2023 Impact of Biochar on Soil Chemical Properties and Corn Yield and Quality

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Dr. Heather Darby, UVM Extension Agronomist
Lindsey Ruhl, Ivy Krezinski, and Sara Ziegler
UVM Extension Research Specialists
802-524-6501

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THE UNIVERSITY OF VERMONT EXTENSION

2023 IMPACT OF BIOCHAR ON SOIL CHEMICAL PROPERTIES AND CORN YIELD AND QUALITY

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 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 application methods (broadcast and injection) on soil nutrient content, corn crop yield, and corn quality.

MATERIALS AND METHODS

The biochar corn trial was established at Borderview Research Farm in Alburgh, VT in 2023. The experimental design was a randomized complete block with split plots and 4 replications. The main plots were urea (46-0-0), injected liquid dairy manure, broadcast dairy manure, and a control (no additional fertility). The subplots were the addition of biochar or no 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 and abbreviations, Alburgh, VT, 2023.

Fertility	With Biochar	Treatment abbreviation
Urea	No	$Urea^-$
Urea	Yes	$Urea^+$
Injected manure	No	$Injected^-$
Injected manure	Yes	$Injected^+$
Broadcast manure	No	$Broadcast^-$
Broadcast manure	Yes	$Broadcast^+$
Control	No	$Control^-$
Control	Yes	$Control^+$

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
		Soil test rating‡§:	H	L	H	H	H	H	O	L	L	L	L	L

† N, nitrogen; P, phosphorus; K, potassium; S, sulfur; Ca, calcium; Mg, magnesium; Fe, iron; Mn, manganese; Zn, Zinc; Cu, Copper; B, Boron.
‡ Soil test by Predictive Nutrient Solutions (Walla Walla, Wa).
§ H – high; O – optimal; L – Low

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. Treatments with manure were in 20' x 50' plots and all others were in 10' x 50' plots. The field was tilled with a Pottinger TerraDisc on 2-Jun. Corn (Pioneer P8820Q, relative maturity (RM) 88) was seeded at a rate of 34,000 seeds ac^{-1} in 30" rows with a John Deere 1750 corn planter on 14-Jun. Biochar was applied at a rate of 17 tons ac^{-1} on 9-Jun with a Tebbes MS140 box spreader (Whittemore, IA). Manure was broadcasted and injected at a rate of 7,000 gallons ac^{-1} on 11-Jun 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. Urea was applied at a rate of 200 lbs ac^{-1} on 11-Jun with a 3-pt hitch broadcast spreader. Broadcast manure, urea, and biochar were incorporated with Pottinger TerraDisc™ on the day of application.

Table 3. General agronomic information, Alburgh, VT, 2023.

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
Corn variety	Pioneer P8820Q (88 RM)
Seeding rates (seeds ac^{-1})	34,000
Planting equipment	John Deere 1750 corn planter
Tillage date	27-Apr
Planting date	14-Jun
Row width (in.)	30
Biochar	17 tons ac^{-1}, 9-Jun
Manure (broadcast and inject)	7,000 gal ac^{-1}, 11-Jun
Urea (46-0-0)	200 lbs ac^{-1}, 11-Jun
Corn harvest date	6-Oct

The routine soil samples were collected on 21-Jun 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 Dairy One's Soil Laboratory using KCl (potassium chloride) extract and ion chromatograph.

Corn was harvested for silage on 6-Oct 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 and coarsely-ground plot samples were brought to the E. E. Cummings Crop Testing Laboratory at the University of Vermont (Burlington, VT) where they were reground using a cyclone sample mill (1 mm screen) from the UDY Corporation. The samples were sent to Dairy One's Forage Laboratory where they were 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 5000 degrees Celsius. 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.

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. Yield data and stand characteristics were analyzed using mixed model analysis using the mixed procedure of SAS (SAS Institute, 1999). Replications within trials were treated as random effects, and corn cropping systems were treated as fixed. Treatment mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant ($p<0.10$).

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

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 2023 growing season (Table 4). Historical weather data are from 1991-2020 at cooperative observation stations in Burlington, VT, approximately 45 miles from Alburgh, VT.

On average, the 2023 corn growing season was cooler and wetter than average. The growing season for this trial was an average 1.2°F cooler than the 30-year average**.** Although there was rainfall deficit early in the season (May), in July and August, there was 7.78 more inches than the 30-year average. The corn growing season had a total of 2,183 Growing Degree Days (GDDs) for corn from Jun through Sep—63 GDDs less than the historical average (Table 3).

Table 4. Consolidated weather data and GDDs for corn, Alburgh, VT, 2023.

Alburgh, VT	June	July	August	September
Average temperature (°F)	65.7	72.2	67.0	63.7
Departure from normal	-1.76	-0.24	-3.73	1.03
Precipitation (inches)	4.40	10.8	6.27	2.40
Departure from normal	0.14	6.69	2.73	-1.27
Corn GDDs (base 50°F)	483	712	540	449
Departure from normal	-41	17	-101	62

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 Test Results

On 21-Jun, after fertility applications, soil samples were collected on all plots. There were some statistical differences in soil chemical properties among the fertility treatments, but not for organic matter (OM), macronutrients P and K, secondary nutrient Mg, micronutrients B or Mn, or base saturation of Mg (Tables 5 and 6). This may be because there was too little time between biochar application and soil sample collection for the impact of biochar to be realized. Average soil test P and K results for all treatments were less than optimal (<4.1 P ppm and <100 K ppm). Average soil test Mg results for all treatments were in the optimal range (50-100 ppm). Average soil test B results for all treatments were within the typical range found in Vermont (VT) (0.10-0.60 B ppm). Average soil Mn results for all treatments except Inject$^-$ were within the typical range found in VT (2.1-9.3 Mn ppm). All treatment averages were below the typical range of Mg base saturation (10.0-30.0% of CEC).

Although there was significant difference in pH, with lower pH in treatments receiving biochar than Control$^-$ or Urea$^-$, all fertility treatments fell within the recommended range for corn (5.8-7.5 pH). Treatments receiving biochar were more acidic (had lower pH) and also had higher exchangeable acidity (EA) than Control$^-$ or Urea$^-$. Control$^-$ and Urea$^-$ had higher CEC than Control$^+$ and Broadcast$^+$ treatments. Although all treatment averages were above the optimum range for Ca (>1,000 ppm), treatments that received biochar had lower Ca than Control$^-$ or Urea$^-$. Although all treatments were within typical Aluminum (Al) ranges found in VT, Al was significantly lower in the treatments without biochar than the Broadcast$^+$, Control$^+$, and Urea$^+$ treatments. There was no significant difference in Al between Inject$^+$ and any other treatment. The addition of biochar to the Control, Broadcast, and Urea treatments significantly increased plant available S in the soil compared to those same treatments without biochar. The Control$^-$ and Urea$^-$ treatments had lower S content than what is typically found in VT (5.0-17 ppm). Biochar had no impact on S availability in treatments with injected manure.

Although the biochar was considered low in Zn, Fe, and Cu, the general trend was that the addition of biochar increased these micronutrients. The addition of biochar to the Control and Urea treatments significantly increased plant available Zn in the soil compared to Broadcast$^-$, Urea$^-$, and Control$^-$. Zn levels were within the typical range found in VT (0.4-3.2 ppm) in the Control$^+$, Urea$^+$, and Inject$^+$. Biochar had no impact on Zn availability in treatments with injected manure. Although soil Fe results for all treatments were within the typical range found in VT (2.4-10.6 Fe ppm), there was a significant difference among treatments. Control$^+$, Urea$^+$, and Broadcast$^+$ treatments all had higher Fe than Urea$^-$ or Control$^-$ treatments. Although soil Cu results for all treatments were below the typical range found in VT (0.16-0.30 Cu ppm), there was a significant difference among treatments. Inject$^+$, Urea$^+$, and Control$^+$ treatments had higher Cu than Control$^-$, Urea$^-$, and Broadcast$^-$ treatments.

Ca base saturation was higher in Urea$^-$, Control$^-$, and Inject$^-$ treatments than Urea$^+$, Inject+, Broadcast$^+$, and Control$^+$ treatments. Broadcast$^+$ and Control$^+$ treatments were within the typical range Ca base saturation range (40-80% of CEC), all others were above the typical range. Control$^+$ and Broadcast$^+$ had higher K base saturation than the Control$^-$ and Urea$^-$ treatments. All treatment averages were below the typical range of K base saturation (2.0-7.0% of CEC).

Table 5. pH, OM, CEC, EA, P, K, Mg, Ca, and Al for fertility treatments with and without biochar, Alburgh, VT, 2023.

Treatment	pH	OM %	CEC meq/100 g	EA meq/100 g	P ppm	K ppm	Mg ppm	Ca ppm	Al ppm
Broadcast$^-$	6.48^{bc}†	4.10	14.1^{abc}	0.915^{bcd}	3.80	65.3	83.8	2457^{bc}	17.0^{a}
Broadcast$^+$	6.07^{e}	3.49	12.6^{c}	1.77^{e}	2.08	68.5	87.0	1996^{d}	35.5^{b}
Control$^-$	6.69^{ab}	3.71	14.9^{ab}	0.275^{ab}	1.93	61.0	84.3	2755^{ab}	16.0^{a}
Control$^+$	6.07^{e}	3.65	13.1^{c}	1.79^{e}	2.95	78.0	94.8	2059^{d}	34.3^{b}
Urea$^-$	6.89^{a}	3.65	15.7^{a}	0.105^{a}	1.93	56.5	84.3	2938^{a}	15.8^{a}
Urea$^+$	6.29^{cde}	3.94	13.5^{bc}	1.31^{cde}	2.90	65.0	87.0	2250^{cd}	31.0^{b}
Inject$^-$	6.45^{bcd}	3.92	14.2^{abc}	0.653^{abc}	3.10	60.8	81.0	2543^{bc}	15.5^{a}
Inject$^+$	6.14^{de}	3.71	13.6^{bc}	1.57^{de}	1.95	71.5	89.0	2209^{cd}	27.5^{ab}
LSD (0.10)‡	0.340	NS§	1.65	0.741	NS	NS	NS	379	13.6
Trial mean	6.39	3.77	13.9	1.05	2.58	65.8	86.4	2401	24.1

† 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 6. Mn, B, Fe, S, Zn, Cu, and base saturation of Ca, Mg, and K for fertility treatments with and without biochar, Alburgh, VT, 2023.

Treatment	Mn ppm	B ppm	Fe ppm	S ppm	Zn ppm	Cu ppm	Ca Base saturation (% of CEC)	Mg	K
Broadcast$^-$	2.45	0.475	3.50^{bc}†	5.00^{bc}	0.238^{cd}	0.050^{c}	86.7^{bc}	4.94	1.18^{bcd}
Broadcast$^+$	2.40	0.350	8.05^{ab}	6.00^{a}	0.338^{abcd}	0.063^{bc}	78.6^{d}	5.59	1.38^{ab}
Control$^-$	2.75	0.400	2.88^{c}	4.75^{c}	0.225^{d}	0.050^{c}	92.1^{ab}	4.74	1.06^{cd}
Control$^+$	2.55	0.363	9.63^{a}	6.25^{a}	0.500^{a}	0.075^{ab}	77.8^{d}	5.89	1.55^{a}
Urea$^-$	4.40	0.438	3.48^{c}	4.25^{c}	0.213^{d}	0.050^{c}	93.9^{a}	4.46	0.94^{d}
Urea$^+$	2.38	0.400	8.80^{a}	5.75^{ab}	0.425^{ab}	0.075^{ab}	83.2^{cd}	5.33	1.27^{abc}
Inject$^-$	1.85	0.425	3.88^{bc}	5.00^{bc}	0.288^{bcd}	0.063^{bc}	89.5^{ab}	4.77	1.10^{bcd}
Inject$^+$	2.35	0.350	7.40^{abc}	5.00^{bc}	0.400^{abc}	0.088^{a}	81.6^{cd}	5.44	1.35^{abc}
LSD (0.10)‡	NS§	NS	4.57	0.829	0.167	0.024	6.19	NS	0.298
Trial mean	2.64	0.400	5.95	5.25	0.328	0.064	85.4	5.15	1.23

† 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.

Forage Yield and Quality Results

There was no statistical difference in dry matter (DM) yield at 35% moisture (MST) among the treatments (Table 7). There were no forage quality differences among treatments for most major forage quality indicators e.g., crude protein, ADF, NDF, lignin, starch crude fat, ash, TDN, NE_L, milk lbs ton^{-1}, S, etc. (Tables 7-9). However, there were statistical differences among treatments for NDFD30, P, Mg, and K (Table 8). Control$^+$, Urea$^+$, and Broadcast$^+$ have higher NDFD30 than Urea$^-$, Inject$^-$, and Inject$^+$. Phosphorus was lower in Urea$^-$ than Control$^-$, Control$^+$, Broadcast$^-$, Broadcast$^+$, and Inject$^-$. Control$^-$ and Urea$^-$ treatments have higher Mg than Broadcast$^+$, Control$^+$, Urea$^+$, and Inject$^+$. Conversely, the general trend is that K is higher in treatments with biochar than without. Potassium is higher in Broadcast$^+$, Control$^+$, and Inject$^+$ treatments than Inject$^-$, Control$^-$, or Urea$^-$.

Table 7. DM yield, crude protein, ADF, NDF, lignin, NFC, starch, crude fat, and ash for fertility treatments with and without biochar, Alburgh, VT, 2023.

Treatment	DM Yield 35% MST	Crude protein %	ADF %	NDF %	Lignin %	NFC %	Starch %	Crude fat %	Ash %
Broadcast$^-$	18.3	6.75	21.2	36.8	2.60	49.8	41.8	3.20	3.49
Broadcast$^+$	20.2	6.78	22.7	39.7	2.98	46.9	38.7	2.98	3.71
Control$^-$	16.8	6.55	23.7	40.9	2.68	46.4	38.8	2.80	3.40
Control$^+$	17.2	6.50	22.4	39.9	2.80	46.9	38.1	2.95	3.78
Urea$^-$	18.7	7.08	23.8	40.5	2.98	46.5	38.4	2.85	3.19
Urea$^+$	21.8	6.78	23.9	41.9	3.38	45.1	35.4	2.80	3.43
Inject$^-$	18.9	6.65	21.8	36.9	2.73	50.0	40.9	3.03	3.42
Inject$^+$	18.7	6.60	25.7	43.5	3.30	43.7	35.6	2.65	3.57
LSD (0.10)‡	NS§	NS	NS	NS	NS	NS	NS	NS	NS
Trial Mean	18.8	6.71	23.1	40.0	2.93	46.9	38.5	2.91	3.50

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

Table 8. TDN, NE_L, NDF30, milk lbs ton^{-1}, milk lbs proc ton, Ca, P, Mg, and K for fertility treatments with and without biochar, Alburgh, VT, 2023.

Treatment	TDN %	NE_L Mcall b^{-1}	NDFD30 % of NDF	Milk lbs ton^{-1}	Ca	P	Mg	K
Broadcast$^-$	75.3	0.800	54.3^{bcd}†	2,941	0.243	0.250^{a}	0.093^{bcd}	0.808^{bc}
Broadcast$^+$	75.5	0.790	58.0^{abc}	2,959	0.233	0.233^{ab}	0.088^{cd}	0.930^{a}
Control$^-$	73.3	0.760	53.8^{cd}	2,828	0.265	0.223^{ab}	0.098^{ab}	0.703^{d}
Control$^+$	75.8	0.790	59.3^{a}	2,986	0.238	0.243^{a}	0.088^{cd}	0.890^{ab}
Urea$^-$	73.0	0.763	52.8^{de}	2,834	0.283	0.185^{c}	0.103^{a}	0.695^{d}
Urea$^+$	75.3	0.775	58.8^{ab}	2,987	0.255	0.203^{bc}	0.085^{d}	0.810^{bc}
Inject$^-$	74.0	0.783	51.5^{de}	2,867	0.228	0.248^{a}	0.095^{abc}	0.758^{cd}
Inject$^+$	69.8	0.715	48.8^{e}	2,642	0.238	0.220^{abc}	0.088^{cd}	0.870^{ab}
LSD (0.10)‡	NS§	NS	4.95	NS	NS	0.036	0.008	0.089
Trial mean	74.0	0.772	54.6	2,880	0.248	0.225	0.092	0.808

† 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 9. Na, Fe, Zn, Cu, Mn, Mo, S, and IVTD30 for fertility treatments with and without biochar, Alburgh, VT, 2023.

Treatment	Na	Fe	Zn	Cu	Mn	Mo	S	IVTD30
Broadcast$^-$	0.009	45.3	17.8	4.00	23.3	0.600	0.093	83.0
Broadcast$^+$	0.009	46.5	18.3	4.00	28.3	0.450	0.093	83.5
Control$^-$	0.010	45.5	16.3	4.25	21.3	0.550	0.088	81.3
Control$^+$	0.010	50.0	17.0	4.25	25.3	0.550	0.088	83.8
Urea$^-$	0.012	44.8	14.0	4.50	20.8	0.275	0.088	80.8
Urea$^+$	0.009	45.3	15.0	4.25	32.0	0.525	0.085	83.0
Inject$^-$	0.009	51.0	16.8	3.75	18.0	0.600	0.088	81.8
Inject$^+$	0.010	53.8	16.5	3.50	25.3	0.575	0.085	78.0
LSD (0.10)‡	NS§	NS	NS	NS	NS	NS	NS	NS
Trial Mean	0.010	47.8	16.4	4.06	24.3	0.516	0.088	81.9

‡ 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 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. In terms of soil chemical properties, it may be too soon to capture the impacts of biochar. Soil samples were taken 12 days after biochar application, and it may take longer for the effects of biochar to be realized in the soil. Nevertheless, there were some trends. Overall, despite biochar having high pH and Ca, the addition of biochar moderately lowered pH, CEC, Ca, and Ca base saturation. The addition of biochar tended to increase EA, Al, S, Zn, Fe, Cu, and K base saturation. It is worth noting that the Al content of biochar was not included in the biochar analysis, so it is difficult to determine how much Al was derived directly from the biochar as opposed to the soil interactions biochar may have stimulated to release Al into the soil solution.

There were several cases in which soil nutrients were outside typical VT ranges and had significant statistical difference where the addition of biochar placed them in the typical range. For example, when compared to Control$^-$, the addition of biochar to Control+ increased levels of S, Zn, and decreased Ca base saturation to within typical VT ranges. These results indicate that the immediate effect of applying biochar has some soil benefits and potential disadvantages. More data is needed on the long-term impacts of biochar on this site to draw definitive conclusions about the impact of biochar.

Although there was no impact on corn silage yield of fertility application method or biochar addition, there were some significant differences in nutrient quality. The general trend was that applications with biochar had higher NDFD30 (were more digestible), except there was no difference between Inject$^-$ and Inject$^+$.

Although the biochar was high in P, there was no difference in soil test P concentrations and P soil nutrient levels were below optimal, the general trend was that applications with urea had lower feed P than other treatments, including the Control which did not have any fertility applied. Despite biochar having high K content, there were no differences in soil test K, which was below the optimal range. Concentrations of Mg in the biochar and soil were in the optimal range. With these biochar and soil test K and Mg results, it is interesting that corn silage grown on biochar applied soil tended to have lower Mg and higher K content. It is possible that over the course of the season, the crop was able to luxury consume the K from the biochar and the acidity of the biochar bound up the positively charged Mg.

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 only represents one year and data analysis over multiple years provides an opportunity to make observations about long-term trends. In 2024, we will collect more data to inform long-term trend analysis.

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