



The Use of Biochar in Agroforestry to Promote Soil Microbial Health, Tree Productivity, and Carbon Sequestration

INTERIM SARE REPORT

Dec 2024

Arthur's Point Farm, Ghent, New York

Analyses by:



Interpretation by:



Research Trial Location (2020)



Research Trial Location (2024)

Research Trial Rows (2024)

Google Earth



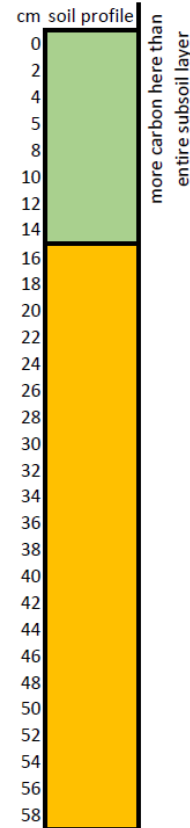
ARTHUR'S POINT FARM

200 ft

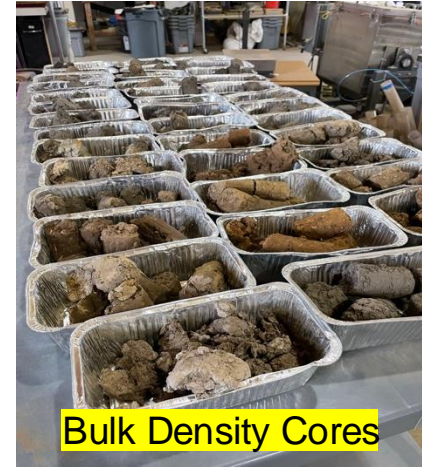
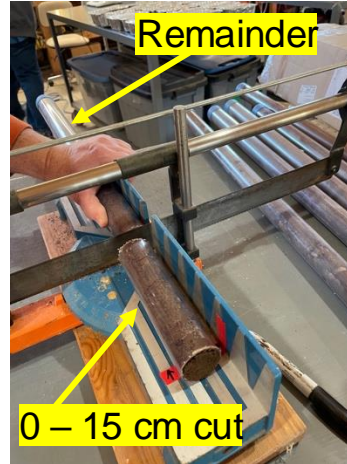
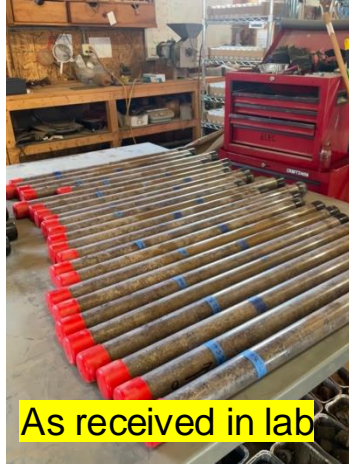


Completed Test Metrics (Soil & Deep Core Samples)

- Samples taken in March 2022 and 2025
- Soil Health, Biochemistry and Nutrients assessed for 60 sample points at 6" depth
- *Deep carbon sampling*, 40 samples
 - A. Topsoil considered as 0 - 15 cm
 - B. Average Max Attained Depth : 58 cm (see inset)
- Carbon and Bulk Density for each (A, B)



Soil Sample Processing



Hydraulic Soil Cores sent to lab and cut at 15 cm and *remainder*

- Air-dry entire core sections for weight capture
- Measured total soil dry weight versus tube volume for Bulk density
- Separated stone fraction from soil
- Calculated particle density of each fraction
- Measured Total-C * on soil fraction less stone fraction
- Calculated carbon stock correcting for soil density

Challenges on the way

soil weight (g)	soil dried weight (g)	Moisture %	BD g/cc	Rocks (g)	% soil	Top Tube Volume	Top Rock Volume	Corrected BD g/cc
359.53	255.37	30.05	1.120	130.16	46.33	216.44	49.12	0.671

- Significant stones in all bulk density samples
- *In some cores, less than 50% is soil*
- Carbon measured only in soil fraction.

Original Sample Stones Portion sieved soil for testing



Baseline (2022) Results

- *Mass per Area by Layer*
 - A. Separate soil from stones (!)
 - B. Correct BD and analyze TOC soil
 - C. Compare topsoil to depth (layer)
 - D. Huge difference in layers
 - E. Compare topsoil by 2 methods

Topsoil 0–15 cm Results:

Avg in Core samples:

1.32 ± 0.34 %TOC

Avg in Fertility samples:

1.26 ± 0.38 %TOC

Remainder (15 ~ 60cm)

Avg. in core samples:

0.19% ± 0.11 %TOC

Close agreement by 2 different
sampling methods (n=40 vs n=60)

Topsoil 0 - 15 cm Samples

Apparent Bulk Density, g/cc

1.443

Corrected Bulk Density after stone removal

1.095

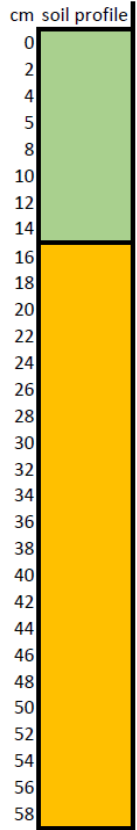
Remainder to Depth Samples

Apparent Bulk Density, g/cc

1.876

Corrected Bulk Density after stone removal

1.121



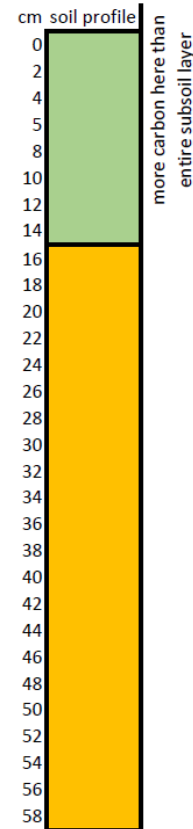
Summary Carbon Stock

- Depth stratification of C is great as is variability between samples
- Of total carbon at depth, 60% is in the top 6" (15 cm) layer
- Suggested: *not necessary to examine carbon below 15 cm since quantities likely to be very low with very high variability*

0 – 15 cm Avg. SOC stock is **17 t/ha**

CARBON STOCK FINDINGS

Remainder Depth SOC is **11 t/ha**



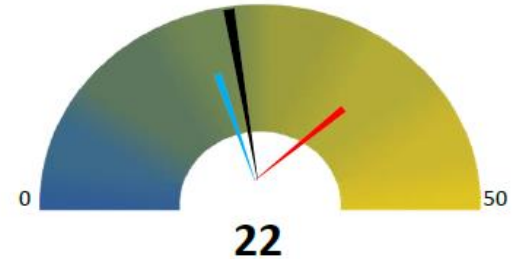
Overview – Field Soil Health and the Bigger Picture - 2022

- Average field fertility is 70% of target (best condition expected for region)
 - pH is optimal; Ca, Mg adequate
 - N-min is moderate and K-potassium the most likely deficient crop nutrient element
- Health Index (7 indicators) is 22 or 60% of target for this region and soil type.
- Ranked less-than-target mostly due to:
 - Lower than normal OM and carbon so improvements can be expected
 - Low soil crumb (aggregate) structure possibly linked to structureless Inceptisol

AVERAGE of 60 samples



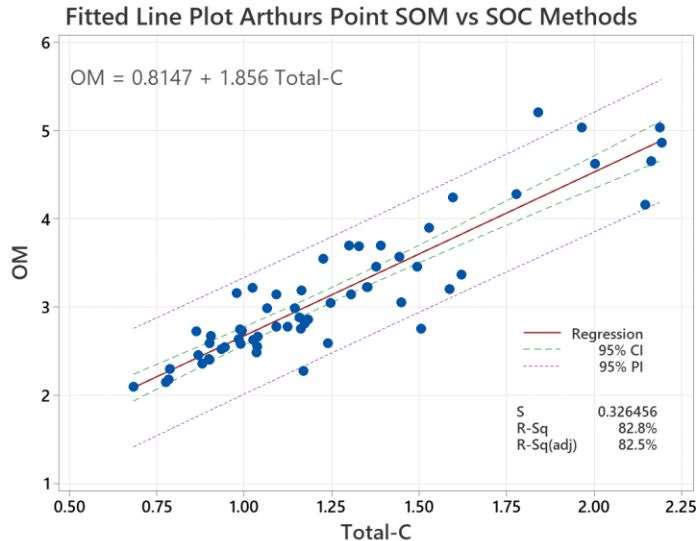
OVERALL FERTILITY SCORE
YOUR VALUE IS BLACK. RED LINE IS REGION-EXPECTED TARGET



SOIL HEALTH SCORE
YOUR VALUE IS BLACK POINTER.
BLUE is Minimum and RED is Optimal Target

Results Details First Sampling Period 2022

Traditional Organic Matter methods closely correlated to modern carbon combustion



Baseline Results: No significant differences in TOC between 5 treatments in layout*

TR ID	N	Mean	Grouping
1. Control	12	1.340	a*
2. +Biochar(BC)	12	1.3113	a
3. +Compost(Com)	12	1.249	a
4. +BC+Com	12	1.248	a
5. +BC+Com+Ad	12	1.1353	a

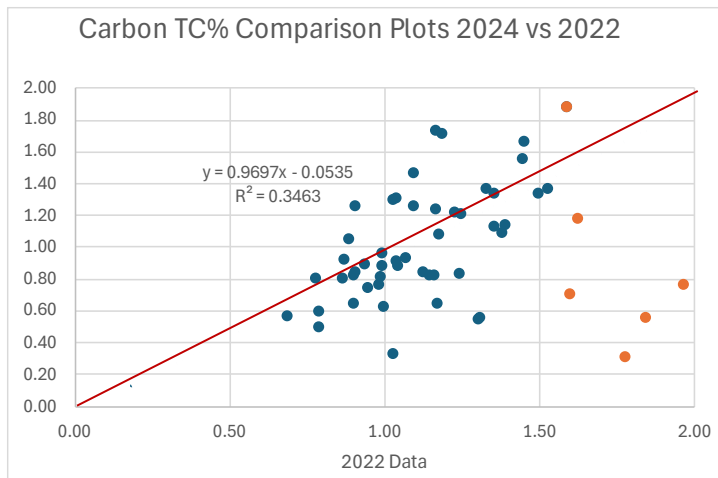
Notes: BC = Biochar 4 cups each; Com = compost 1 gal each

Grouping Information using Fisher mean separation method and 95% Confidence Intervals

*Means that do not share a letter are significantly different.

2024 Year 2 - Sampling Period Results

a) Carbon comparison of 2022 and 2024. Close correlation is good but with several outliers which may be sampling variance.



2nd Yr (2024) Results: 15% apparent decline from 2022 in sampled zones; could also be sampling error. TR 5 has more carbon

TR ID	N	Mean	% TC
1.	Control	12	0.939
2.	+Biochar(BC)	12	0.811 b
3.	+Compost(Com)	12	0.926
4.	+BC+Com	12	1.057
5.	+BC+Com+Ad	12	1.124 a

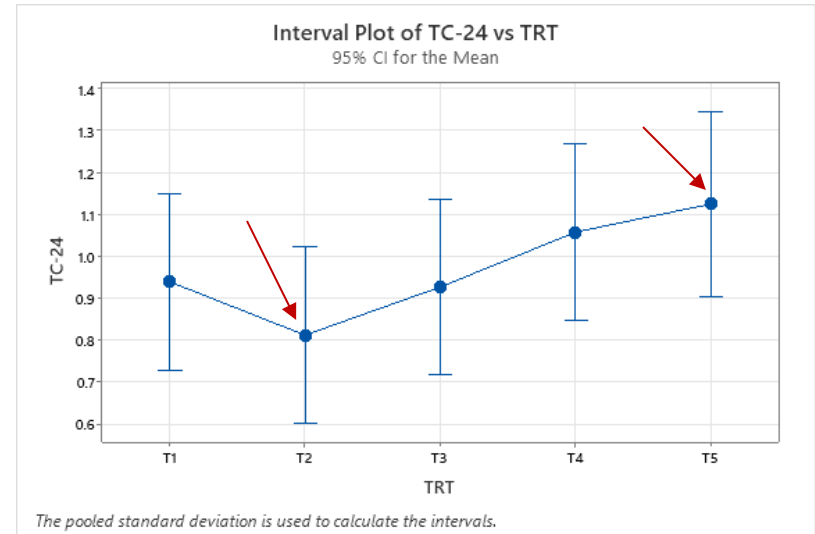
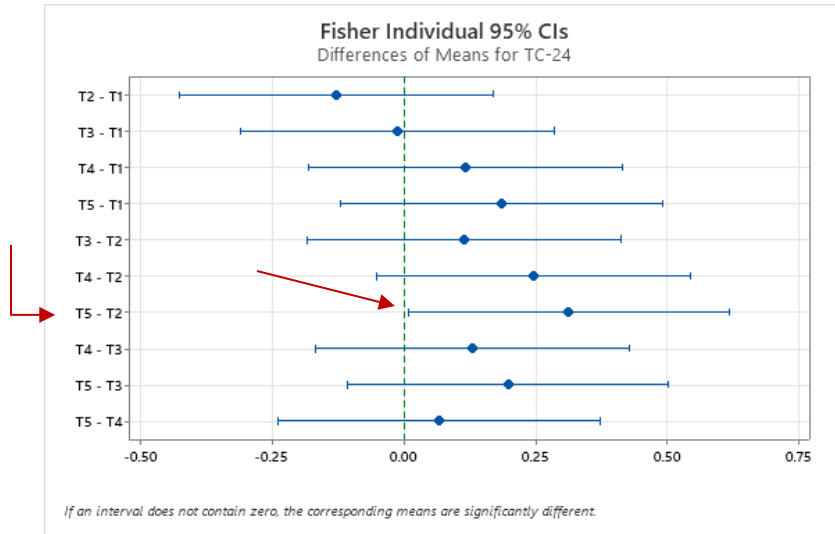
reatment 5 is statistically different than Treatment 2 by Fishers Test.

* All soils self-sampled to 6" deep.

Emergent Results for Year 2 (2024)

Recent tests show a significant result: Treatment-5 (full treatment) is higher in carbon than T2 (biochar alone)

Range of % TC in soil samples versus treatments- only the lowest versus highest are significant

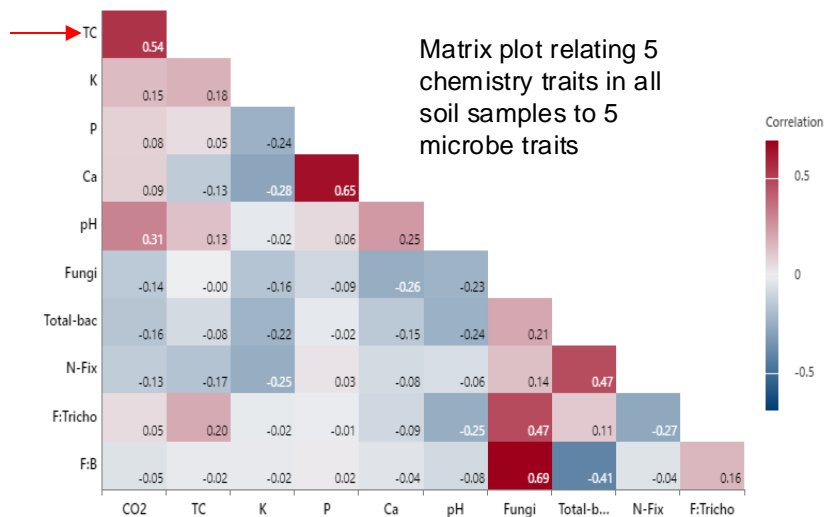


Notes: Data based on Fisher LSD comparison. The Fisher test is less conservative than a Tukey Mean Separation Analysis.

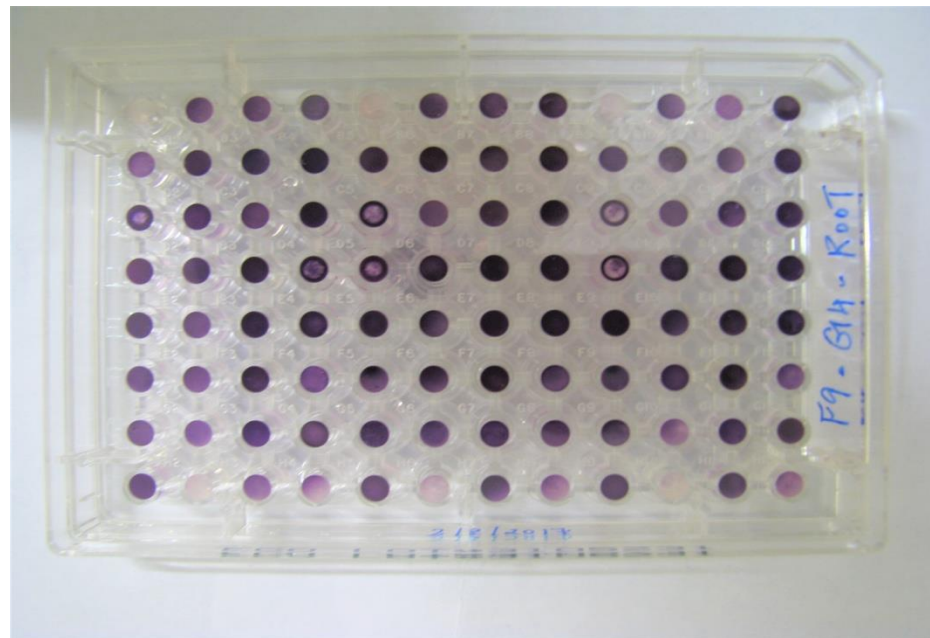
Are there measurable biological effects by 2024?

Microbiology traits by modified *substrate utilization* assay which examines 12 microbial properties

- TC* and CO₂-microbial respiration are well correlated
- No definitive relation of SU[‡] microbiology to other traits



* TC = total carbon, CO₂ is a chemical test for microbial emissions of carbon dioxide



‡ SU - Substrate utilization test, a 12 x 8 array of modified protocol for semi-quantitative estimates of activity based on level of dye staining. A&L Canada

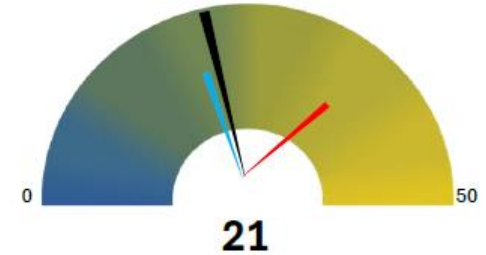
Overview – Field Soil Health - 2024

- Average field fertility essentially no change from 2022
 - K-potassium exhibiting very high levels in certain locations; especially treatment 5 (full suite); this is where fungi are the lowest (both statistically significant)
 - Biochar treatment has least nutrients; most fungi- an indirect effect?

AVERAGE of 59 samples

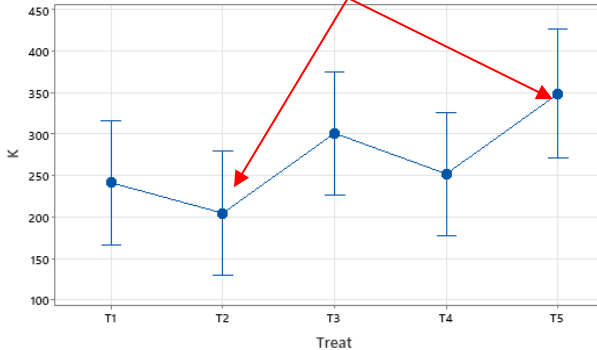


OVERALL FERTILITY SCORE
YOUR VALUE IS BLACK. RED LINE IS REGION-EXPECTED TARGET



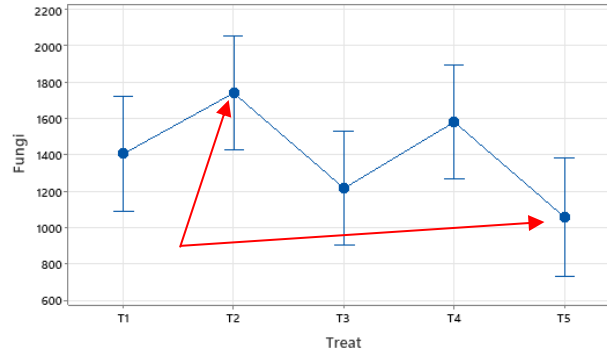
SOIL HEALTH SCORE
YOUR VALUE IS BLACK POINTER.
BLUE is Minimum and RED is Optimal Target
Color range based on Solvita Color Scale

Interval Plot of K vs Treat
95% CI for the Mean



The pooled standard deviation is used to calculate the intervals.

Interval Plot of Fungi vs Treat
95% CI for the Mean



The pooled standard deviation is used to calculate the intervals.

Microbial : Nutrient chemistry relationships – 2024

Microbiology traits by modified *substrate utilization* assay which examines 12 features

- 1,034 unique pairs of test data for 59 soil samples were examined by comparing microbiological with soil health-nutrient variables‡
- 24 pairs showed some level of statistical importance (> 95% certainty or $p < 0.05$)
- 4 pairs indicated positive interactions; 20 matched negative influences.§

Generally, higher levels of pH corresponded to lesser microbiology. Related to this, higher levels of K, Ca, Mg affected microbe utilization negatively. Higher pH and basic elements Ca, K and Mg often result from biochar and compost additions, but compost also provides organic nitrogen,

‡ Pairwise Pearson correlation, 95% confidence intervals;

§ A negative correlation means one variable adversely affected by the other – see table

Microbial Factor	Nutrient Factor Pairs		Correlation	P-Value	
Aer:Anaer	SLAN	59	0.377	0.0030	} Positive - stronger to weaker
G+	TC	59	0.329	0.0110	
Gram Neg	BD	59	0.271	0.0380	
N-Fixers	BD	59	0.266	0.0420	
Pseudomonas	NO3	59	-0.416	0.0010	} Negative - stronger to weaker
Bacteria	K	59	-0.335	0.0090	
Rhizobium	pH	59	-0.322	0.0130	
Rhizobium	Mg	59	-0.313	0.0160	
Total-Microbes	BS %	59	-0.313	0.0160	
Total-bacteria	NO3	59	-0.31	0.0170	
Total-Microbes	NO3	59	-0.308	0.0180	
Fungi	BS %	59	-0.301	0.0210	
Total-Microbes	pH	59	-0.295	0.0230	
Anaerobes	SLAN	59	-0.293	0.0240	
Gran Neg	Mg	59	-0.293	0.0240	
Gran Neg	N-Min	59	-0.278	0.0330	
Rhizobium	BS %	59	-0.278	0.0330	
Total-bacteria	Mg	59	-0.275	0.0350	
N-Fixers	WSA	59	-0.272	0.0370	
Gram Neg	WSA	59	-0.271	0.0380	
Gram Pos	b-pH	59	-0.267	0.0410	
Gr+:Act	CN	59	-0.261	0.0460	
Actinomycetes	Mn	59	-0.26	0.0470	
Total-Microbe	K	59	-0.258	0.0480	
Fungi	Ca	59	-0.258	0.0490	

Microbe factors from Substrate Utilization Array

Nutrient factors from Soil Health Analysis

Note: P-value the smaller the number the more significant. P 0.01 = 99% certainty

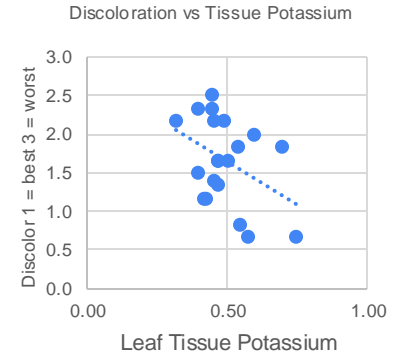
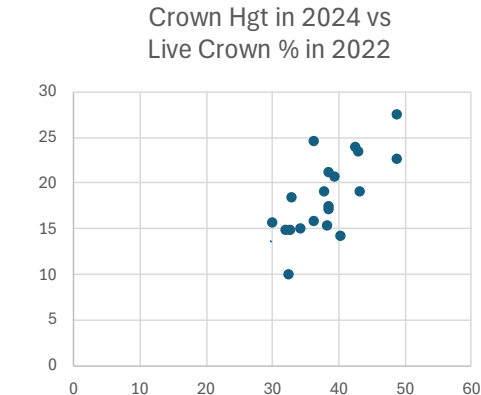
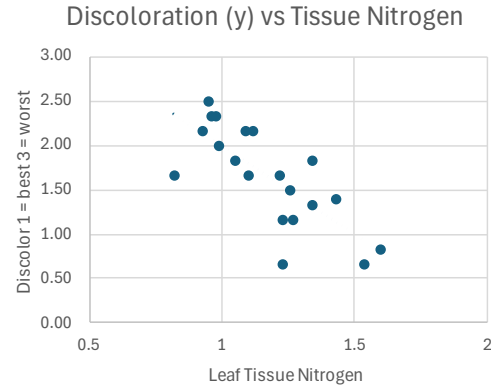
Microbial : Tree Health Metrics 2022-2024

- 6 attributes assessed by farm crew[§]

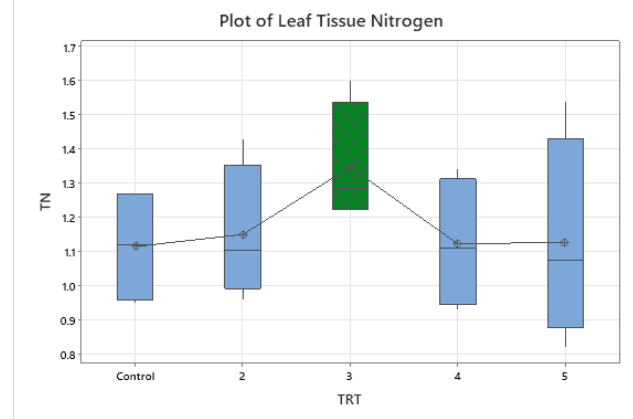
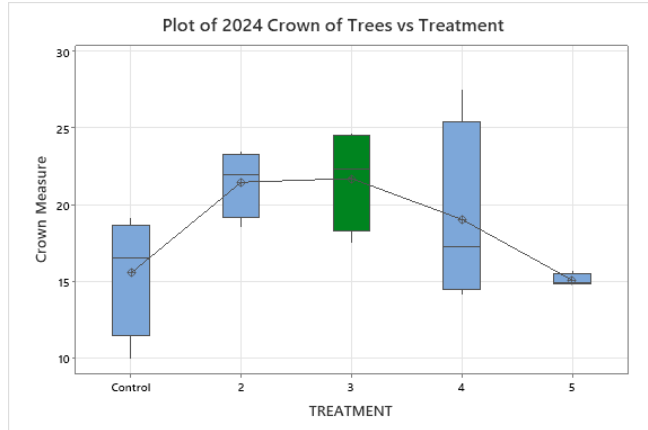
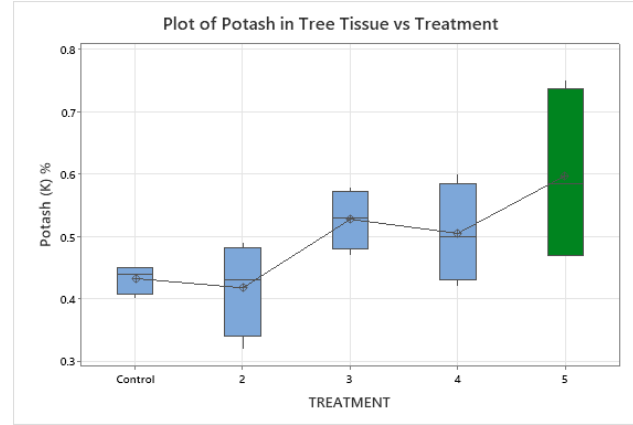
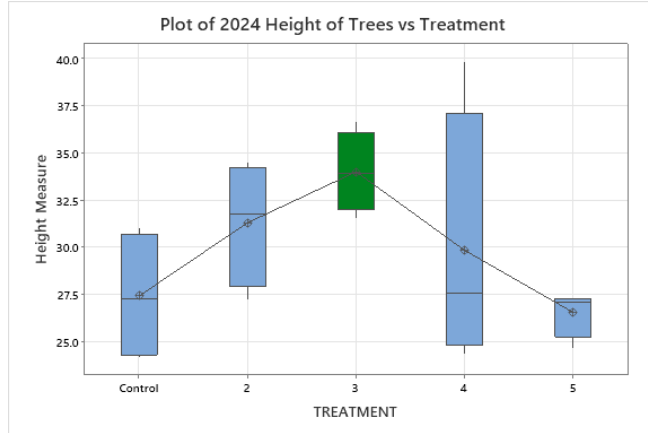
<u>METRIC</u>	<u>SCALE</u>	<u>Best Score</u>
Height	0 - 40	largest
Crown	0 - 30	largest
LiveCrown Ratio	0 - 100%	largest
Vigor	1 - 5	1 or smallest
Dieback	0 - 100%	smallest
Discoloration	0 - 3	0 or smallest

Generally, best performance corresponded to more tissue nitrogen. Least discoloring with more plant nitrogen and potassium. Performance in 2022 correlated with crown height in 2024.

[§] Vermont Forest Health Monitoring Protocol, 2019



Microbial : Tree Health vs Treatments in 2024



Levels of statistical significance for high points are as p:

- 1- ≤ 0.079
- 2- ≤ 0.052
- 3- ≤ 0.058
- 4- > 0.10