NORTHWEST CROPS & SOILS PROGRAM

2022 Corn Cropping Systems to Improve Economic and Environmental Health

Dr. Heather Darby, UVM Extension Agronomist
Lindsey Ruhl, Sophia Wilcox-Warren, and Sara Ziegler
UVM Extension Research Specialists
802-524-6501

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THE UNIVERSITY OF VERMONT EXTENSION

2022 CORN CROPPING SYSTEMS TO IMPROVE ECONOMIC AND ENVIRONMENTAL HEALTH

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

In 2022, UVM Extension's Northwest Crops & Soils Program continued a multi-year trial at Borderview Research Farm in Alburgh, VT to assess the impact of corn cropping systems on overall health and productivity of the crop and soil. Management choices involving crop rotation, tillage, nutrient management, and cover crops also make differences in the long term. Yields are important and they affect the bottom line immediately and obviously. Growing corn with practices that enhance soil quality and crop yields improves farm resiliency to both economics and the environment. This project evaluated yield and soil health effects of six different corn rotations: continuous corn, no-till, no-till with cover crop, corn planted in a rotation with perennial forage, corn planted after a cover crop of winter rye, and a perennial forage fescue planted after continue corn.

MATERIALS AND METHODS

The corn cropping system trial was established at Borderview Research Farm in Alburgh, VT in 2014. The experimental design was a randomized complete block with replicated treatments of corn grown in various cropping systems (Table 1). In 2020, in plots that were planted in corn every year since 2014, a mixture of alfalfa/fescue was planted. Also in 2020, plots that had been perennial forage since 2008 were tilled, and the first year of corn was planted after first cut. In the fall, winter cover crops were planted in conventional and no-till corn plots.

Table 1. Corn cropping system specifics for corn yield and soil health, Alburgh, VT, 2022.

Crop	Management method	Treatment abbreviation
Corn silage	Continuous corn, tilled	CC
Corn silage	Third year in corn silage in 5-year corn/5-year hay rotation	RotYr3
Corn silage	No-till corn	NT
Corn Silage	No-Till with winter cover crop	NTCC
Corn silage	Winter cover crop, tilled	WCCC
Perennial Forage	Third year in perennial forage in 5-year corn/5-year hay rotation	RotYr8

The soil type at the research site was an Amenia silt loam with 0-2% slopes (Table 2). Each cropping system was replicated 4 times in 20' x 50' plots, except the NT plots which were split in half (10' x 50') to study effects of cover crops in a long-term no-till corn system. Soil samples were collected on 2-May and were submitted to the Cornell Soil Health Laboratory for the Comprehensive Assessment of Soil Health analysis (Ithaca, NY). Ten soil samples from five locations within each plot were collected six inches in depth with a trowel, thoroughly mixed, put in a labeled gallon bag, and mailed.

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℃ to remove water then ashed for two hours at 500℃. 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 aforementioned quality indicators as well as pH, phosphorus, and potassium levels. It should be considered as a general summary for 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.

On 2-May, cover crops were sampled in all WCCC plots, except one as it was not planted in the fall. Dried and coarsely-ground plot samples were reground using a cyclone sample mill (1mm screen) from the UDY Corporation and brought to UVM's Agricultural and Environmental Testing Laboratory (AETL) where they were analyzed for carbon and nitrogen using gas chromatography. The CC, WCCC, and RotYr3 plots were tilled with a Pottinger TerraDisc on 7-May (Table 2). Corn was seeded in 30" rows with a John Deere 1750 corn planter on 10-May in the CC, WCCC, NT, and RotYr3 plots. At planting, 200 lbs ac^{-1} of an 7-18-36 starter fertilizer was applied to all corn plots. The corn variety was Syngenta NK8618-GTA, relative maturity (RM) of 86 days, at 34,000 seeds ac^{-1}.

Table 2. Agronomic information for corn cropping system, Alburgh, VT, 2022.

Location	Borderview Research Farm – Alburgh, VT
Soil type	Amenia silt loam, 0-2% slope
Previous crop	Corn or Alfalfa/Fescue
Plot size (ft)	20 x 50, except 10 x 50 for NT & NTCC
Replications	4
Management treatments	Tilled continuous corn (CC), tilled rye cover crop (WCCC), 3rd year corn (RotYr3), no-till corn (NT), no-till with cover crop (NTCC), 3rd year perennial forage (RotYr8)
Corn variety	Syngenta NK8618-GTA (86 RM)
Seeding rates (seeds ac^{-1})	34,000
Planting equipment	John Deere 1750 corn planter
Cover crop (2021)	100 lbs ac^{-1} VNS winter rye, 20-Sep-2021
Tillage date	7-May (CC, WCCC, RotYr3)
Planting date	10-May (CC, WCCC, NT, NTCC, RotYr3)
Row width (in.)	30
Corn Starter fertilizer (at planting)	200 lbs ac^{-1} 7-18-36, 10-May
Corn nitrogen sidedress	250 lbs ac^{-1} (46-0-0) with ContaiN Max™, 21-Jun

Table 2 (cont'd). Agronomic information for corn cropping system, Alburgh, VT, 2022.

Location	Borderview Research Farm – Alburgh, VT
RotYr8 1st harvest date	31-May
Forage fertilizer	300 lbs ac^{-1} 10-20-20, 3-Jun
RotYr8 2nd harvest date	7-Jul
Forage fertilizer	100 lbs ac^{-1} 0-0-60, 7-Jul
RotYr8 3rd harvest date	19-Aug
Corn harvest date	5-Sep

The PSNT soil samples were collected on 14-Jun with a 1-inch diameter Oakfield core to six inches in depth at five locations per plot. The samples were combined by plot and analyzed by UVM's AETL using KCl extract and ion chromatograph. Corn was topdressed on 21-Jun with 250 lbs ac^{-1} urea (46-0-0) with ContaiN Max^{TM}, a nitrogen urease inhibitor.

Corn was harvested for silage from NT, WCCC, CC, and RotYr3 plots on 5-Sep with a John Deere 2-row chopper and weighed in a wagon fitted with scales. Corn populations were determined by counting number of corn plants in a 17.5 feet section in the middle two rows of each plot. 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 (1mm screen) from the UDY Corporation. The samples were then analyzed using the FOSS NIRS DS2500 for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), and Net Energy-Lactation (NE_L).

Perennial forage was harvested and weighed with a Carter Forage Harvester fitted with scales in one 3' x 50' strips. RotYr8 was harvested on 31-May, 7-Jul, and 19-Aug. After 1st cut, RotYr8 plots received 300 lbs ac^{-1} 10-20-20 on 3-Jun. After 2nd cut, RotYr8 received 100 lbs ac^{-1} 0-0-60 on 7-Jul. Perennial forage moisture and dry matter yield were calculated with an approximate two-pound subsample of the harvested material from each strip was collected, dried, ground, and then analyzed at the University of Vermont's Cereal Grain Testing Laboratory, Burlington, VT, for quality analysis with the methods outlined above. CP, ADF, NDF and 30-hour digestible NDF (NDFD) were determined.

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 acre and milk per ton of harvested feed are two measurements used to combine yield with quality and arrive at a benchmark number indicating how much revenue in milk can be produced from an acre or 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 or milk per acre 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 a 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 different 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, indicated in bold.

Treatment	**Yield**
A	6.0[b]
B	7.5[a]
C	**9.0[a]**
LSD	**2.0**

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 2022 growing season (Tables 3 and 4). Historical weather data are from 1991-2020 at cooperative observation stations in Burlington, VT, approximately 45 miles from Alburgh, VT.

With the exception of May, the 2022 growing season was cooler than the 30-year average. Throughout the growing season there was 3.87 more inches than the 30-year average. Most of the above average rainfall occurred in June. There was a total of 2157 Growing Degree Days (GDDs) for corn from May through August—2 GDDs less than the historical average (Table 3). All months except May had lower than average GDDs. The forage growing season was cooler and wetter than usual (Table 4). May had higher than usual temperatures, whereas all other months were cooler. Rainfall was higher than average in April and June with the forage season ending with 6.40 more inches of rain than the 30-year average. There was a total of 3406 GDDs for forages from April through August—35 GDDs less than the historical average.

Table 3. Consolidated weather data and GDDs for corn, Alburgh, VT, 2022.

Alburgh, VT	May	June	July	August
Average temperature (°F)	60.5	65.3	71.9	70.5
Departure from normal	2.09	-2.18	-0.54	-0.20
Precipitation (inches)	3.36	8.19	3.00	4.94
Departure from normal	-0.40	3.93	-1.06	1.40
Corn GDDs (base 50°F)	394	459	674	630
Departure from normal	93	-64	-20	-11

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.

Table 4. Consolidated weather data and GDDs for perennial forage, Alburgh, VT, 2022.

Alburgh, VT	April	May	June	July	August
Average temperature (°F)	44.8	60.5	65.3	71.9	70.5
Departure from normal	-0.81	2.09	-2.18	-0.54	-0.20
Precipitation (inches)	5.57	3.36	8.19	3.00	4.94
Departure from normal	2.50	-0.40	3.93	-1.06	1.40
Perennial forage GDDs (base 41°F)	201	617	726	953	909
Departure from normal	-14	77	-67	-20	-11

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 2-May, before field operations, soil samples were collected on all plots. Overall, treatments that were in RotYr3 had superior soil quality when compared to any of the cropping systems (Tables 5 and 6). The RotYr3 treatment had significantly higher organic matter, active carbon, total carbon, total nitrogen, soil protein, soil respiration, and aggregate stability. For the last eight years, RotYr3 consistently had significantly higher soil respiration than the corn treatments. This indicates that after its third year in corn, the legacy effects of perennial forage are still having a positive impact on soil health. Conversely, RotYr8 with its third year in perennial forage, did not have a soil health score significantly different from CC. The WCCC treatment had the lowest soil health score.

There were individual soil health metric differences among treatments. NT and NTCC had statistically similar levels of all soil health metrics except soil respiration where NTCC had higher soil respiration than NT. The cover crop combined with no-tillage likely created a more active biology. With the exception of aggregate stability and total score, RotYr8 had similar results to NTCC. RotYr8 had lower aggregate stability than the NT treatments. This indicates that 3 years of perennial forage following long-term continuous corn silage has led to some improvements in soil health, but has not fully recovered from the effects of long term tillage. The CC consistently had the lowest soil health metric measurements. WCCC performed similarly to CC in all metrics except active carbon, in which it was significantly lower than CC.

Table 5. Organic matter, active carbon, total carbon, total nitrogen, soil proteins, and soil respiration for six cropping systems, Alburgh, VT, 2022.

Cropping system	Organic matter %	Active carbon ppm	Total carbon %	Total nitrogen %	Soil proteins N mg/soil g	Soil respiration CO_2 mg/soil g
CC	3.30[c†]	568[b]	1.96[c]	0.203[c]	6.76[c]	0.349[d]
RotYr3	4.63[a]	659[a]	3.01[a]	0.291[a]	9.35[a]	0.615[a]
NT	3.73[b]	545[bc]	2.31[b]	0.237[b]	7.92[b]	0.411[c]
NTCC	3.66[b]	546[bc]	2.23[b]	0.227[b]	7.73[b]	0.482[b]
WCCC	3.31[c]	496[c]	1.96[c]	0.202[c]	6.68[c]	0.365[d]
RotYr8	3.59[bc]	515[bc]	2.10[bc]	0.214[bc]	7.59[b]	0.476[b]
LSD (0.10)‡	0.308	57.0	0.252	0.024	0.583	0.037
Trial mean	3.71	555	2.26	0.229	7.67	0.450

† Within a column, treatments with the same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.

Table 6. Aggregate stability, available water capacity, surface hardness, sub-surface hardness, and overall soil health score for six cropping systems, Alburgh, VT, 2022.

Cropping system	Aggregate stability %	Available water capacity m/m	Surface hardness psi	Sub-surface hardness psi	Soil health score
CC	18.0[d†]	0.227	92.5	185	69.2[c]
RotYr3	58.4[a]	0.231	78.8	180	80.2[a]
NT	48.2[b]	0.225	88.8	171	74.1[b]
NTCC	47.5[b]	0.228	86.3	178	74.7[b]
WCCC	22.4[cd]	0.222	82.5	188	66.1[c]
RotYr8	27.1[c]	0.236	82.5	188	69.4[c]
LSD (0.10)‡	6.28	NS§	NS	NS	3.57
Trial Mean	36.9	0.228	85.2	181	72.3

† 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.

On 14-Jun, soil samples were collected for nitrate analysis (Table 7). There was no significant difference in corn cropping systems for soil nitrate concentrations or nitrogen recommendations for 25 ton ac^{-1} yields. Mean soil nitrate-N (NO^-_3-N) among the treatments was 14.9 ppm with a mean N recommendation of 81 N lbs ac^{-1}.

Table 7. Soil nitrate-N and N recommendations for high yield potential, Alburgh, VT, 2022.

Corn cropping system	NO_3^--N ppm	N recommendation for 25 ton ac^{-1} corn
CC	14.5	89
RotYr3	14.0	91
NT	18.0	69
NTCC	14.0	66
WCCC	14.0	90
LSD (0.10)†	NS‡	NS
Trial mean	14.9	81

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

Cover Crop Results

On 2-May, cover crop samples were taken in the NTCC and WCCC plots. The winter rye cover plots yielded an average of 1196 dry matter (DM) lbs ac^{-1}. On average, cover crop biomass was 42% carbon and 3.08% nitrogen for an average C:N ratio of 42:3. This equivalates to 499 lbs ac^{-1} of carbon and 38 lbs ac^{-1} of nitrogen.

Corn and Perennial Forage Crop Results

On 5-Sep, data was collected on corn silage populations. Corn plots were harvested on 5-Sep to determine moisture and yield (Table 8). Perennial forage plots were harvested on 31-May, 7-Jul, and 19-Aug to determine moisture and yield (Table 8). There were no differences in dry matter yield or yield at 35% DM among any of the cropping systems indicating the potential of perennial forage to rival corn silage yields (Table 8).

Table 8. Corn silage population, harvest dry matter, and yield by treatment, Alburgh, VT, 2022.

Corn cropping system	Harvest population plants ac^{-1}	Yield at DM ton ac^{-1}	Yield at 35% DM ton ac^{-1}
CC	29,565	9.10	25.9
RotYr3	30,392	9.70	27.7
NT	32,221	8.90	25.5
NTCC	31,568	8.10	23.1
WCCC	30,740	10.9	31.1
RotYr8	n/a	7.00	15.3
LSD (0.10)‡	NS§	NS	NS
Trial mean	30,897	8.90	24.8

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

Standard components of corn silage and the average RotYr8 perennial forage quality across cuts were analyzed for basic quality parameters (Table 9). There were no significant differences in milk lbs ac^{-1} among any of the treatments. Among corn treatments, there were no significant differences in CP, ADF, NDF, TDN, NE_L, or lbs of milk per ton of feed. Among the corn treatments, WCCC had higher NDFD 30 values than NTCC and CC. Higher fiber digestibility could be related to differences in grain ear yields and starch concentrations in each treatment. Higher yielding treatments also had the potential to produce larger ear size and better quality feed.

Table 9. Impact of cropping systems on crop quality, 2022.

Cropping system	CP % of DM	ADF % of DM	NDF % of DM	NDFD 30 % of NDF	TDN % of DM	NE_L Mcal lb^{-1}	Milk lbs ton^{-1}	Milk lbs ac^{-1}
CC	8.90[b]	25.1[a]	44.3[a]	57.7[cd]	62.8[a]	1.43[a]	3,301[b]	30,002
RotYr3	8.80[b]	23.6[a]	42.7[a]	60.6[abc]	63.0[a]	1.43[a]	3,329[b]	32,203
NT	9.00[b]	23.9[a]	43.5[a]	60.8[ab]	63.0[a]	1.42[a]	3,317[b]	29,457
NTCC	8.43[b]	23.6[a]	43.4[a]	57.9[bcd]	63.8[a]	1.45[a]	3,332[b]	26,969
WCCC	8.98[b]	22.7[a]	41.1[a]	61.5[a]	63.3[a]	1.45[a]	3,349[b]	36,547
RotYr8	17.4[a]	33.8[b]	48.3[b]	55.8[d]	58.8[b]	1.30[b]	10,670[a]	24,934
LSD (0.10)‡	0.621	2.71	3.28	3.07	1.25	0.042	119	NS§
Trial mean	10.3	25.5	43.9	59.0	62.4	1.41	4,550	30,019

† 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 monitor long-term soil and crop health in these cropping systems. Based on the analysis of the data, some conclusions can be made about the results of this year's trial. In terms of soil quality, the system with the most recent rotation from sod, RotYr3, performed best overall. Continuous corn treatments or treatments recently out of continuous corn (CC, WCCC, & RotYr8) had the statistically lowest soil health scores. This indicates that it may take more than three years of perennial forage to build soil health levels different from continuous corn production or similar to NT production.

No-till plots (NT & NTCC) had the second highest soil health scores. This indicates that there are some benefits from not tilling the soil. The NT and NTCC treatments were transitioned from perennial forage to corn eight years ago and the lack of soil disturbance is reflected in many of the soil quality measurements. These treatments clearly show the potential for no-till corn to maintain soil quality during the corn years of a rotation. Their similar scores indicate that perhaps it takes more than two years for the synergistic effects of no-till and cover cropping to make an effective difference on soil health.

There were no significant differences among the plant populations of the corn treatments and no yield differences among any of the treatments. Typically, we observe suppressed yields in the NT corn treatment compared to other corn treatments with tillage. However, in an unusually cool and wet year, the corn and perennial forage treatments did not perform significantly different from each other. 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 2023, we will collect more data to inform long-term trend analysis.

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