Integrating Cover Crops and Manure into Corn Silage Cropping Systems

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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 2017 and the fall of 2020 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 21-Sep 2017, 24-Sep 2018 and 25-Sep 2019 at a rate of 6200 gal ac^{-1}. The manure was surface applied and immediately incorporated using an aerway 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 25-Sep 2017, 24-Sep 2018 and 25-Sep 2019 into cover crop plots using a Sunflower no-till grain drill. The following spring, soils were sampled by collecting approximately 10 soil cores at a 6" depth within each plot using a soil probe. These samples were immediately dried and transported to the AETL to be analyzed for soil nitrate (NO_3) nitrogen (N) content. An additional sample was collected according to the Cornell Soil Health sampling protocol and sent to the Cornell Soil Health Laboratory to be analyzed (https://soilhealth.cals.cornell.edu/). Cover crop ground cover, height, and biomass was measured on 8-May 2017, 6-May 2019 and 28-Apr 2020. Ground cover was measured by processing photographs using the Canopeo smartphone application (https://canopeoapp.com/#/login). Cover crop height was measured at three randomly selected locations within each plot. Cover crop biomass was collected from two $0.25m^2$ areas within each plot. The material from the area was cut at ground height, collected, weighed, and dried to determine dry matter yield. All cover crop plots were terminated on 14-May 2018 by an application of Roundup herbicide at a rate of 1qt ac^{-1}. All plots containing cover crops were terminated on 7-Jun 2019 by an application of Lumax EZ herbicide at a rate of 3 pints ac^{-1} and on 19-May 2020 by an application of Acuron herbicide at a rate of 3 qt ac^{-1}. In plots receiving tillage, cover crop biomass was then incorporated into the soil using disc harrows to prepare the seedbed for corn planting. Manure was surface applied to spring manure plots on 11-May 2018, 8-May 2019 and 2-May 2020 at a rate of 5800 gal ac^{-1} in 2018 and 2019 and 6,200 gal ac^{-1} in 2020.

Table 1. No-Till Cover Crop Trial Management, Alburgh, VT, 2017-2020.

Location	Borderview Research Farm – Alburgh, VT
Soil type	Benson rocky silt loam
Previous crop	Corn silage
Tillage treatments	Conventional tillage: immediate incorporation with aerway No-Till: manure not incorporated
Manure treatments	Fall application Spring application
Cover crop treatments	Winter rye No cover crop
Seeding rates (rye/corn)	100 lbs ac^{-1}/34,000 seeds ac^{-1}
Corn variety	Syngenta NK8618, 86 RM
Replications	4
Plot size (ft)	10' x 40'
Manure application dates (rate, gal ac^{-1})	Fall: 21-Sep 2017 (6,200) 24-Sep 2018 (6,200) 25-Sep 2019 (6,200) Spring: 11-May 2018 (5,800) 8-May 2019 (5,800) 2-May 2020 (6,200)
Planting dates	Rye: 25-Sep 2017 24-Sep 2018 25-Sep 2019 Corn: 8-Jun 2018 13-May 2019 13-May 2020
Cover crop termination	Roundup 1 qt ac^{-1} applied 14-May 2018 Lumax EZ 3 pints ac^{-1} applied 7-Jun 2019 Acuron 3 qt ac^{-1} applied 19-May incorporated with disc harrow in conventional tillage plots
Harvest date	17-Sep 2018 19-Sep 2019 4-Sep 2020

Corn was planted on 8-Jun 2018 at a rate of 34,000 seeds ac^{-1} with 250 lbs ac^{-1} 15-15-15 corn starter fertilizer using a John Deere 7500 no-till corn planter. On 13-May 2019, corn was planted at a rate of 34,000 seeds ac^{-1} with 245 lbs ac^{-1} 10-20-20 corn starter fertilizer using a John Deere 7500 no-till corn planter. In 2020, corn was planted on 13-May 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. Soil was again collected from plots at a 6" depth on 1-Jul 2019 and 15-Jun 2020 and sent to the AETL to determine pre-side dress nitrate concentration. No additional N was applied to the plots. Just prior to corn harvest, corn populations were counted and 8" basal corn stalk segments from 6" above ground level were collected from three randomly selected corn plants in each plot.

The stalk samples were dried, ground to 1mm particle size, and analyzed for nitrate content at the Dairy One Forage Laboratory (Ithaca, NY). Corn was harvested on 17-Sep 2018, 19-Sep 2019 and 4-Sep 2020 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 UVM Cereal Grain Testing Lab via NIR techniques as described for the cover crop biomass.

Data was analyzed using the PROC MIXED procedure SAS (SAS Institute, 1999). Year and replications were treated as random effects, and manure, cover crop, and tillage treatments were treated as fixed. Treatment mean pairwise comparisons were made using the Tukey-Kramer adjustment. Treatments were considered different at the 0.10 level of significance. Orthogonal contrasts were conducted to determine mean differences 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 was recorded with a Davis Instrument Vantage Pro2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT (Tables 2-4). From September 2017 through May 2018, there were 3376 Growing Degree Days (GDDs) accumulated for the winter rye, 691 more than the 30-year normal. Precipitation during this time was below normal for all months except for April with a total of 3.53 inches below normal being accumulated. For the corn there were 2298 GDDs accumulated from June through September, 285 more than normal. Precipitation during this time was below normal for all months with a total of 2.78 inches below normal being accumulated.

From September 2018 through May 2019, there were 2759 Growing Degree Days (GDDs) accumulated for the winter rye, 384 fewer than the 30-year normal. Precipitation during this time fluctuated monthly resulting in 2.78 inches above normal being accumulated over the duration. For the corn there were 2254 GDDs accumulated from May through September, 92 fewer than normal. Precipitation during this time was below normal for all months except May and September with a total of 1.14 inches below normal being accumulated.

Table 2. 2017-2018 weather data for Alburgh, VT.

	2017				2018								
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average temperature (°F)	64.4	57.4	35.2	18.5	17.1	27.3	30.4	39.2	59.5	64.4	74.1	72.8	63.4
Departure from normal	3.76	9.16	-2.96	-7.41	-1.73	5.79	-0.66	-5.58	3.10	-1.38	3.51	3.96	2.76
Precipitation (inches)	1.84	3.29	2.28	0.78	0.79	1.16	1.51	4.43	1.94	3.74	2.43	2.96	3.48
Departure from normal	-1.80	-0.31	-0.84	-1.59	-1.26	-0.60	-0.70	1.61	-1.51	0.05	-1.72	-0.95	-0.16
Growing Degree Days (base 32°F)	971	786	202	56	53	93	90	272	853				
Departure from normal	113	284	17	56	53	93	90	-112	97				
Growing Degree Days (base 50°F)										447	728	696	427
Departure from normal										-27	88	115	109

Table 3. 2018-2019 weather data for Alburgh, VT.

	2018				2019								
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average temperature (°F)	63.4	45.8	32.2	25.4	15.0	18.9	28.3	42.7	53.3	64.3	73.5	68.3	60.0
Departure from normal	2.86	-2.26	-5.79	-0.15	-3.87	-2.48	-2.79	-2.11	-3.21	-1.46	2.87	-0.51	-0.52
Precipitation (inches)	3.48	3.53	4.50	2.96	1.53	1.70	1.36	3.65	4.90	3.06	2.34	3.50	3.87
Departure from normal	-0.18	-0.03	1.38	0.61	-0.47	-0.02	-0.86	0.84	1.51	-0.57	-1.88	-0.41	0.21
Growing Degree Days (base 32°F)	941	435	136	72	23	38	108	346	660				
Departure from normal	86	-78	-115	-8	-26	-18	-58	-68	-99				
Growing Degree Days (base 50°F)									189	446	716	568	335
Departure from normal									-103	-36	86	-14	-25

Table 4. 2019-2020 weather data for Alburgh, VT.

	2019				2020								
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average temperature (°F)	60.0	50.4	31.2	26.0	23.5	21.8	35.0	41.6	56.1	66.9	74.8	68.8	59.2
Departure from normal	-0.51	2.32	-6.76	0.46	4.62	0.41	3.94	-3.19	-0.44	1.08	4.17	0.01	-1.33
Precipitation (inches)	3.87	6.32	2.38	1.29	2.63	1.19	2.79	2.09	2.35	1.86	3.94	6.77	2.75
Departure from normal	0.21	2.76	-0.74	-1.06	0.63	-0.53	0.57	-0.72	-1.04	-1.77	-0.28	2.86	-0.91
Growing Degree Days (base 32°F)	840	571	128	67	37	48	193	315	746				
Departure from normal	-15	58	-122	-13	-12	-8	27	-99	-13				
Growing Degree Days (base 50°F)									298	516	751	584	336
Departure from normal									6	35	121	2	-24

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.

From September 2019 through May 2020, there were 2945 GDDs accumulated for the winter rye, 197 fewer than the 30-year normal. Precipitation during this time was approximately normal resulting in a total of 0.08 inches above normal being accumulated. For the corn there were 2485 GDDs accumulated from May through September, 140 more than normal. Precipitation during this time was below normal for all months except August with a total of 1.14 inches below normal being accumulated.

Interactions

The only significant year x treatment interaction observed was for corn silage yield (Table 5, Figure 1). The no-till with fall applied manure and no winter cover crop (NT-FM-NOCC) as well as the conventional tillage with spring applied manure and no winter cover crop (CT-SM-NOCC) treatment responded differently than the other treatments, in terms of yield, across the three trial years. The NT-FM-NOCC treatment decreased in yield in 2019 and then returned to a similar level to 2018 in 2020 while the CT-SM-NOCC treatment increased in yield in 2019 before returning to a level similar to 2018 in 2020. This could be due to the cool and wet spring in 2019, which delayed corn planting and reduced nitrogen availability. We would expect a no-till system with no additional fertility added would suffer more significantly from this situation than other systems. Conversely, in the conventional tillage system with spring applied manure, nitrogen was more readily available to the corn crop despite the spring weather conditions.

Table 5. **Effect (*p*-values) of year and treatment on soil and crop parameters.**

	Year	Treatment	Year x Treatment interaction
	Level of significance		
Ground cover	***	***	***
Spring soil nitrate	**	NS	NS
Aggregate stability	**	**	NS
Organic matter	**	**	NS
Respiration	***	**	NS
Overall score	**	**	NS
Soil nitrate at topdress	***	***	NS
Corn yield	NS	**	*
Crude protein (CP)	***	**	NS
Acid detergent fiber (ADF)	***	NS	NS
Neutral detergent fiber (NDF)	***	NS	NS
Ash	***	NS	NS
Fat	***	*	**
Starch	***	NS	NS
Total digestible nutrients (TDN)	***	NS	NS
Net energy for lactation (Nel)	**	NS	NS
Milk yield per ton	***	NS	NS
Milk yield per acre	**	NS	NS

NS - Not statistically significant at the *p*=0.10 probability level.
*Significant at the *p*=0.1 probability level.
**Significant at the *p*=0.05 probability level.
***Significant at the *p*=0.0001 probability level.

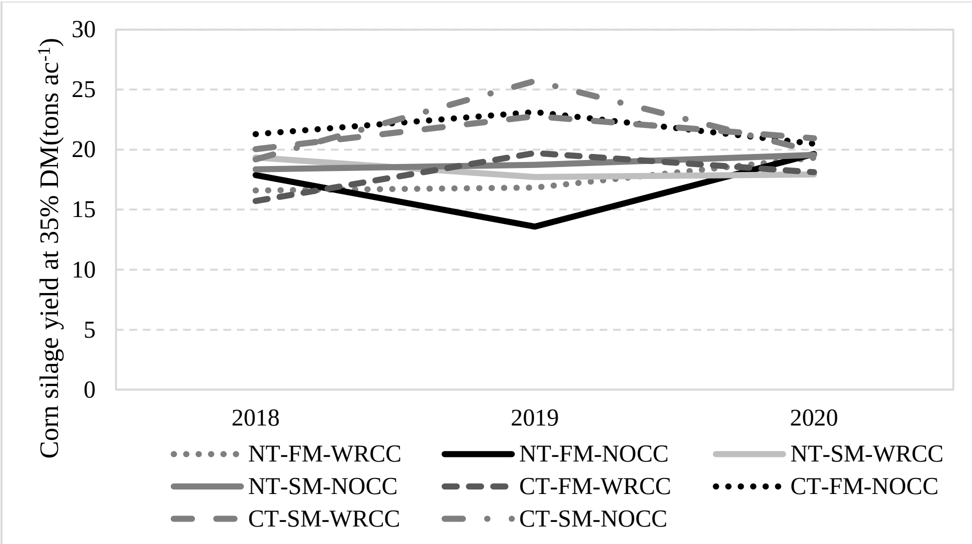

Figure 1. Treatment x year interaction for corn silage yield.
CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop; NoCC- no cover crop

Due to the lack of other significant interactions, data for each of the three trial years were combined and analyzed together to compare the conservation management systems.

Effects of Conservation Management Systems

Conservation management systems differed statistically in spring ground cover and soil health metrics (Table 6). Spring ground cover was highest (59.9%) in the no-till treatment receiving fall manure with winter rye cover crop. This was statistically similar to both conventional tillage treatments with winter cover receiving spring or fall manure. We would expect significantly lower ground cover from treatments without a winter cover crop, however, the no-till treatment receiving spring manure performed statistically differently from all other treatments. Although higher than where no cover crop was implemented, by only changing the timing of manure incorporation from fall to spring, an 18.6% reduction in ground cover was observed. As little to no weeds were growing at this time, increased ground cover can be attributed to increased cover crop establishment.

Soil health metrics also differed by conservation management system. Aggregate stability was highest (41.0%) in the no-till treatment receiving spring manure with a winter cover crop. This was significantly higher than all other treatments. Interestingly, when manure was applied in the fall in both conventional and no-till treatments, no difference was observed between cover crop and non-cover crop treatments. However, when manure was applied in the spring, both conventional and no-till treatments saw significant increases in aggregate stability when cover crops were implemented. Organic matter also differed with the conventionally tilled treatment receiving spring manure with a winter cover crop having the highest organic matter content of 4.64%. Respiration was highest in the no-till treatment receiving fall manure with a winter cover crop, but was statistically similar to all other treatments except for two which both received spring manure and had no winter cover crop. Overall, the conventionally tilled treatment with spring manure and no cover crop had the lowest ground cover and soil health in the spring compared to all other treatments.

Table 6. Ground cover and soil health metrics by conservation management systems.

System treatment	Ground cover	Aggregate stability	Organic matter	Respiration	Overall score
		%		mg CO_2 g soil^{-1}	
CT-FM-NoCC	5.05c	31.8bc	4.18bc	0.710ab	79.2bc
CT-FM-WRCC	58.0a	32.5bc	3.99c	0.726ab	79.6bc
CT-SM-NoCC	0.867c	29.9c	4.07c	0.567c	78.0c
CT-SM-WRCC	59.3a	36.1b	**4.64a**	0.728ab	82.0ab
NT-FM-NoCC	3.02c	35.1b	4.12bc	0.712ab	79.7bc
NT-FM-WRCC	**59.9a**	35.9b	4.20bc	**0.761a**	81.9ab
NT-SM-NoCC	1.78c	33.7bc	4.36b	0.665b	80.0bc
NT-SM-WRCC	41.3b	**41.0a**	4.37b	0.737ab	**83.4a**
LSD (p = 0.10)	8.50	4.46	0.260	0.088	3.27
Trial mean	28.7	34.5	4.24	0.701	80.5

CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop; NoCC- no cover crop.
Treatments that share letters performed statistically similarly to one another. The top performer is indicated in **bold.**

At the beginning of the season, management systems did not differ statistically in soil nitrate content (Table 7). However, by the time the corn was in the V6 growth stage, treatments ranged widely in soil nitrate content. The highest nitrate content was observed in the conventionally tilled treatment with spring manure and winter cover crop, which was significantly higher than all other treatments at 29.6 ppm. Of the no-till treatments, treatment with spring manure but no winter cover crop had significantly higher soil nitrate content at 20.9 ppm. These data suggest that in a no-till system, nitrogen from spring applied manure may be tied up by a cover crop leaving less available to the corn compared to if no cover crop were present. Conversely, with conventional tillage, spring manure application combined with a winter cover crop yielded the highest soil nitrate content as additional nitrogen was added from the decomposition of the cover crop biomass. Based on the soil nitrate contents observed at the V6 growth stage, supplemental nitrogen recommendations were generated using the Nutrient Recommendations for Field Crops in Vermont. Supplemental nitrogen ranged from 0 to 103 lbs ac^{-1}.

Table 7. Soil nitrate content by conservation management system.

System treatment	Spring	Summer	Supplemental N recommendation
	ppm		lbs ac^{-1}
CT-FM-NoCC	4.40	21.7b	41
CT-FM-WRCC	3.91	17.4bc	72
CT-SM-NoCC	3.95	22.3b	45
CT-SM-WRCC	3.76	**29.6a**	**0**
NT-FM-NoCC	**4.44**	12.4c	99
NT-FM-WRCC	3.32	11.8c	103
NT-SM-NoCC	4.38	20.9b	53
NT-SM-WRCC	2.84	14.0c	91
LSD (p = 0.10)	NS	6.71	
Trial mean	3.88	18.8	

CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop; NoCC- no cover crop.
Treatments that share a letter performed statistically similarly to one another. The top performer is indicated in **bold.**
NS-Not statistically significant.

Corn silage yield and protein content also varied by management system (Table 8). Because no supplemental nitrogen was added to these treatments, those with higher available soil nitrate at the time of topdress yielded higher than those with lower available nitrate. A similar trend was observed for crude protein content, which we would expect to be higher in instances where available nitrogen was higher.

Table 8. Corn silage yield and quality by conservation management system.

	Corn yield	CP	ADF	NDF	Ash	Fat	Starch	TDN	Nel	Milk yield	
System treatment	tons ac^{-1}	% of DM								lbs ton^{-1}	lbs ac^{-1}
CT-FM-NoCC	**21.6a**	8.61c	22.7	39.6	**3.46**	3.91a	**35.5**	**67.3**	**0.690**	**3395**	**25757a**
CT-FM-WRCC	17.9c	9.09ab	22.3	39.3	3.86	3.67a	33.8	66.6	0.682	3358	21080c
CT-SM-NoCC	21.6a	**9.50a**	23.5	40.6	4.26	3.55ab	30.4	66.0	0.670	3301	25167ab
CT-SM-WRCC	21.2ab	9.33ab	**21.6**	**38.2**	3.86	3.68a	34.6	66.5	0.684	3378	25245a
NT-FM-NoCC	17.0c	8.88bc	21.9	38.8	3.69	3.61ab	33.9	66.9	0.686	3370	20102c
NT-FM-WRCC	17.6c	8.65c	22.4	39.6	3.65	3.80a	34.6	66.6	0.682	3370	20809c
NT-SM-NoCC	18.9bc	9.00abc	22.5	40.0	3.98	3.13b	32.0	65.2	0.663	3250	21507c
NT-SM-WRCC	18.3c	8.85bc	22.2	38.9	3.64	**3.98a**	34.8	67.0	0.686	3393	21822bc
LSD (p = 0.10)	2.65	0.521	NS	NS	NS	0.506	NS	NS	NS	NS	3393
Trial mean	19.3	8.99	22.4	39.4	3.80	3.67	33.7	66.5	0.680	3352	22686

CT- conventional tillage; NT- no-till; FM- fall manure; SM- spring manure; WRCC- winter rye cover crop; NoCC- no cover crop.
Treatments that share a letter performed statistically similarly to one another. 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 9).

Table 9. Cover, manure, and tillage treatment contrast effects (*p*-values) on soil and crop parameters.

	Cover treatment	Manure timing treatment	Tillage treatment
		Level of significance	
Ground cover	***	**	**
Spring soil nitrate	*	NS	NS
Aggregate stability	**	**	NS
Organic matter	*	NS	**
Respiration	**	NS	**
Overall score	**	*	NS
Soil nitrate at topdress	NS	***	**
Corn yield	NS	**	**
Crude protein (CP)	NS	**	**
Acid detergent fiber (ADF)	NS	NS	NS
Neutral detergent fiber (NDF)	NS	NS	NS
Ash	NS	NS	*
Fat	*	NS	NS

Starch	NS	NS	NS
Total digestible nutrients (TDN)	NS	NS	NS
Net energy for lactation (Nel)	NS	NS	NS
Milk yield per ton	NS	NS	NS
Milk yield per acre	NS	**	*

NS - Not statistically significant at the p=0.10 probability level.
*Significant at the p=0.1 probability level.
**Significant at the p=0.05 probability level.
***Significant at the p=0.0001 probability level.

Impact of Cover Crop

Treatments that contained cover crops exhibited higher soil aggregate stability, organic matter, soil respiration, and overall soil health scores than plots with no cover crop (Table 10). Increased aggregate stability was likely due to increased root and microbial activity, which helps create stable soil aggregates through microbial exudates. This was supported by higher soil respiration, a measure of microbial activity, in cover crop plots compared to plots with no cover crop (Figure 2).

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

Cover crop treatment	Ground cover	Aggregate stability	Organic matter	Respiration	Overall score
		%		mg CO_2 g soil^{-1}	
No cover crop	2.70	32.6	4.18	0.663	79.2
Cover crop	**54.6**	**36.4**	**4.30**	**0.738**	**81.7**
Level of significance	***	**	*	**	**
Trial Mean	28.7	34.5	4.24	0.701	80.5

*Significant at the P=0.1 probability level.
**Significant at the P=0.05 probability level.
***Significant at the P=0.0001 probability level.

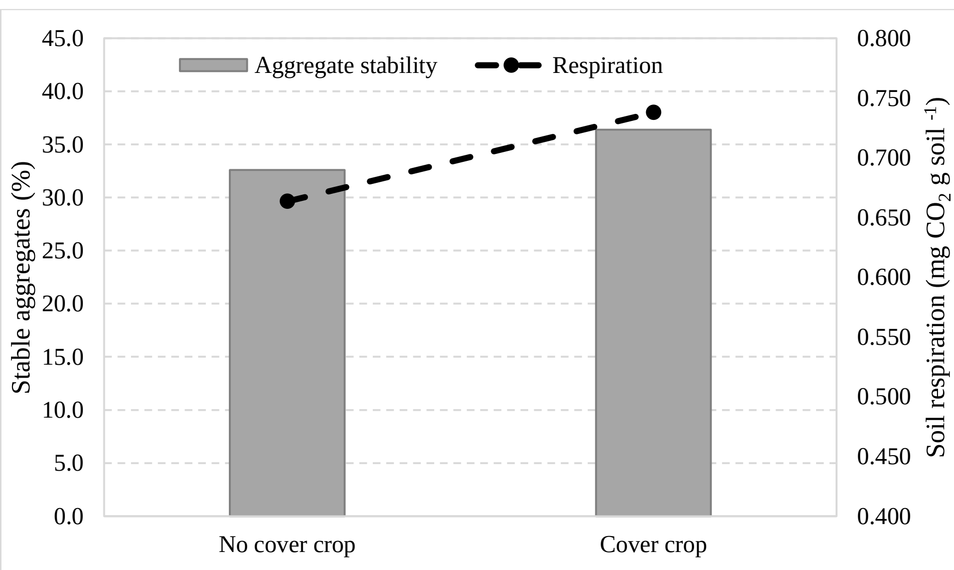

Figure 2. Soil aggregate stability and respiration by cover crop treatment.

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. While plots with cover crops contained statistically lower soil nitrate-N in the spring than plots without cover crops (Figure 3), this equated to a difference of less than 1ppm. Furthermore, as the season progressed, soil nitrate concentrations were similar at the V6 growth stage (normal time of topdress) and supported similar corn silage yields without additional fertility (Figure 4).

Figure 3. Soil nitrate content before planting and at the time of topdress.
Treatments with the same letter performed statistically similarly to one another.

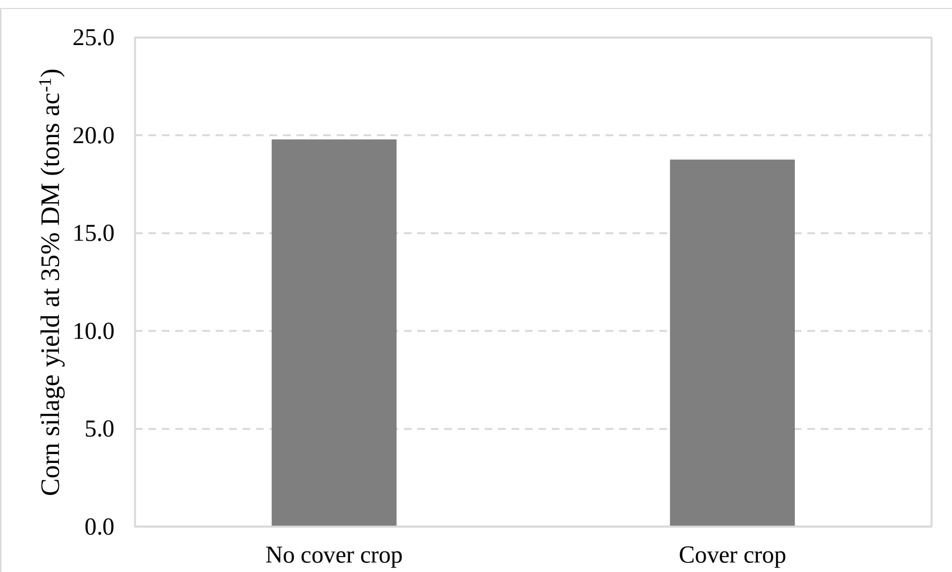

Figure 4. Corn silage yield by cover crop treatment.
Cover crop treatments performed statistically similarly to one another.

Corn silage quality characteristics were also not significantly impacted by the presence of cover crops in the cropping system (Table 11). Fat content was statistically higher where there were cover crops, however, this only equated to a less than 0.5% difference.

Table 11. Corn silage quality characteristics by cover crop treatment.

Cover crop treatment	CP	ADF	NDF	Ash	Fat	Starch	TDN	Nel	Milk yield	Milk yield
	% of DM								lbs ton^{-1}	lbs ac^{-1}
No cover crop	9.00	22.7	39.8	3.85	3.55	33.0	66.4	0.677	3329	23133
Cover crop	8.98	22.1	39.0	3.75	3.78	34.5	66.7	0.684	3375	22239
Level of significance	NS†	NS	NS	NS	*	NS	NS	NS	NS	NS
Trial mean	8.99	22.4	39.4	3.80	3.67	33.7	66.5	0.680	3352	22686

†NS - Not statistically significant.
*Significant at the P=0.1 probability level.

Impact of Manure Application Timing

Plots that received manure in the fall produced 1.50 tons ac^{-1} less corn silage than plots receiving spring manure (Figure 5). As described in the previous section, there was no significant impact from cover crop treatment on corn silage yield. Therefore, this decreased yield is likely a result of less nitrogen availability as evidenced by the lower soil nitrate concentrations at the time of topdress (approximately the V6 growth stage) in plots receiving fall manure. Manure applied in the fall provided approximately 42 lbs N ac^{-1} while spring applied manure supplied 67 lbs N ac^{-1} (Table 12). This is further supported by higher observed soil nitrate-N concentrations in spring manure plots at the time of corn topdress compared to fall manure plots and lower crude protein content in fall manure plots (Table 13). Based on soil nitrate-N concentrations at this time, spring manure plots would require an additional 45 lbs ac^{-1} N while fall manure plots would require an additional 80 lbs ac^{-1} N.

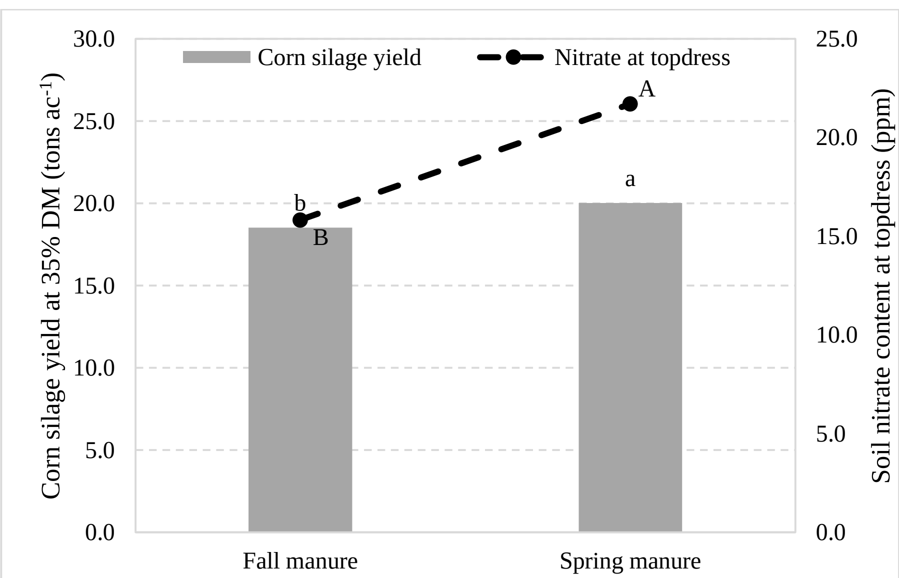

Figure 5. Cover crop biomass and ground cover by manure application timing.
Treatments that share the same letters performed statistically similarly to one another.

Table 12. Nitrogen supplied by manure*.

Manure Treatment	Available N lbs ac^{-1}
Spring	67
Fall	42

*Estimated from Nutrient Recommendations for Field Crops in Vermont.

Given these nitrate levels at the time of topdress, plots that received fall manure would require **almost twice as much** additional N as plots that received spring manure to produce the same target yield.

Spring ground cover was 5.7% higher in plots receiving fall manure (Table 14) However, spring manure plots had 1.4% higher aggregate stability and a statistically higher overall soil health score.

Table 13. Corn silage yield and quality characteristics by manure application timing.

Manure application timing	Corn yield at 35% DM	CP	ADF	NDF	Ash	Fat	Starch	TDN	Nel	Milk yield	
	tons ac^{-1}	% of DM								lbs ton^{-1}	lbs ac^{-1}
Fall manure	18.5	8.81	22.3	39.3	3.66	3.75	34.5	66.9	0.685	3373	21937
Spring manure	20.0	9.17	22.5	39.4	3.93	3.59	33.0	66.2	0.676	3330	23435
Level of significance	**	*	NS†	NS	NS	NS	NS	NS	NS	NS	**
Trial mean	19.3	8.99	22.4	39.4	3.80	3.67	33.7	66.5	0.680	3352	22686

†NS - Not statistically significant.
*Significant at the P=0.1 probability level.
**Significant at the P=0.05 probability level.

Table 14. Soil health characteristics by manure application timing.

Manure application timing	Ground cover	Aggregate stability	Organic matter	Respiration	Overall score
	%			mg CO_2 g $soil^{-1}$	
Fall manure	31.5	33.8	4.12	0.703	80.1
Spring manure	25.8	35.2	4.36	0.674	80.8
Level of significance	**	**	NS†	NS	*
Trial mean	28.7	34.5	4.24	0.701	80.5

†NS - Not statistically significant.
*Significant at the P=0.1 probability level.
**Significant at the P=0.05 probability level.

Impact of Tillage Method

Corn silage yields were 2.60 tons ac^{-1} higher in conventionally tilled plots compared to no-till plots (Figure 6). This may have been related to nitrogen availability in conventionally tilled plots as exhibited by soil nitrate-N concentrations at the time of topdress. Based on the soil nitrate concentrations at this time, conventionally tilled plots would have required an additional 40 lbs N ac^{-1} while the no-till plots would have required an additional 85 lbs N ac^{-1}. Since additional nitrogen beyond manure was not applied, corn silage yields were lower in no-till plots. Furthermore, crude protein levels in no-till plots were 0.29% lower (Table 15).

Table 15. Corn silage yield and quality by tillage treatment.

	Corn yield	CP	ADF	NDF	Ash	Fat	Starch	TDN	Nel	Milk yield	
	tons ac^{-1}	% of DM								lbs ton^{-1}	lbs ac^{-1}
Conventional	20.6	9.13	22.5	39.4	3.86	3.71	33.6	66.6	0.681	3358	24312
No-till	18.0	8.84	22.2	39.3	3.74	3.63	33.8	66.4	0.679	3346	21060
Level of significance	**	**	NS†	NS	*	NS	NS	NS	NS	NS	*
Trial mean	19.3	8.99	22.4	39.4	3.80	3.67	33.7	66.5	0.680	3352	22686

†NS - not statistically significant.
*Significant at the P=0.1 probability level.
**Significant at the P=0.05 probability level.

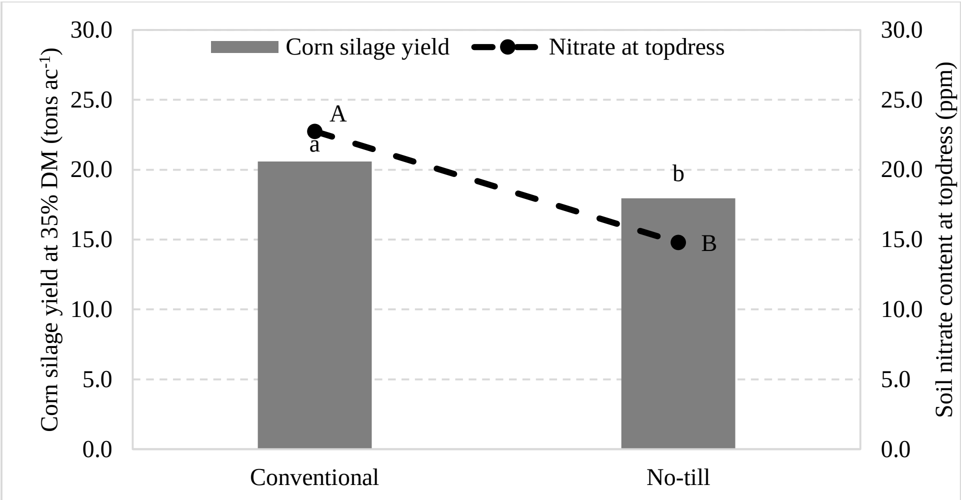

Figure 6. Corn silage yield and soil nitrate content at topdress by tillage treatment.
Treatments that share the same letters performed statistically similarly to one another.

Ground cover differed statistically between tillage treatments (Table 16) as cover crops established more consistently in conventionally tilled plots (Images 1 and 2). Organic matter content and soil respiration were higher in no-till plots while aggregate stability and overall soil health scores did not differ statistically.

Table 16. Cover crop and soil health metrics by tillage method.

Tillage treatment	Ground cover	Aggregate stability %	Organic matter	Respiration mg CO_2 g soil^{-1}	Overall score
Conventional	30.8	32.6	4.22	0.683	79.7
No-till	26.5	36.4	4.26	0.719	81.3
Level of significance	**	NS†	**	**	NS
Trial mean	28.7	34.5	4.24	0.701	80.5

†NS - not statistically significant.
*Significant at the P=0.1 probability level.
**Significant at the P=0.05 probability level.

Image 1 - 2. Cover in conventionally tilled (left) and no-till (right) plots.

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 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 (Table 17). 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. However, the additional cover crop biomass may further exacerbate the lack of N in these systems, 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.

Table 17. Available N supplied to the corn crop*.

Manure treatment	Tillage treatment	Available N lbs ac^{-1}
Spring	Conventional	79
	No-Till	54
Fall	Conventional	54
	No-Till	30

*Available N was estimated from Nutrient Recommendations for Field Crops in Vermont (https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2021%20Events/NMP%20Class/NutrientRec_BR1390.3_Sept2020.pdf).

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