2025 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality After Two Years

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2025 IMPACT OF BIOCHAR ON SOIL CHEMICAL PROPERTIES AND CORN YIELD AND QUALITY AFTER TWO YEARS

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Biochar is a solid "charred" organic residue produced by heating plant material in the absence of oxygen (pyrolysis). Biochar tends to have high aromaticity and reduced oxygen to carbon and hydrogen to carbon ratios. As such, it is more resistant to microbial decomposition than the original plant residues or 'feedstocks' (e.g., crop residue, straw, wood, shells, etc.). Applying biochar to agricultural soils has shown potential to increase soil carbon storage, reduce GHG emissions, enhance soil health, and improve yields. However, much remains uncertain about the practical application and impacts of biochar in working agricultural systems. This trial aims to assess the impact of the incorporation of biochar with different fertility treatments e.g., fertilizer and manure on soil health indicators, corn crop yield, and corn quality. Data from 2025 represents results one year after biochar application and a second growing season of corn. This report contains soil health and corn silage yield and quality results for 2025 and comparisons to results from last year.

MATERIALS AND METHODS

The biochar corn trial was established at Borderview Research Farm in Alburgh, VT in 2024. The experimental design was a randomized complete block with split plots and four replications. The main plots were fertility treatments: urea (46-0-0), broadcast dairy manure, and a control (no additional fertility). The subplots were biochar amendment treatments e.g., the addition or absence of biochar (Table 1). The biochar was produced by Wakefield Agricultural Carbon LLC (Georgia) from carbonized Southern Yellow Pine and manufactured using a continuous flow pyrolysis system to heat the feedstock to over 1,300° F in a low oxygen environment. This biochar analysis is shown in Table 2.

Table 1. Trial treatments, Alburgh, VT, 2024 - 2025.

Fertility	With Biochar
Urea	No
Urea	Yes
Manure	No
Manure	Yes
Control	No
Control	Yes

Table 2. Biochar analysis, Wakefield BioChar, 2022.

Wood based carbon	Wood based ash	Moisture content	pH	N†	P	K	S	Ca	Mg	Fe	Mn	Zn	Cu	B
---------------	%	---------------		------------	------------	------------	------------	------------	ppm	------------	------------	------------	------------	------------
85-95	5.0	3-55	8.85	4.84	41.2	203	38.7	684	43.6	1.26	0.66	0.02	0.01	0.0

† N – nitrogen; P – phosphorus; K – potassium; S – sulfur; Ca – calcium; Mg – magnesium; Fe – iron; Mn – manganese; Zn – zinc; Cu – copper; B – boron.

The soil type at the research site was a Benson rocky silt loam with 8-15% slopes (Table 3). Each treatment was replicated four times in 10 x 50' plots in the same location as in year one of this trial (2024). Biochar was applied at a rate of 17 tons ac^{-1} on 12-Jun 2024 with a Tebbes MS140 box spreader (Whittemore, IA). Urea was applied at a rate of 200 lbs ac^{-1} on 17-May 24 with a 3-point hitch broadcast spreader. Manure was broadcasted at a rate of 7,000 gallons ac^{-1} on 17-May 24 with a Vertical Tillage Injector (VTI LLC) with 30" spacing and 20' width (Washington, IA). For the broadcast application, the manure flowed from the manure slot on the injector onto the soil surface. A manure sample was collected at the time of application and sent to the University of Vermont Agricultural and Environmental Testing Lab (AETL) for nutrient analysis (Table 4). The 2024 manure analysis had slightly higher nutrient content than the average reported in Nutrient Recommendations for Fields Crops in Vermont (2018). Broadcast manure, urea, and biochar were incorporated with Pottinger TerraDisc™ on the day of application.

In 2025, there were no urea or manure applications. On 15-May 25, corn variety RT41T19-D2 treated with neonicotinoid and fungicide with a relative maturity (RM) of 91, was planted at a rate of 34,000 seeds ac^{-1} in 30" rows with a John Deere 1750 corn planter.

Table 3. General agronomic information, Alburgh, VT, 2024 -2025.

Location	Borderview Research Farm – Alburgh, VT
Soil type	Benson rocky silt loam, 8-15% slopes
Previous crop	Corn silage
Plot size (ft)	10 x 50
Replications	4
Biochar	17 tons ac^{-1}, 12-Jun 2024
Manure	7,000 gal ac^{-1}, 17-May 24
Urea (46-0-0)	200 lbs ac^{-1}, 17-May 24
Tillage date	17-May 24, broadcast manure and urea
Planting date	15-May 25
Corn variety	RT41T19-D2 (91 RM)
Seeding rates (seeds ac^{-1})	34,000
Row width (in.)	30
Planting equipment	John Deere 1750 corn planter
Corn harvest date	16-Sep 25

Table 4. Manure analysis, University of Vermont Agricultural and Environmental Testing Laboratory, 2024.

Year	Dry matter %	NH_4	Organic N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	B
		lbs 1,000 gal^{-1}											
2024	12.8	12.8	17.0	10.5	17.7	12.4	6.20	4.30	<0.050	0.100	8.00	0.300	<0.050

Routine and soil health samples were collected on 14-May 25 before field operations. Five soil health samples were collected with a trowel to six inches in depth at five locations within each plot, thoroughly mixed, put in a labeled plastic bag, and mailed to the Cornell Soil Health Laboratory for the Comprehensive

Assessment of Soil Health (Ithaca, NY) for analysis. The routine soil samples were collected with a 1-inch diameter Oakfield core to twelve inches in depth at five locations per plot. The samples were combined by plot and analyzed by University of Vermont's Agricultural and Environmental Testing Laboratory using KCl extract and ion chromatograph for cation exchange capacity, exchangeable acidity, and base saturation of calcium (Ca), magnesium (Mg), and potassium (K).

Percent aggregate stability was measured by Cornell Sprinkle Infiltrometer and indicates ability of soil to resist erosion. Predicted percent available water capacity and predicted soil protein (N mg/soil g) was calculated with a Random Forest model from a suite of measured parameters and soil texture (Cornell Soil Health Manual Series, Fact Sheet Number 19-05b). Predicted soil protein is used to quantify organically bound nitrogen (N) that microbial activity can mineralize from soil organic matter and make plant available. Percent organic matter was measured by loss on ignition when soils are dried at 105°C to remove water then ashed for two hours at 930° F. Total carbon (organic and inorganic forms) is measured using complete oxidation of carbon at high temperature combustion (2,000° F). Total nitrogen is measured with DUMAS combustion methodology. It measures organic (living and non-living) and inorganic (mineral) forms of nitrogen. Active carbon (active C mg/soil kg) was measured with potassium permanganate and is used as an indicator of available carbon (i.e. food source) for the microbial community. Soil respiration (CO_2 mg/soil g) is measured by amount of CO_2 released over a four-day incubation period and is used to quantify metabolic activity of the soil microbial community. The Overall Quality Score is an average of all soil health indicator ratings. It includes the quality indicators as well as pH, phosphorus, and potassium levels. It should be considered as a general summary of soil quality. The scores range between 0-100%. 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.

Corn was harvested for silage on 16-Sep with a John Deere 2-row chopper and weighed in a wagon fitted with scales. Dry matter yields were calculated and adjusted to 35% dry matter. Silage quality was analyzed using the FOSS NIRS (near infrared reflectance spectroscopy) DS2500 Feed and Forage analyzer. Dried samples were sent to Dairy One's Forage Laboratory where they were ground to 1 mm and analyzed using the FOSS NIRS DS2500 for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), Net Energy-Lactation (NE_L), and other analytes. Mineral concentration was analyzed by use of inductively coupled plasma spectroscopy (ICP). The procedure is to digest the samples in acid and then inject a small portion into a hot argon plasma flame at over 5,000° C. This causes the electrons in an element to emit light energy characteristic of that element that are used to identify presence and determine concentration (Metals and Other Elements in Plants (985.01). Official Methods of Analysis, 17th edition. 2000. Association of Official Analytical Chemists).

Mixtures of true proteins, composed of amino acids and non-protein nitrogen, make up the CP content of forages. The CP content of forages is determined by measuring the amount of nitrogen and multiplying by 6.25. The bulky characteristics of forage come from fiber. Forage feeding values are negatively associated with fiber since the less digestible portions of plants are contained in the fiber fraction. The detergent fiber analysis system separates forages into two parts: cell contents, which include sugars, starches, proteins, non-protein nitrogen, fats and other highly digestible compounds; and the less digestible components found in the fiber fraction. The total fiber content of forage is contained in the neutral detergent fiber (NDF).

Chemically, this fraction includes cellulose, hemicellulose, and lignin. Because of these chemical components and their association with the bulkiness of feeds, NDF is closely related to feed intake and rumen fill in cows. In recent years, the need to determine rates of digestion in the rumen of the cow has led to the development of NDFD. This in vitro digestibility calculation is very important when looking at how fast feed is being digested and passed through the cow's rumen. Higher rates of digestion lead to higher dry matter intakes and higher milk production levels. Similar types of feeds can have varying NDFD values based on growing conditions and a variety of other factors. In this research, the NDFD calculations are based on 30-hour in vitro testing (NDFD30).

Net energy for lactation (NE_L) is calculated based on concentrations of NDF and ADF. NE_L can be used as a tool to determine the quality of a ration, but should not be considered the sole indicator of the quality of a feed, as NE_L is affected by the quantity of a cow's dry matter intake, the speed at which her ration is consumed, the contents of the ration, feeding practices, the level of her production, and many other factors. Most labs calculate NE_L at an intake of three times maintenance. Starch can also influence NE_L, where the greater the starch content, the higher the NE_L (measured in Mcal per pound of silage), up to a certain point. High grain corn silage can have average starch values exceeding 40%, although levels greater than 30% are not considered to affect energy content and might in fact have a negative impact on digestion. Starch levels vary from field to field, depending on growing conditions and variety.

Milk per ton of harvested feed is a measurement used to combine yield with quality and arrive at a benchmark number indicating how much revenue in milk can be produced from a ton of corn silage. This calculation relies heavily on the NE_L calculation and can be used to make generalizations about data, but other considerations should be analyzed when including milk per ton in the decision-making process.

Soil health metrics, yield, and quality data were analyzed using fixed effects linear model analysis with R version 4.5.3 (2026) using the *agricolae* (de Mendiburu, 2023), *car* (Fox and Weisberg, 2019), and *emmeans* (Lenth, 2024) packages. Treatment mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant ($p<0.10$).

Treatment	Yield
A	6.0^b
B	7.5^a
C	9.0^a
LSD	2.0

Variations in yield and quality can occur because of variations in genetics, soil, weather, and other growing conditions. Statistical analysis makes it possible to determine whether a difference among hybrids is real or whether it might have occurred due to other variations in the field. At the bottom of each table an LSD value is presented for each variable (i.e. yield). Least Significant Differences (LSDs) at the 0.10 level of significance are shown. Where the difference between two treatments within a column is equal to or greater than the LSD value at the bottom of the column, you can be sure that for 9 out of 10 times, there is a real difference between the two hybrids. Treatments that did not perform significantly differently from each other share the same letter. In this example, treatment C is significantly different from treatment A, but not from treatment B. The difference between C and B is equal to 1.5, which is less than the LSD value of 2.0. This means that these treatments did not differ in yield. The difference between C and A is equal to 3.0 which is greater than the LSD value of 2.0. This means that the yields with these treatments were significantly different from one another. The shared letter indicates that treatment B was not significantly lower than the top yielding treatment C.

RESULTS

Weather Data

Weather data were collected with an onsite Davis Instruments Vantage Pro2 weather station equipped with a WeatherLink data logger. Temperature, precipitation, and accumulation of Growing Degree Days (GDDs) are consolidated for the 2025 growing season (Table 5). Historical weather data are from 1991-2020 at cooperative observation stations in Burlington, VT, approximately 45 miles from Alburgh, VT.

On average, the 2025 growing season started and ended cooler than the 30-year average for the corn growing season. Although it was wetter than usual early in the season (May), from June through August, there was 4.22 less inches of rain than the 30-year average. The corn growing season had a total of 2,114 Growing Degree Days (GDDs) from May through August—47 GDDs less than the historical average (Table 5).

Table 5. Consolidated weather data and GDDs for corn, Alburgh, VT, 2025.

Alburgh, VT	May	June	July	August
Average temperature (°F)	57.5	67.8	73.2	69.0
Departure from normal	-0.93	0.35	0.82	-1.67
Precipitation (inches)	5.78	2.38	3.76	1.50
Departure from normal	2.02	-1.88	-0.30	-2.04
Corn GDDs (base 50°F)	280	545	706	583
Departure from normal	-21	21	12	-59

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger.
Historical averages are for 30 years of NOAA data (1991-2020) from Burlington, VT.

Soil Health Test Results

On 14-May, before planting, soil health and routine samples were collected on all plots (Table 6). Cation exchange capacity (CEC), exchangeable acidity (EA), and base saturation ratio results presented here are from routine soil samples. All other soil metric results are from soil health samples. There were some differences among treatments in physical properties (i.e., available water capacity, aggregate stability, surface hardness, and subsurface hardness) biological properties (i.e., organic matter, SOC, total carbon, total nitrogen, and soil proteins), many chemical properties, and overall soil health results (Table 6).

Physical Soil Health Test Results

There was not a significant fertility treatment by biochar interaction for any of the measured physical soil health metrics measured, except available water capacity. There were no statistical differences among fertility treatments or presence of biochar for available water capacity, aggregate stability, and surface hardness (Tables 6 and 7). However, there was a significant difference in subsurface hardness among biochar ($p=0.0608$), but not fertility treatments. Subsurface hardness was 9.96% higher in biochar treatments (355 psi) compared to those without biochar (322 psi).

Table 6. Physical soil health indicators for fertility effects, Alburgh, VT, 2025.

Fertility	Available water capacity m/m	Aggregate stability %	Surface hardness psi	Subsurface hardness psi
Control	0.217	53.7	168	331
Manure	0.221	53.3	170	338
Urea	0.215	52.0	177	348
LSD (0.10)‡	NS§	NS	NS	NS
Trial Mean	0.218	53.0	172	339

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments.

Table 7. Physical indicators for biochar effects, Alburgh, VT, 2025.

Biochar	Available water capacity m/m	Aggregate stability %	Surface hardness psi	Subsurface hardness psi
Biochar	0.219	52.0	167	355[b]†
No Biochar	0.216	53.9	177	323[a]
LSD (0.10)‡	NS§	NS	NS	27.8
Trial Mean	0.218	53.0	172	339

† Within a column, treatments with the same letter were not significantly different.

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments.

Biological Soil Health Test Results

There was a significant fertility treatment by biochar interaction for all measured biological soil health indicators (i.e., organic matter (OM), soil organic carbon (SOC), total C, total nitrogen, soil protein, soil respiration, and active carbon) which indicates that there may be a positive or negative synergistic effect of biochar on fertility treatment, impacting these soil properties. There were no statistical differences among fertility treatments for any of the biological soil health metrics (Table 8). However, there were statistical differences among biochar treatments for most biological soil health metrics (Table 9). Total nitrogen, soil respiration, and active carbon were not impacted by presence or absence of biochar additions.

Table 8. Biological indicators for fertility effects, Alburgh, VT, 2025.

Fertility	Organic matter %	SOC %	Active carbon ppm	Total carbon %	Total nitrogen %	Soil proteins N mg/soil g	Soil respiration CO_2 mg/soil g
Control	4.25	2.64	634	2.68	0.245	7.33	0.630
Manure	4.29	2.71	638	2.78	0.239	7.48	0.686
Urea	4.15	2.57	604	2.60	0.238	7.43	0.567
LSD (0.10)‡	NS§	NS	NS	NS	NS	NS	NS
Trial Mean	4.23	2.64	625	2.69	0.241	7.41	0.627

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments.

Table 9. Biological indicators for biochar effects, Alburgh, VT, 2025.

Biochar	Organic matter %	SOC %	Active carbon ppm	Total carbon %	Total nitrogen %	Soil proteins N mg/soil g	Soil respiration CO_2 mg/soil g
Biochar	4.51[a]†	2.99[a]	627	3.05[a]	0.236	8.06[a]	0.636
No Biochar	3.95[b]	2.29[b]	624	2.33[b]	0.245	6.77[b]	0.619
LSD (0.10)‡	0.238	0.207	NS	0.221	NS§	0.491	NS
Trial Mean	4.23	2.64	625	2.69	0.241	7.41	0.627

† Within a column, treatments with the same letter did not perform significantly different from each other.

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments

Organic matter was significantly higher ($p=0.0009$) with biochar (4.51%) than without (3.95%). Soil organic carbon was significantly higher ($p<0.0001$) by a mean of 0.705% with biochar (2.99%) than without (2.29%). Total C was significantly higher ($p<0.0001$) with biochar (3.05%) than without (2.33%). Predicted soil protein was significantly higher ($p=0.0003$) with biochar (8.06 $mg^{-soil\ g}$) than without (6.77 $mg^{-soil\ g}$).

This indicates that biochar that is 85-95% carbon and applied at a rate of 17 ton ac^{-1} can increase soil OM, SOC, Total C, and soil protein levels one year after application, which may be the result of biochar contributions to higher pools of stable carbon and available nitrogen.

Chemical Soil Test Results

There was not a significant fertility treatment by biochar interaction for any of the measured chemical soil health metrics, except Mg, Ca, manganese (Mn), boron (B), and copper (Cu), which indicates that there may be a positive or negative synergistic effect of biochar on fertility treatment, impacting these soil properties. There were some statistical differences among fertility treatments (i.e., K, Mg, Ca, and Mn). There were statistical differences among biochar application treatments in P, K, Mg, and B**.** There were no differences among fertility and biochar applications for pH, CEC, EA, Al, Fe, S, Zn, or base saturation of Ca, Mg, and K. Although biochar has a relatively high pH, it can also add organic matter, which upon decay can acidify the soil thus neutralizing the impact the high pH of the biochar could have had.

There were some statistical differences by fertility treatment (Tables 10, 11, and 12). There were statistical differences in K by fertility treatment (p=0.0789). K was significantly higher by mean of 8.97 ppm in manure treatment (57.3 ppm) than other treatments (average 43.3 ppm). There were statistical differences in Mg by fertility treatment (p=0.0004). Mg was significantly higher by mean of 14.1 ppm with manure (76.9 ppm) than other treatments (average 62.8 ppm). Calcium was significantly higher (p=0.0930) with manure (3308 ppm) than with urea (2227 ppm), but the Control (2537 ppm) was not significantly different from either. Manganese was significantly higher (p=0.0215) by mean of 1.10 ppm with manure (4.20 ppm) than other treatments (average 3.01 ppm). These higher soil test values may be because manure contains K, Ca, and Mg.

Table 10. pH and macronutrients for fertility effects, Alburgh, VT, 2025.

Fertility	pH	P ppm	K ppm	Ca ppm	Mg ppm	S ppm
Control	6.45	3.79	47.2[b]†	2537[ab]	64.2[b]	4.33
Manure	6.56	4.71	57.3[a]	3308[a]	76.9[a]	4.60
Urea	6.30	4.39	49.4[b]	2227[b]	61.4[b]	4.42
LSD (0.10)‡	NS§	NS	7.55	826	5.50	NS
Trial Mean	6.44	4.30	51.3	2691	67.5	4.45

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments

Table 11. Micronutrients for fertility effects, Alburgh, VT, 2025.

Fertility	Fe ppm	Mn ppm	Zn ppm	Al ppm	Cu ppm	B ppm
Control	3.51	3.18[b]†	0.263	20.9	0.055	0.324
Manure	2.59	4.20[a]	0.300	16.2	0.040	0.384
Urea	3.88	3.03[b]	0.238	25.5	0.053	0.283
LSD (0.10)‡	NS§	0.708	NS	NS	NS	NS
Trial Mean	3.33	3.47	0.267	20.8	0.049	0.330

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments

Table 12. Exchangeable acidity, CEC, and base saturation for fertility effects, Alburgh, VT, 2025.

Fertility	Exchangeable acidity meq 100^{-g}	CEC meq 100^{-g}	Ca base saturation (%)	Mg base saturation (%)	K base saturation (%)
Control	0.842	16.4	88.2	3.82	0.838
Manure	0.945	19.1	87.3	3.94	0.882
Urea	0.672	13.3	89.1	4.03	0.882
LSD (0.10)‡	NS§	NS	NS	NS	NS
Trial Mean	0.820	16.3	88.2	3.93	0.867

‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments

There were some statistical differences by biochar treatment (Tables 13, 14, and 15). Phosphorus was significantly higher (p=0.0259) by a mean of 2.76 ppm with biochar (5.68 ppm) than without (2.92 ppm). Potassium was significantly higher (p=0.0386) by a mean of 7.97 ppm with biochar (55.3 ppm) than without (47.3 ppm). Magnesium was significantly higher (p<0.0002) by a mean of 13.0 ppm with biochar (74.0 ppm) than without (61.0 ppm). Boron (B) was significantly higher (p=0.0715) by a mean of 0.118 ppm with biochar (0.389 ppm) than without (0.271 ppm). Available P, K, Mg, and B may have increased through direct release of nutrients from biochar (Table 2). This indicates that biochar that is 85-95% carbon and applied at a rate of 17 ton ac^{-1} can increase P, K, Mg, and B levels, without decreasing other soil nutrients one year after application.

Table 13. pH and macro nutrients for biochar effects, Alburgh, VT, 2025.

Fertility	pH	P ppm	K ppm	Ca ppm	Mg ppm	S ppm
Biochar	6.54	5.68[a]†	55.3[a]	2990	74.0[a]	4.56
No Biochar	6.34	2.92[b]	47.3[b]	2392	61.0[b]	4.34
LSD (0.10)‡	NS§	1.75	6.16	NS	4.49	NS
Trial Mean	6.44	4.30	51.3	2691	67.5	4.45

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments

Table 14. Micro nutrients for biochar effects, Alburgh, VT, 2025.

Fertility	Fe ppm	Mn ppm	Zn ppm	Al ppm	Cu ppm	B ppm
Biochar	3.10	3.62	0.258	19.8	0.045	0.389[a]†
No Biochar	3.55	3.32	0.275	21.9	0.053	0.271[b]
LSD (0.10)‡	NS§	NS	NS	NS	NS	0.107
Trial Mean	3.33	3.47	0.267	20.8	0.049	0.330

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments

Table 15. Exchangeable acidity, CEC, and base saturation for biochar effects, Alburgh, VT, 2025.

Fertility	Exchangeable acidity meq 100-g	CEC meq 100-g	Ca base saturation (%)	Mg base saturation (%)	K base saturation (%)
Biochar	0.883	15.7	86.9	4.20	0.926
No Biochar	0.757	16.8	89.5	3.67	0.809
LSD (0.10)‡	NS§	NS	NS	NS	NS
Trial Mean	0.820	16.3	88.2	3.93	0.867

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments

Overall Soil Health Score Results

There was not a significant fertility treatment by biochar interaction for soil health. There was a statistical difference in overall soil health score by fertility treatment (p=0.0890) (Table 16). Overall soil health was highest with manure (74.1%), lowest with urea (68.7%), and the Control (72.4%) was statistically similar to both. However, these scores were within the Cornell Soil Health "high" rating which indicates that soil processes are functioning at a non-limiting level. There was a significant difference by biochar treatment (p=0.0385) (Table 17). Overall soil health score was significantly higher by a mean of 4.27% with biochar (73.9%) than without (69.6%). However, both scores were within the Cornell Soil Health "high" rating which indicates that soil processes are functioning at a non-limiting level.

Table 16. Soil health score for fertility effects, Alburgh, VT, 2025.

Fertility	Soil health score %
Control	72.4ab†
Manure	74.1a
Urea	68.7b
LSD (0.10)‡	4.04
Trial Mean	71.7

† Within a column, treatments with the same letter were not significantly different from each other.

‡ LSD – Least Significant Difference at p=0.10.

Table 17. Soil health score for biochar effects, Alburgh, VT, 2025

Biochar	Soil health score %
Biochar	73.9a†
No Biochar	69.6b
LSD (0.10)‡	3.30
Trial Mean	71.7

† Within a column, treatments with the same letter were not significantly different from each other.

‡ LSD – Least Significant Difference at p=0.10.

Forage Yield and Quality Results

At harvest on 16-Sep, forage samples were taken for yield and forage quality analysis (Tables 18-23). There was not a significant fertility treatment by biochar interaction for yield or forage quality metrics, except for Na which indicates that there may be a positive or negative synergistic effect of biochar on fertility treatment, impacting these soil properties. There were some differences among fertility treatments for crude protein (CP), NE_L, and K. There were some differences among biochar treatments for yield and P. There were no differences among fertility or biochar treatments in digestibility metrics (i.e., ADF, NDF, NDFD30, IVTD30, NFC, TDN), milk lbs ton^{-1}, Ca, Mg, Fe, Zn, Cu, Mn, or Mo.

Table 18. Yield, CP, and digestibility for fertility effects, Alburgh, VT, 2025.

Fertility	Yield at 35% DM ton ac^{-1}	CP % of DM	ADF % of DM	NDF % of DM	NDFD 30 % of NDF	IVTD30 % of DM	NFC % of DM	TDN % of DM
Control	13.8	6.22[b]†	17.6	31.9	53.7	85.3	53.4	75.3
Manure	15.4	7.17[a]	19.5	34.9	48.7	82.3	49.5	72.5
Urea	12.5	6.20[b]	18.5	33.5	53.7	84.3	51.8	75.0
LSD (0.10)‡	NS§	0.410	NS	NS	NS	NS	NS	NS
Trial mean	13.9	6.53	18.5	33.4	52.0	84.0	51.5	74.3

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments.

Table 19. Forage quality production metrics for fertility effects, Alburgh, VT, 2025.

Fertility	NE_L Mcal lb^{-1}	Milk Lbs ton^{-1}
Control	0.815[a]†	2884
Manure	0.773[b]	2743
Urea	0.805[a]	2875
LSD (0.10)‡	0.031	NS§
Trial mean	0.798	2834

† Within a column, treatments with the same letter were not significantly different.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments.

Table 20. Forage quality mineral content for fertility effects, Alburgh, VT, 2025.

Fertility	Ca	P	K	Mg	Na	Fe	Zn	Cu	Mn	Mo
	----------	----------	----------	----------	-----% of DM-----	----------	----------	----------	----------	----------
Control	0.312	0.188	0.598[b]†	0.118	0.008	94.0	21.3	4.17	22.8	0.583
Manure	0.327	0.185	0.683[a]	0.125	0.008	88.7	20.2	5.00	28.5	0.600
Urea	0.320	0.175	0.573[b]	0.123	0.008	93.2	20.0	4.50	24.0	0.683
LSD (0.10)‡	NS§	NS	0.076	NS	NS	NS	NS	NS	NS	NS
Trial mean	0.319	0.183	0.618	0.122	0.008	91.9	20.5	4.56	25.1	0.622

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments.

Crude protein was higher (p=0.0022) with manure (7.17%) than the other treatments (6.21% average). NE_L was lower (p=0.0779) with manure (0.773%) than the other treatments (0.810% average). Although soil test K, Mg, Ca, and Mn were higher with manure, fertility treatment only impacted K forage quality. Potassium levels were higher (p=0.0596) with manure (0.683%) than the other treatments (0.586% average).

Yield was significantly lower (p=0.0907) by a mean of 2.34 tons ac^{-1} with biochar (12.7 tons ac^{-1}) than without (15.0 tons ac^{-1}), a difference of 16.9%. Although soil test P, K, and Mg were higher with biochar, biochar treatment only impacted P forage quality. Phosphorus was significantly higher (p=0.0785) by a mean of 0.017% or 1.10X with biochar (0.191%) than without (0.174%).

This indicates that biochar that is 85-95% carbon and applied at a rate of 17 ton ac^{-1}, can increase P but decrease yields the first year after biochar application in the second growing season. This year was a hard growing season with a colder, wetter spring and dry summer. It is possible that it may take more than one full year after application for the positive effects of biochar to be realized in crop yield and quality.

Table 21. Yield, CP, and digestibility for biochar effects, Alburgh, VT, 2025.

Biochar	Yield at 35% DM ton ac^{-1}	CP % of DM	ADF % of DM	NDF % of DM	NDFD 30 % of NDF	IVTD30 % of DM	NFC % of DM	TDN % of DM
Yes	12.7[b]†	6.58	18.2	32.9	50.9	83.9	52.0	74.1
No	15.0[a]	6.48	18.9	34.0	53.1	84.1	51.0	74.4
LSD (0.10)‡	2.27	NS§	NS	NS	NS	NS	NS	NS
Trial mean	13.9	6.53	18.5	33.4	52.0	84.0	51.5	74.3

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments.

Table 22. Forage quality production metrics for biochar effects, Alburgh, VT, 2025.

Biochar	NE_L Mcal lb^{-1}	Milk Lbs ton^{-1}
Yes	0.798	2815
No	0.798	2853
LSD (0.10)‡	NS§	NS
Trial mean	0.798	2834

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments.

Table 23. Forage quality mineral content for biochar effects, Alburgh, VT, 2025.

Biochar	Ca	P	K	Mg	Na	Fe	Zn	Cu	Mn	Mo
	-----% of DM-----									
Yes	0.313	0.191[a]†	0.634	0.121	0.008	94.0	20.6	4.44	25.4	0.578
No	0.326	0.174[b]	0.602	0.123	0.008	89.9	20.4	4.67	24.8	0.667
LSD (0.10)‡	NS§	0.015	NS	NS	NS	NS	NS	NS	NS	NS
Trial mean	0.319	0.183	0.618	0.122	0.008	91.9	20.5	4.56	25.1	0.622

† Within a column, treatments with the same letter did not perform significantly different from each other.

‡ LSD – Least Significant Difference at p=0.10.

§ NS – No significant difference was determined among the treatments.

DISCUSSION

The goal of this project is to assess the impact of biochar on soil physical, biological, and chemical properties, corn silage yield, and corn silage quality. Based on the analysis of the data, some conclusions can be made about the results of this year's trial.

Soil property results after one full year of application are summarized in Table 24. Fertility treatment did not impact physical or biological properties but did impact some chemical properties. Although there were significant differences in soil health among fertility treatments, all treatments scored in the high functioning range. This is the first year where K, Ca, Mn, were higher with manure. Similar to the year prior, Mg was higher in manure. Unlike 2024, fertility treatment did not impact P. The higher content of these nutrients compared to other treatments is most likely due to the accumulative effects of multiples years of manure additions increasing K, Ca, Mg, and Mn from manure. Similar to 2024, OM was not impacted by fertility treatment. Comparisons to the previous year are unable to be made for other biological and physical indicators as indicators beyond a routine soil health test were not measured.

One physical property and many biological and chemical properties were impacted by biochar. Sub-surface hardness, organic matter, SOC, total C, soil protein, P, K, Mg, and B were higher with biochar addition. Although biochar had higher soil health, without biochar was also in the high functioning range. Interestingly, some soil chemical property trends from the first year of the trial, taken 13 days after biochar application continued and some did not. (Soil samples were collected to a depth of 12 inches and submitted to University of Vermont's Agricultural and Environmental Testing Laboratory for chemical analysis. Soil samples were not collected for physical or biological analysis.) Compared to 2024, some soil metrics were sustained and others increased with biochar. Although not significantly different in 2024, in 2025 biochar application increased organic matter, K, Mg, and B. Similar to 2024, P was also higher with biochar in 2025. These results indicate that it can take multiple years for the impacts of biochar to be realized.

Table 24. Soil health summary results, Alburgh, VT, 2025.

	Soil health metric	Fertility	Biochar	Interaction
Physical	Available water capacity	N†	N	Y
	Aggregate stability	N	N	N
	Surface hardness	N	N	N
	Sub-surface hardness	N	Y-higher with biochar‡	N
Biological	Organic matter	N	Y-higher with biochar	Y
	SOC	N	Y-higher with biochar	Y
	Total C	N	Y-higher with biochar	Y
	Total N	N	N	Y
	Soil protein	N	Y-higher with biochar	Y
	Respiration	N	N	Y
	Active carbon	N	N	Y
Chemical	pH	N	N	N
	CEC	N	N	N
	EA	N	N	N
	P	N	Y-higher with biochar	N
	K	Y-higher with manure	Y-higher with biochar	N
	Mg	Y-higher with manure	Y-higher with biochar	Y
	Ca	Y-lower with urea; higher with manure	N	Y
	Al	N	N	N
	Mn	Y-higher with manure	N	Y
	B	N	Y-higher with biochar	Y
	Fe	N	N	N
	S	N	N	N
	Zn	N	N	N
	Cu	N	N	Y
	Ca base saturation	N	N	N
	Mg base saturation	N	N	N
	K base saturation	N	N	N
	Soil health score	Y-lower with urea; higher with manure	Y-higher in biochar	N

† N- No, there was not a statistical difference or interaction among treatments for this metric ($p \leq 0.10$).
‡ Y- Yes, there was a statistical difference or interaction among treatments for this metric ($p \leq 0.10$).

Corn silage quality and forage quality results after one year of application are summarized in Table 25. Although there were no differences in digestibility forage quality indices, there were some differences in yield, crude protein, production metrics, and mineral components among fertility and biochar treatments. Comparatively, there are more observed differences in forage quality metrics in 2025 than 2024. This indicates that some forage quality metrics may be temporary while others sustained. In 2025, crude protein and K were higher with manure while NE_L was lower. Unlike 2024 where P was lower with urea, there were no differences among fertility treatments in 2025. Similar to 2024, K was higher in manure than with urea. Unlike 2024 when there were differences in Mg and Zn among fertility treatments, there was no difference in 2025. Similar to 2024, there were no differences among fertility treatments in yield, digestibility, milk lbs ton^{-1}, Ca, P, Mg, Fe, Zn, Cu, Mn, and Mo.

Table 25. Corn silage yield and quality summary results, Alburgh, VT, 2025.

	Corn yield and quality	Fertility	Biochar	Interaction
	DM Yield (35% MST)	N†	Y-lower with biochar‡	N
	Crude protein	Y-higher with manure	N	N
Digestibility	ADF	N	N	N
	NDF	N	N	N
	NDFD30	N	N	N
	IVTD30	N	N	N
	NFC	N	N	N
	TDN	N	N	N
Production	NE_L	Y-lower with manure	N	N
	Milk lbs ton^{-1}	N	N	N
Mineral	Ca	N	N	N
	P	N	Y-higher with biochar	N
	K	Y- higher with manure	N	N
	Mg	N	N	N
	Na	N	N	Y
	Fe	N	N	N
	Zn	N	N	N
	Cu	N	N	N
	Mn	N	N	N
	Mo	N	N	N

† N- No, there was not a statistical difference or interaction among treatments for this metric ($p \leq 0.10$).
‡ Y- Yes, there was a statistical difference or interaction among treatments for this metric ($p \leq 0.10$).

Unlike 2024 when biochar did not impact yield or P, in 2025, the biochar application decreased yield and increased P. Unlike 2024 when Zn was higher in biochar, there were no difference in zinc among treatments in 2025. This year was a hard growing season with a colder, wetter spring and dry summer. It is possible that it may take more than one full year after application for the positive effects of biochar to be realized in crop yield and quality.

It is important to note that not all biochar is the same and the effect of biochar on soil and crops may depend on biochar composition e.g., feedstock and pyrolysis procedure. The data presented here is preliminary and data analysis over multiple years provides an opportunity to make observations about long-term trends. For the full report on the first year of results, see 2024 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality: Year 1. To see results from a longer term concurrent study see: 2023 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality report, 2024 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality After Two Years, and 2025 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality After Three Years.

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