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

Dr. Heather Darby, UVM Extension Agronomist
Lindsey Ruhl, Ivy Krezinski, and Sara Ziegler
UVM Extension Crops and Soils Research Specialists
(802) 656-7610

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

Dr. Heather Darby, University of Vermont Extension
heather.darby[at]uvm.edu

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 the 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 two years after biochar application and a third growing season of corn. This report contains soil health and corn silage yield and quality results for 2025 and comparisons to results from previous years.

MATERIALS AND METHODS

The biochar trial was established at Borderview Research Farm in Alburgh, VT in 2023. 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 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, 2023 - 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 the same location as in year one of this trial (2023). Treatments with manure were in 20' x 50' plots, all others were in 10' x 50' plots. Biochar was applied at a rate of 17 tons ac^{-1} on 9-Jun 2023 with a Tebbes MS140 box spreader (Whittemore, IA). Urea was applied at a rate of 200 lbs ac^{-1} on 11-Jun 23 and 17-May 24 with a 3-point hitch broadcast spreader.

Manure was broadcasted at a rate of 7,000 gallons ac^{-1} on 11-Jun 23 and 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 2023 and 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, 2023 -2025.

Location	Borderview Research Farm – Alburgh, VT
Soil type	Benson rocky silt loam, 8-15% slope
Previous crop	Corn silage
Plot size (ft)	20 x 50 for plots receiving manure, all others 10 x 50
Replications	4
Biochar	17 tons ac^{-1}, 9-Jun 2023
Manure	7,000 gal ac^{-1}, 11-Jun 23 and 17-May 24
Urea (46-0-0)	200 lbs ac^{-1}, 11-Jun-23 and 17-May 24
Tillage date	11-Jun 23 and 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, 2023 and 2024.

Year	Dry matter %	NH_4	Organic N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	B
		lbs 1,000 gal^{-1}											
2023	4.43	8.50	15.1	7.10	16.5	9.70	4.10	5.60	0.100	0.100	2.30	0.200	<0.050
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 2025 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 (C), 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 be mineralized 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 have an effect on 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 soil 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 8).

Physical Soil Health Test Results

There was no significant fertility treatment by biochar interactions for any of the physical soil health metrics measured. There were also no statistical differences among fertility or biochar treatments for available water capacity, aggregate stability, and surface hardness (Tables 6 and 7). However, there was a significant difference in subsurface hardness among biochar treatments (p=0.0263), but not fertility treatments. Subsurface hardness was higher by a mean of 41.3 psi or 1.13X in biochar (359 psi) than without biochar (318 psi).

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

Fertility	Available water capacity m/m	Aggregate stability %	Surface hardness psi	Subsurface hardness psi
Control	0.219	44.7	168	345
Manure	0.216	44.2	151	343
Urea	0.220	40.3	170	326
LSD (0.10) †	NS ‡	NS	NS	NS
Trial mean	0.218	43.1	163	338

† 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	44.4	169	359[b] †
No Biochar	0.218	41.7	157	318[a]
LSD (0.10)‡	NS§	NS	NS	4.34
Trial mean	0.218	43.1	163	338

† Within a column, treatments with the same letter were statistically similar to one another.
‡ LSD – Least Significant Difference at p=0.10.
§ NS – No significant difference was determined among the treatments.

Biological Soil Health Test Results

There was no significant fertility by biochar treatment interactions for any of the biological soil health indicators. There were also 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 the presence or absence of biochar**.**

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	4.28	2.63	600	2.66	0.224	7.89	0.592
Manure	4.36	2.75	644	2.78	0.251	8.18	0.574
Urea	4.20	2.54	627	2.57	0.233	7.93	0.505
LSD (0.10) †	NS ‡	NS	NS	NS	NS	NS	NS
Trial Mean	4.28	2.64	624	2.67	0.236	8.00	0.557

† 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	4.46[a]	2.91[a]	621	2.93[a]	0.229	9.01[a]	0.572
No Biochar	4.10[b]	2.38[b]	627	2.41[b]	0.242	6.99[b]	0.541
LSD (0.10)‡	0.233	0.187	NS§	0.189	NS	0.538	NS
Trial Mean	4.28	2.64	624	2.67	0.236	8.00	0.557

† 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 ($p=0.0143$) with biochar (4.46%) than without (4.10%). Soil organic carbon was significantly higher ($p<0.0002$) by 1.22X with biochar (2.91%) than without (2.38%). Total C was significantly higher ($p=0.0002$) by 1.22X with biochar (2.93%) than without (2.41%). Predicted soil protein was significantly higher ($p<0.0001$) by 1.29X with biochar (9.01 mg$^{-soil\ g}$) than without (6.99 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 two years 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 a significant fertility treatment by biochar interaction for P which indicates that there may be a positive or negative synergistic effect of biochar on fertility treatment, impacting these soil properties. There were no significant interactions for other chemical soil health metrics.

Soil nutrient concentrations of K, Mg, sulfur (S), Mg base saturation, and K base saturation were significantly impacted by fertility treatment (Tables 10, 11, and 12). As might be expected, manure fertility treatments increased K, Mg, S compared to the control and urea only treatments. As a result, the base saturation levels for Mg and K were higher in manure treatments as well. Manure contains K, Mg, and S and is often used as critical source for supplying these nutrients to crops.

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

Fertility	pH	P ppm	K ppm	Ca ppm	Mg ppm	S ppm
Control	6.33	3.14	47.2[b] †	2161	88.4[a]	4.49[b]
Manure	6.42	3.49	58.1[a]	2134	97.3[a]	5.58[a]
Urea	6.13	2.90	40.3[b]	2046	66.8[b]	4.56[b]
LSD (0.10)‡	NS§	NS	6.95	NS	11.1	0.514
Trial Mean	6.29	3.18	48.5	2114	84.1	4.87

† Within a column, treatments with the same letter were statistically similar.
‡ 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	4.18	2.48	0.350	21.4	0.084	0.204
Manure	4.15	2.45	0.350	22.3	0.078	0.265
Urea	5.86	2.76	0.338	25.5	0.071	0.198
LSD (0.10) †	NS ‡	NS	NS	NS	NS	NS
Trial Mean	4.73	2.56	0.346	23.1	0.078	0.222

†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	0.851	14.0	86.4	5.21b†	0.860b
Manure	0.903	12.6	84.8	5.97a	1.09a
Urea	1.06	13.8	85.8	4.30c	0.812b
LSD (0.10)‡	NS§	NS	NS	0.700	0.156
Trial Mean	0.936	13.5	85.7	5.16	0.920

† Within a column, treatments with the same letter were statistically similar.
‡ LSD; Least Significant Difference at p=0.10.
§ NS; No significant difference was determined among the treatments

There were statistical differences among biochar application treatments in all the soil chemical health metrics measured except pH, manganese (Mn), boron (B), S, and copper (Cu) (Tables 13, 14, and 15).

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

Fertility	pH	P ppm	K ppm	Ca ppm	Mg ppm	S ppm
Biochar	6.20	3.93a †	54.9a	1937b	98.0a	5.05
No Biochar	6.39	2.43b	42.2b	2290a	70.3b	4.70
LSD (0.10)‡	NS§	0.592	5.68	258	9.05	NS
Trial mean	6.29	3.18	48.5	2114	84.1	4.87

† Within a column, treatments with the same letter were statistically similar.
‡ LSD; Least Significant Difference at p=0.10.
§ NS; No significant difference was determined among the treatments

Table 14. Micronutrients for biochar effects, Alburgh, VT, 2025.

Fertility	Fe ppm	Mn ppm	Zn ppm	Al ppm	Cu ppm	B ppm
Biochar	5.93a †	2.53	0.425a	27.6b	0.076	0.228
No Biochar	3.53b	2.60	0.267b	18.6a	0.079	0.217
LSD (0.10)‡	2.05	NS§	0.080	8.67	NS	NS
Trial mean	4.73	2.56	0.346	23.1	0.078	0.222

† Within a column, treatments with the same letter were statistically similar.
‡ 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	1.46[a] †	11.8[b]	79.7[b]	6.17[a]	1.069[a]
No Biochar	0.416[b]	15.1[a]	91.6[a]	4.15[b]	0.770[b]
LSD (0.10)‡	0.386	1.87	0.128	0.571	0.128
Trial Mean	0.936	13.5	85.7	5.16	0.920

† Within a column, treatments with the same letter were statistically similar.

‡ LSD – Least Significant Difference at p=0.10.

Although biochar has a relatively high pH, it can also add organic matter, which upon decay can acidify the soil thus neutralizing the impact of the high pH biochar. EA was significantly higher ($p<0.0003$) with biochar (1.46 meq^{-100g}) than without (0.416 meq^{-100g}). Although biochar typically decreases EA, EA may be increased in this trial because the soil has a non-acidic pH and organic matter is significantly higher with addition of biochar. In neutral soils, EA can temporarily increase with biochar addition as acidic functional groups are released and carbonic acid is produced by microbial activity during organic matter decomposition. Phosphorus, K, Mg, Al, Fe, Zn, were all significantly higher when soils were amended with biochar. Mg base saturation was significantly higher ($p<0.0001$) by a mean of 2.02 % CEC with biochar (6.17 % CEC) than without (4.15 % CEC), an increase of 1.49X or 48.6%. K base saturation was significantly higher ($p=0.0009$) by a mean of 0.299 % CEC with biochar (1.07 % CEC) than without (0.770 % CEC ppm), an increase of 1.39X or 38.9%. Available P, K, and Mg may have increased through direct release of nutrients from biochar (Table 2). Although the addition of biochar did not impact pH, it did impact EA, which may have increased the amount of available Fe, Al, and Zn.

Cation exchange capacity (CEC) was significantly lower ($p=0.0082$) by a mean of 3.25 meq^{-100g} with biochar (11.8 meq^{-100g}) than without (15.1 meq^{-100g}), a difference of 24.2%. In soils with high pH, biochar can decrease CEC because it is a material with lower surface functional groups. Calcium (Ca) was significantly lower ($p=0.0301$) by a mean of 352 ppm with biochar (1937 ppm) than without (2290 ppm), a decrease of 15.4%. Available Ca in soil may have become immobilized by adsorption to biochar or dilution of Ca in the soil from the relatively low Ca content biochar. Ca base saturation was significantly lower by a mean of 11.9 % CEC with biochar (79.7 % CEC) than without (91.6 % CEC), a decrease of 13.0%. Lower Ca base saturation may be the result of lower available Ca and an overall lower CEC that favors Mg and K.

This indicates that biochar that is 85-95% carbon and applied at a rate of 17 ton ac^{-1} can increase EA, P, K, Mg, Al, Fe, and Zn levels and Mg and K base saturation, but result in lower CEC, Ca levels, and Ca base saturation two years after application.

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 ($p=0.0145$) (Table 16). Overall soil health was highest with manure (75.1%), lowest with urea (67.3%), and the Control (71.1%) 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=0.0109) (Table 17). Overall soil health score was significantly higher by a mean of 5.47% with biochar (73.9%) than without (68.4%). 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	71.1[ab] †
Manure	75.1[a]
Urea	67.3[b]
LSD (0.10)‡	4.04
Trial Mean	71.1

† Within a column, treatments with the same letter were statistically similar.
‡ LSD; Least Significant Difference at p=0.10.

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

Biochar	Soil health score %
Biochar	73.9[a] †
No Biochar	68.4[b]
LSD (0.10)‡	3.30
Trial Mean	71.1

† Within a column, treatments with the same letter were statistically similar.
‡ LSD; Least Significant Difference at p=0.10.

Forage Yield and Quality Results

At harvest on 16-Sep, forage samples were taken to determine dry matter yield, forage quality, and mineral concentrations (Tables 18-23). There was not a significant fertility by biochar treatment interaction for yield or forage quality metrics, except for NDFD30, P, and Zn 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 ADF, Ca, K, Mg, and Na. There were some differences among biochar treatments for yield, Ca, K, and Mg. There were no differences among fertility or biochar treatments in crude protein (CP), NDF, IVTD30, NFC, TDN, NE_L, milk lbs ton^{-1}, Fe, 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	22.6	6.95	18.9[a] †	35.1	58.8	85.8	49.5	76.1
Manure	23.2	7.01	19.6[a]	35.4	59.1	85.5	49.1	76.3
Urea	24.0	7.06	21.3[b]	37.0	56.9	84.0	47.5	74.8
LSD (0.10)‡	NS§	NS	1.61	NS	NS	NS	NS	NS
Trial mean	23.3	7.01	19.9	35.8	58.3	85.1	48.7	75.7

† Within a column, treatments with the same letter were statistically similar.
‡ 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	0.813	2969
Manure	0.811	2980
Urea	0.790	2913
LSD (0.10) †	NS ‡	NS
Trial mean	0.805	2954

† 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	0.305[b]†	0.178	0.584[b]	0.129[ab]	0.016[b]	100	18.3	5.38	19.4	0.425
Manure	0.291[b]	0.174	0.649[a]	0.121[b]	0.017[b]	90.6	17.3	5.13	20.6	0.400
Urea	0.340[a]	0.166	0.545[b]	0.139[a]	0.020[a]	125	17.6	5.50	23.9	0.375
LSD (0.10)‡	0.034	NS§	0.059	0.011	0.002	NS	NS	NS	NS	NS
Trial mean	0.312	0.173	0.593	0.130	0.017	105	17.7	5.33	21.3	0.400

† 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.

There was a significant difference in ADF among fertility treatments (p=0.0448). ADF was significantly higher with urea (21.3%) than with manure (19.6%) and Control (18.9%). Calcium was significantly higher (p=0.0601) by a mean of 0.041% with urea (0.340%) than other treatments (0.298%). Similar to soil test trends, K levels were higher (p=0.0244) with manure (0.649%) than the other treatments (0.564%) and Mg levels were higher (p=0.0346) with urea (0.139%) than manure (0.121%), but the Control (0.129%) was not different than the other treatments. Sodium was significantly higher (p=0.0444) by a mean of 0.003% with urea (0.020%) than the other treatments (0.016%). It is possible that when the urea is applied, the ammonium (NH_4) is hydrolyzed, replacing Na held onto the soil, releasing the Na into the soil solution.

Yield was significantly higher (p=0.0287) by a mean of 5.19 tons ac^{-1} with biochar (25.9 tons ac^{-1}) than without (20.7 tons ac^{-1}). Calcium was significantly lower (p=0.0163) by a mean of 0.043% with biochar (0.291%) than without (0.333%), a decrease of 14.6%. Potassium was significantly higher (p=0.0180) by a mean of 0.073% with biochar (0.629%) than without (0.556%), an increase of 13.2%. Magnesium was significantly lower (p=0.0438) by a mean of 0.011% with biochar (0.124%) than without (0.135%), a decrease of 8.72%.

This indicates that biochar that is 85-95% carbon and applied at a rate of 17 ton ac^{-1} can improve yields and increase K. Although this biochar applied at a rate of 17-ton ac^{-1} may lower forage levels of Ca and Mg, the range of these nutrients is still adequate and this decrease corn silage quality with lower levels of Ca and Mg.

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	25.9[a]†	6.96	19.9	35.7	57.7	84.9	48.9	75.6
No	20.7[b]	7.06	20.0	36.0	58.8	85.3	48.5	75.8
LSD (0.10)‡	3.76	NS§	NS	NS	NS	NS	NS	NS
Trial mean	23.3	7.01	19.9	35.8	58.3	85.1	48.7	75.7

† Within a column, treatments with the same letter were statistically similar.
‡ 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	0.804	2943
No	0.805	2965
LSD (0.10) †	NS ‡	NS
Trial mean	0.805	2954

† 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	0.291[b] †	0.172	0.629[a]	0.124[b]	0.018	98	17.8	5.25	21.8	0.400
No	0.333[a]	0.173	0.556[b]	0.135[a]	0.017	113	17.7	5.42	20.8	0.400
LSD (0.10)‡	0.028	NS§	0.048	0.009	NS	NS	NS	NS	NS	NS
Trial mean	0.312	0.173	0.593	0.130	0.017	105	17.7	5.33	21.3	0.400

† 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.

Impacts on soil properties after two years of treatment application are summarized in Table 24. Fertility treatment did not impact physical or biological properties but did impact chemical properties. 2025 marks the first year where fertility treatments had a significant impact on K, Mg, Mg base saturation, K base saturation, and the overall soil health score. In general, these soil nutrients were lower with urea and higher with manure. Like prior year's results, S was higher in manure treatments. 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, S, and Mg from the manure. Although there were significant differences in soil health among fertility treatments, all treatments scored in the high functioning range.

One physical property and many biological and chemical properties were impacted by biochar. Although not significantly different in 2024, in 2025, subsurface hardness was higher with biochar. Similar to 2024, additions of biochar resulted in higher organic matter, SOC, Total C, soil protein, EA, P, K, Mg, Al, Fe, Zn, Mg base saturation, K base saturation, and overall soil health score. Different from 2024, was that in 2025 there was no impact of biochar on total N or S whereas in 2024, biochar had significantly lower total N and higher S. However, also similar to 2024, biochar additions also resulted in lower CEC, Ca, and Ca base saturation. Some of these results are surprising as biochar is widely known to increase CEC, but those results are typically observed when biochar is applied to acidic soil. In soils with neutral or high pH, biochar can temporarily reduce CEC and otherwise increase organic matter and EA which can impact availability of other nutrients.

Interestingly, some soil chemical property trends (samples from top 12 inches) from the first year of the trial, taken 12 days after biochar application continued and some did not. For example, CEC, Ca, and Ca base saturation were lower in the biochar treatments directly after biochar application in 2023 and into 2025. Furthermore, EA, Al, S, Zn, Fe, and K base saturation were higher in the biochar treatment directly after biochar application in 2023 and into 2025. Conversely, the impact of biochar on pH differed between the two years. Although pH directly after application and one year later were within the recommended range for corn (5.8-7.5 pH), pH in treatments receiving biochar were slightly higher right after application. However, this was a relatively short-term trend as there were no differences in pH in the second or third year of the trial. Additionally, we observed sustained increases in P, K, Mg, and Mg base saturation two years after biochar application when there was no immediate impact of biochar in 2023. The inverse for Cu was observed where Cu was higher in biochar additions in 2023 and there were no differences in Cu among any of the treatments observed in 2024 or 2025.

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

	Soil health metric	Fertility	Biochar	Interaction
Physical	Available water capacity	N†	N	N
	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	N
	SOC	N	Y-higher with biochar	N
	Total C	N	Y-higher with biochar	N
	Total N	N	N	N
	Soil protein	N	Y-higher with biochar	N
	Respiration	N	N	N
	Active carbon	N	N	N
Chemical	pH	N	N	N
	CEC	N	Y-lower with biochar	N
	EA	N	Y-higher with biochar	N
	P	N	Y-higher with biochar	Y
	K	Y-higher with manure	Y-higher with biochar	N
	Mg	Y-lower with urea	Y-higher with biochar	N
	Ca	N	Y-lower with biochar	N
	Al	N	Y-higher with biochar	N
	Mn	N	N	N
	B	N	N	N
	Fe	N	Y-higher with biochar	N
	S	Y-higher with manure	N	N
	Zn	N	Y-higher with biochar	N
	Cu	N	N	N
	Ca base saturation	N	Y-lower with biochar	N
	Mg base saturation	Y-lower with urea; higher with manure	Y-higher with biochar	N
	K base saturation	Y-higher with manure	Y-higher with biochar	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 mineral concentrations after two years of treatment application are summarized in Table 25. Although there were no differences in CP or milk production indices, there were some differences in yield, digestibility, and mineral components among fertility and biochar treatments. The concentrations of ADF, Ca, and Na in the forage were higher with urea applications, and K was higher with manure applications. Biochar increased corn silage yield and K forage concentrations and resulted in decreased Ca and Mg. Following trends in soil tests, higher K concentrations in the forage may be due to higher soil test K in biochar and lower Ca in forage quality may be the result of lower soil Ca when biochar was added. Contrary to forage results, soil test Mg was higher when biochar was added. This may be the result of one nutrient inhibiting the uptake of other nutrients or it is possible that over the course of the season, the crop was able to luxury consume the K from the biochar and the exchangeable acidity of the biochar bound up the positively charged Mg. Compared to 2024, there was less impact of fertility and biochar treatments on corn silage. In 2024, there were no impacts of treatments on yield and fertility did not impact ADF or Na.

Compared to 2024, in 2025, there were no impacts from fertility treatments on concentrations of P, Zn, Cu, Mn, or CP in forage. However, similar trends were observed for Ca and Mg.

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-higher with biochar‡	N
	Crude protein	N	N	N
Digestibility	ADF	Y-higher with urea	N	N
	NDF	N	N	N
	NDFD30	N	N	Y
	IVTD30	N	N	N
	NFC	N	N	N
	TDN	N	N	N
Production	NE_L	N	N	N
	Milk lbs ton^{-1}	N	N	N
Mineral	Ca	Y-higher with urea	Y-lower with biochar	N
	P	N	N	Y
	K	Y- higher with manure	Y-higher with biochar	N
	Mg	Y	Y-lower with biochar	N
	Na	Y-higher with urea	N	N
	Fe	N	N	N
	Zn	N	N	Y
	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 ($p \leq 0.10$).

There were more differences in forage quality observed in 2025 compared to 2023, but less than in 2024. This indicates that some soil nutrient dynamics influenced by our treatments may impact forage quality over the short term whilst others may have a slower or more sustained impact. For example, in 2023, despite the relatively high levels of P and K in biochar, there was no significant difference in soil or forage quality tests because of biochar. In 2024, soil and forage concentrations of P and K were higher when biochar was added and in 2025, K was higher when biochar was added whereas P was not. Importantly, in the third growing season following the biochar application, yield was significantly higher when biochar was added. The impact of biochar on corn silage yield is yet to be fully understood. Increases in organic carbon and organic matter may help buffer soil extremes experienced in 2025, but multiple years of data are needed to confirm findings. Biochar may take multiple years to interact with soil properties to result in sustained or other meaningful crop differences.

It is important to note that not all biochar is the same and the effect of biochar on soil and crop 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 over time. For the full report on the first year of results, see [2023 Impact of Biochar on Soil Chemical Properties and Corn Yield and

Quality report and for the full report on the second year of results see 2024 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality After Two Years. To see results from the first year after biochar in a concurrent trial see the 2025 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality After Two Years report found on our Research Results webpage.

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