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INTEGRATING COVER CROPS AND MANURE INTO CORN SILAGE CROPPING SYSTEMS

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With increasing focus on managing environmental impacts from agriculture, farmers are looking for ways to manage nutrients efficiently on their farms without sacrificing crop productivity. Cover cropping and no-till crop production are strategies that have been promoted as methods that help retain nutrients on farms and minimize losses to the environment. However, integrating these practices into the cropping system requires changes to other aspects of the system. For instance, manure management becomes more difficult when using no-till production methods as the timing or method of application may need to be altered to fit appropriately into the new production system. Farmers are curious what benefits to the soil, nutrient cycling, or crop production, may be realized from the additions of cover crops or transition to no-till methods within a corn silage cropping system. To help answer these questions, University of Vermont Extension's Northwest Crops and Soils Program conducted a field experiment between the fall of 2022 and the fall of 2023 to investigate the impacts of cover crops, tillage, and manure application in corn silage.

MATERIALS AND METHODS

The field trial was conducted at Borderview Research Farm in Alburgh, VT (Table 1). Treatments included tillage methods (conventional vs. no-till), manure application timing (fall vs spring), and cover crop integration (cover crop vs. no cover crop). Plots were 10' x 40' and replicated four times. Manure was applied to fall manure plots on 16-Sep 2022 at a rate of 6000 gal ac^{-1}. The manure was surface applied and immediately incorporated using a Pottinger TerraDisc in conventional tillage plots, and surface applied in no-till plots. 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. Winter rye was planted on 16-Sep 2022 into cover crop plots using a Sunflower no-till grain drill. Soil samples were collected according to the Cornell Soil Health sampling protocol on 27-Apr 2023 and sent to the Cornell Soil Health Laboratory to be analyzed (https://soilhealth.cals.cornell.edu/). Cover crop ground cover and biomass were also measured at this time. Ground cover was measured by processing photographs using the Canopeo smartphone application (https://canopeoapp.com/#/login). Cover crop biomass was measured by harvesting the material within a 0.25 m^2 quadrat in each plot. The samples were weighed and dried to determine dry matter content and yield. The dried samples were then ground and sent to Dairy One for total nitrogen and carbon analysis. Manure was surface applied to spring manure plots on 28-Apr 2023 at a rate of 6000 gal ac^{-1}. Conventional tillage plots were tilled using a Pottinger TerraDisc to incorporate manure and/or cover crop biomass. All remaining cover crop plots were terminated on 27-Apr 2023 by an application of Glystar Plus herbicide at a rate of 1 qt ac^{-1}.

Corn was planted on 9-May 2023 at a rate of 34,000 seeds ac^{-1} with 200 lbs ac^{-1} 10-20-20 corn starter fertilizer using a John Deere 7500 no-till corn planter. Plots were sprayed with Cornerstone and Resolve Q herbicides at 1 and 1.5 qts ac^{-1} respectively on 10-Jun. Soil was collected from plots at a 6" depth on 12-Jun 2023 and sent to DairyOne to determine soil nitrate concentration.

Table 1. No-Till Cover Crop Trial Management, Alburgh, VT, 2022-2023.

Location	Borderview Research Farm – Alburgh, VT
Soil type	Benson rocky silt loam
Previous crop	Corn silage
Tillage treatments	Conventional tillage: immediate incorporation with PottingerTerraDisc No-Till: manure not incorporated
Manure treatments	Fall application (16-Sep 2022) Spring application (28-Apr 2023)
Cover crop treatments	Winter rye No cover crop
Seeding rates (rye/corn)	100 lbs ac^{-1}/34,000 seeds ac^{-1}
Corn variety	P9608AM, 96 RM
Replications	4
Plot size (ft)	10' x 40'
Manure application dates (rate, gal ac^{-1})	Fall: 16-Sep 2022 (6,000) Spring: 28-Apr 2023 (6,000)
Planting dates	Rye: 16-Sep 2022 Corn: 9-May 2023
Cover crop termination	Glystar Plus 1 qt ac^{-1} applied 27-Apr 2023 incorporated with Pottinger TerraDisc in conventional tillage plots
Harvest date	14-Sep 2023

No additional fertility was added. Prior to harvest, corn populations were measured on 12-Sep. At the same time, corn stalk samples were collected from three random plants in each plot and sent to DairyOne for nitrate analysis. Corn was harvested on 14-Sep 2023 using a John Deere 2-row chopper and a wagon fitted with scales. The yield of each plot was recorded and an approximate 1 lb subsample was collected and dried to determine dry matter content and calculate yield. The samples were then ground and analyzed for forage quality at the E. E. Cummings Crop Testing Laboratory at the University of Vermont (Burlington, VT) via near-infrared reflectance spectroscopy (NIR) procedures using a FOSS DS2500 NIRS.

Data were analyzed using the general linear model procedure in SAS (SAS Institute, 1999). Replications were treated as a random effect and manure, cover crop, and tillage treatments were treated as fixed. Treatments were considered different at the 0.10 level of significance. Orthogonal contrasts were conducted to determine mean differences of cover crop versus no cover crop, tillage versus no-tillage, and spring versus fall manure applications. Variations in yield and quality can occur because of variations in genetics, soil, 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 hybrids 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. Hybrids that were not significantly lower in performance than the highest hybrid in a particular column are indicated with an asterisk. In this example, hybrid C is significantly different from hybrid A but not from hybrid 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 hybrids 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 of these hybrids were significantly different from one another. The asterisk indicates that hybrid B was not significantly lower than the top yielding hybrid C, indicated in bold.

Hybrid	Yield
A	6.0
B	7.5*
C	**9.0***
LSD	2.0

RESULTS

Weather data were recorded with a Davis Instrument Vantage Pro2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT (Table 2). From October 2022 through April 2023 there were 1377 Growing Degree Days (GDDs) accumulated for the winter rye, 155 more than the 30-year normal. Precipitation monthly accumulations were at or below normal from October through March. Precipitation exceeded the normal by over 1.8 inches in April before being 1.78 inches below normal the next month at the time of planting and crop establishment. The remainder of the season was exceptionally wet with 10.75 inches of rain falling in July and 6.27 inches in August. Temperatures during this time were relatively low contributing to a total of just over 2000 GDDs accumulated from May through August, 124 fewer than the 30-year normal.

Table 2. 2022-2023 weather data for Alburgh, VT.

	2022			2023							
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Average temperature (°F)	51.3	41.5	30.7	26.9	23.6	32.2	48.3	57.1	65.7	72.2	67.0
Departure from normal	0.96	2.24	2.50	6.01	0.65	-0.07	2.70	-1.28	-1.76	-0.24	-3.73
Precipitation (inches)	2.56	3.01	2.43	2.04	1.36	2.00	4.94	1.98	4.40	10.75	6.27
Departure from normal	-1.27	0.31	-0.07	-0.09	-0.41	-0.24	1.87	-1.78	0.14	6.69	2.73
Growing Degree Days (base 32°F)	607	346	112	42	77	103	280				
Departure from normal	39	111	64	42	66	-35	-132				
Growing Degree Days (base 50°F)								303	483	712	540
Departure from normal								1	-41	17	-101

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger.
Historical averages are for 30 years of NOAA data (1981-2010) from Burlington, VT.

Effects of Conservation Management Systems

Conservation management systems differed statistically for soil health metrics and nitrate content at topdress and harvest (Table 3). Aggregate stability was highest in the plots with no tillage, fall manure, and a winter cover crop. This was statistically similar to plots with no tillage receiving spring manure both with and without a cover crop. Interestingly, the plots with no tillage, fall manure but no winter cover crop had 6% lower aggregate stability and were more similar to conventionally tilled plots. While the no-till plots generally had higher aggregate stability than conventionally tilled pots, it is interesting that the combination of fall manure and winter cover crop in both tillage systems produced higher aggregate stability. This may relate to better cover crop establishment and growth with fall manure application leading to a larger impact on aggregate stability than just cover crops alone. Soil respiration, a measure of the biological activity of the soil, was highest in the conventionally tilled plots receiving fall manure with a winter cover crop and was higher than all other treatments. However, regardless of tillage or manure application timing, the addition of a cover crop significantly improved soil respiration. This might suggest that the cover crop is providing additional food sources and other resources to the soil that are better supporting a biologically active soil. Despite these differences, the predicted water holding capacity, active carbon, and overall soil health scores did not statistically differ across the conservation management systems.

Table 3. Soil health metrics by conservation management systems.

System treatment	Aggregate stability	Predicted water holding capacity	Active carbon	Respiration	Soil nitrate at topdress	Corn stalk nitrate
	%	g H_2O g soil^{-1}	mg C kg soil^{-1}	mg CO_2 g soil^{-1}	ppm	
CT-FM-NoCC†	19.2c¥	0.247	765	0.540cd	14.0c	47.0c
CT-FM-WRCC	22.4bc	0.241	680	**0.766a**	14.2bc	53.8bc
CT-SM-NoCC	20.2c	0.242	734	0.488d	22.9ab	48.5c
CT-SM-WRCC	22.1c	**0.252**	**839**	0.619b	**27.6a**	47.5c
NT-FM-NoCC	21.9c	0.248	733	0.510d	7.45c	**67.8a**
NT-FM-WRCC	**28.0a**	0.237	710	0.594bc	6.75c	59.0abc
NT-SM-NoCC	24.2abc	0.238	747	0.497d	13.1c	60.3abc
NT-SM-WRCC	27.6ab	0.242	752	0.647b	6.53c	65.8ab
LSD (p = 0.10)‡	5.35	NS§	NS	0.067	8.66	13.7
Trial mean	23.2	0.243	745	0.583	14.1	56.2

†CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop; NoCC- no cover crop
‡Least significant difference (LSD) at the 0.10 level.
¥Treatments that share letters performed statistically similarly to one another. The top performer is indicated in **bold.**
§Not statistically significant.

By the time the corn was in the V6 growth stage, soil nitrate levels ranged from 6.75 to 27.6 ppm and were highest in conventionally tilled plots receiving spring manure. The dry conditions early in the season likely contributed to low levels of nitrogen loss from the spring applied manure that was incorporated into the soil. Nitrate levels were much lower in the plots that received spring manure, but were not incorporated (no-till) which is likely due to more nitrogen being lost to volatilization at the time of surface application. Overall, all no-till plots regardless of manure application timing or cover crop use had low soil nitrate levels by this time. Based on these soil nitrate levels, nitrogen supplementation ranging from 0 to 103 lbs N ac^{-1} would be recommended (based on a 20-ton ac^{-1} yield goal, Nutrient Recommendations for Field Crops in Vermont). By the end of the season, this trend had reversed where the no-till plots had substantially higher nitrate levels in the corn stalks than conventionally tilled plots. This may have been due to a slower mineralization of manure, cover crop, and/or soil organic matter without tillage. Overall, however, the nitrate levels in the corn stalks of all the treatments were very low and indicate insufficient nitrogen was supplied to the plant.

Corn silage yield and quality parameters differed significantly between treatments (Table 4). Yields ranged from 13.5 to 29.5 tons ac^{-1} with the highest yield obtained by the conventional tillage, spring manure with winter cover crop treatment. This was statistically similar only to the conventional tillage, spring manure without winter cover crop treatment. While corn stalk nitrate tests suggest insufficient nitrogen was taken up by the plants in these treatments, the higher soil nitrate levels earlier in the season prior to the excessive rainfall may have allowed these treatments to establish and grow more prior to the onset of poor weather resulting in higher yields despite generally high nitrogen losses. The lowest yielding treatment was the no-till, fall manure without winter cover crop treatment which only yielded 13.5 tons ac^{-1}. Plant populations followed similar trends with conventionally tilled plots generally having higher harvest populations than no-till plots. Fiber digestibility, protein, and overall predicted milk yield per ton were highest in the no-till spring manure without winter cover crop treatment.

Table 4. Corn silage yield and quality by conservation management system.

System treatment	Populations	Corn yield @ 35% DM	CP	aNDFom	Starch	240-hr uNDF	30-hr NDFD	Milk yield	
	plants ac^{-1}	tons ac^{-1}		% of DM		% of NDF		lbs ton^{-1}	cwt ac^{-1}
CT-FM-NoCC†	37516a¥	24.1bc	6.81c	38.7	**37.7**	12.2ab	51.9d	3194bc	269abc
CT-FM-WRCC	37516a	21.6bcd	7.06bc	39.5	36.9	12.0ab	52.5cd	3190bc	241bcd
CT-SM-NoCC	**38442a**	26.0ab	7.01bc	41.5	34.9	13.1b	51.7d	3111c	283ab
CT-SM-WRCC	38333a	**29.5a**	7.69ab	40.5	33.7	13.0b	53.6bcd	3159bc	**326a**
NT-FM-NoCC	26789bc	13.5e	7.37bc	38.4	36.4	11.4a	55.5ab	3235ab	153e
NT-FM-WRCC	33160ab	20.6cd	7.11bc	40.8	34.7	12.7b	53.5bcd	3161bc	228bcd
NT-SM-NoCC	22325c	16.3de	**8.25a**	**36.1**	36.5	**11.1a**	**57.6a**	**3310a**	191de
NT-SM-WRCC	30492abc	19.6cd	7.58ab	38.7	36.0	12.1ab	54.8bc	3200bc	219cd
LSD (p = 0.10)‡	8720	5.31	0.754	NS§	NS	1.16	2.75	100	63.5
Trial mean	33072	21.4	7.36	39.3	35.8	12.2	53.9	3195	239

†CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop; NoCC- no cover crop.
‡Least significant difference (LSD) at the 0.10 level.
¥Treatments that share a letter performed statistically similarly to one another. The top performer is indicated in **bold.**
§NS; Not statistically significant.

Cover crop ground cover and biomass did not differ across system treatments that included cover crops (Table 5). While ground cover was about 10% lower in no-till plots, this was not statistically different from conventionally tilled plots. In addition, cover crop biomass was lowest in the no-till plots receiving spring manure, however, this was also not statistically different than the other treatments. Favorable weather conditions at the time of cover crop establishment may have contributed to better overall establishment of the cover crop especially in no-till plots.

Table 5. Cover crop metrics by system treatment.

System treatment	Ground cover	Cover crop DM yield
	%	tons ac^{-1}
CT-FM-WRCC†	63.5	0.955
CT-SM-WRCC	**63.6**	**1.11**
NT-FM-WRCC	53.2	1.06
NT-SM-WRCC	53.5	0.769
LSD (p = 0.10)‡	NS¥	NS
Trial mean	58.5	0.972

†CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop.
‡Least significant difference (LSD) at the 0.10 level. The top performer is indicated in **bold.**
¥NS; Not statistically significant.

Effects of Individual Conservation Practices

Contrasts between the manure timing, tillage, and cover crop treatments were analyzed to determine the impact of each of these individual components within these system treatments (Table 6).

Table 6. Cover, manure, and tillage treatment contrast effects (*p*-values) on soil and crop parameters.

	Cover treatment	Manure timing treatment	Tillage treatment
		Level of significance†	
Aggregate stability	**	**	NS‡
Organic matter	NS	NS	NS
Respiration	***	**	*
Active carbon	NS	NS	*
Water holding capacity	NS	NS	NS
Overall score	*	NS	NS
Soil nitrate at topdress	NS	**	NS
Corn population	NS	**	NS
Corn stalk nitrate at harvest	NS	**	NS
Corn silage yield	*	***	*
Crude protein	NS	*	**
aNDFom	NS	NS	NS
Starch	NS	NS	NS
240-hr uNDF	NS	**	NS
30-hr NDFD	NS	**	NS
Milk yield per ton	NS	*	NS
Milk yield per acre	NS	**	*

†*Significant at the p=0.10 probability level; **Significant at the p=0.05 probability level; ***Significant at the p=0.0001 probability level.
‡NS; Not statistically significant at the p=0.10 probability level.

Impact of Cover Crop

Treatments that contained cover crops exhibited higher aggregate stability, soil respiration, overall soil health scores, and corn silage yields than plots with no cover crop (Table 7).

Table 7. Crop and soil health metrics by cover crop treatment.

Cover crop treatment	Corn yield @35% DM	Aggregate stability	Respiration	Organic matter	Active carbon	Overall score	Soil nitrate at topdress
	tons ac^{-1}	%	mg CO_2 g soil^{-1}	%	mg C kg soil^{-1}		ppm
No cover crop	20.0	21.4	0.509	4.07	745	76.4	**14.3**
Cover crop	**22.8**	**25.1**	**0.656**	**4.22**	**745**	**78.5**	13.8
Level of significance†	*	**	***	NS‡	NS	*	NS
Trial mean	21.4	23.2	0.583	4.14	745	77.5	14.1

†*Significant at the *p*=0.10 probability level; **Significant at the *p*=0.05 probability level; ***Significant at the *p*=0.0001 probability level. The top performer is indicated in **bold.**

‡NS; Not statistically significant.

Farmers can be hesitant to adopt cover cropping because they believe that the cover crop will immobilize nitrogen, thereby, requiring more additional nitrogen or negatively impacting the corn silage yield. In this trial, soil nitrate levels at the time of topdress were similar between treatments with and without winter cover crops. These would therefore be recommended the same amount of supplemental nitrogen to attain target yields. When treated the same through the remainder of the trial, plots with a winter cover crop yielded almost 3 tons ac^{-1} higher than plots without a cover crop. This may have been due to the higher soil health allowing for better nutrient retention and cycling in cover crop plots despite excessive rainfall.

Impact of Manure Application Timing

Spring manure application supported higher aggregate stability and nitrate content at topdress compared to fall manure application (Table 8). While nitrate levels were higher in spring manure plots at the time of topdress, by harvest the corn stalk nitrate levels were slightly higher in fall manure plots. This may have been related to higher soil respiration allowing for nutrient mineralization from fall applied manure and organic matter over the season albeit slower than spring application. Stalk nitrate levels at the end of the season in both treatments, however, would be considered low indicating that the entire trial had limited nitrogen uptake.

Table 8. Soil health metrics by manure application timing.

Manure application timing	Aggregate stability	Respiration	Overall score	Soil nitrate at topdress	Corn stalk nitrate	Corn population
	%	mg CO_2 g soil^{-1}		ppm		plants ac^{-1}
Fall manure	22.9	**0.603**	76.8	10.6	**56.9**	**33745**
Spring manure	**23.5**	0.562	**78.1**	**17.5**	55.5	32398
Level of significance†	**	**	NS‡	**	**	**
Trial mean	23.2	0.583	77.5	14.1	56.2	33072

†*Significant at the *p*=0.10 probability level; **Significant at the *p*=0.05 probability level; ***Significant at the *p*=0.0001 probability level. The top performer is indicated in **bold.**

‡NS; Not statistically significant.

Yields, protein content, fiber digestibility and predicted milk yield were impacted by manure application timing (Table 9). Spring manure application yielded approximately 3 tons ac^{-1} more silage which had slightly higher protein content and fiber digestibility.

Table 9. Corn silage yield and quality characteristics by manure application timing.

Manure application timing	Yield at 35% DM	CP	aNDFom	Starch	240-hr uNDF	30-hr NDFD	Milk yield	
	tons ac^{-1}	% of DM			% of NDF		lbs ton^{-1}	cwt ac^{-1}
Fall manure	19.9	7.09	**39.4**	**36.4**	12.1	53.4	**3195**	223
Spring manure	**22.8**	**7.63**	39.2	35.3	**12.3**	**54.4**	3195	**255**
Level of significance†	***	*	NS‡	NS	**	**	*	**
Trial mean	21.4	7.36	39.3	35.8	12.2	53.9	3195	239

†*Significant at the p=0.10 probability level; **Significant at the p=0.05 probability level; ***Significant at the p=0.0001 probability level. The top performer is indicated in **bold.**
‡NS; Not statistically significant.

Impact of Tillage Method

Tillage treatment and also soil health metrics are shared in Table 10. Conventionally tilled plots had higher respiration and active carbon. Corn silage yields were also over 6 tons higher than no-till plots. Corn quality was similar between tillage treatments except for protein which was about 0.5% higher in no-till plots. Milk yield on a per acre basis, due to the difference in corn silage yield, was almost 80 hundredweights (cwt) higher than no-till plots.

Table 10. Cover crop and soil health metrics by tillage treatment.

Tillage treatment	Respiration	Active carbon	Yield at 35% DM	CP	Milk yield	
	mg CO_2 g soil^{-1}	mg C kg soil^{-1}	tons ac^{-1}	% of DM	lbs ton^{-1}	cwt ac^{-1}
Conventional	0.603	755	25.3	7.14	3163	280
No-till	0.562	735	17.5	7.58	3226	198
Level of significance†	*	*	*	**	NS‡	*
Trial mean	0.583	745	21.4	7.36	3195	239

†*Significant at the p=0.10 probability level; **Significant at the p=0.05 probability level; ***Significant at the p=0.0001 probability level.
‡NS; Not statistically significant.

DISCUSSION

Integrating no-tillage into corn silage systems can pose challenges with other aspects of the cropping system, especially regarding the method and timing of manure application, and cover crops. Managing cover crop biomass in the spring to adequately prepare the soil for planting can be a challenge. In a conventional tillage system, incorporating the biomass into the soil can sometimes tie up nitrogen that otherwise would be utilized by the crop. Pairing cover crop incorporation with manure application can help provide more available nitrogen to the subsequent crop. However, in a no-till system, manure is left unincorporated and much of the ammonium-N may be lost through volatilization. Cover crops can help build soil health and aide with the transition to no-till. As seen in this trial, cover crop significantly enhanced soil health and supported higher corn silage yields. However, the additional cover crop biomass may further exacerbate the lack of N in these systems if termination timing is not ideal, especially in fields transitioning to no-till systems (such as the one in this study). Additional fertility may be needed in a no-till system to support the corn crop yield goals in these cases.

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