high K fertilizer blend	• Use cover crops to recycle K • Add "maintenance" K per soil recommendations each year to keep K consistently available
Additional Nutrients Low	• Add chelated micronutrients per soil test recommendations • Use cover crops to recycle micronutrients • Do not exceed pH 6.5 for most crops	• Promote mycorrhizal populations • Improve organic matter • Decrease soil P (binds micronutrients) • Add lime (Ca and Mg), gypsum (S), rock powder
Additional Nutrients High	• Raise pH to 6.2-6.5 (for all high micro-nutrients and Aluminum) • Do not use fertilizers with micronutrients	• Maintain a pH of 6.2-6.5 • Monitor irrigation/improve drainage • Avoid compost additions with high micronutrient levels

School of Integrative Plant Science, Soil and Crop Sciences Section, 804 Bradfield Hall, 306 Tower Road, Cornell University, Ithaca, NY 14853, email: soilhealth@cornell.edu

College of Agriculture and Life Sciences, Cornell University

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