Final Report

Project Title: Whole Systems Approach: Modifying Corn Silage Production Practices for Enhanced Cover Crop Growth
Grantee Name: University of Vermont
Project Director: Heather Darby
Period Covered by Report: May 2020 - December 2023
Start Date: May 22, 2020
End Date: December 31, 2023
Agreement Number: NR203A750013G013

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Executive Summary

Purpose

Farmers know how to grow high yield and quality corn silage crops. Typically, this involves a concentration of effort on tending to long season corn and providing fertility at the right time. Farmers also know how to grow hearty cover crops, typically by drilling early and heavy. Often, the systems to grow high yielding corn are not compatible with the methods to grow high biomass cover crops due to the convergence of crop growth inhibiting weather and labor shortages as peak corn harvest and fall cover crop planting overlap. Farmers in the northeast who are pressured by the short growing season to seek alternative cover crop planting strategies are innovating with interseeded cover crops. Interseeded cover crops can have weaker performance compared to fall planted cover crops because the interseeded cover crop becomes shaded by the corn canopy. Shut off from sunlight and photosynthesis, the summer cover crop growth pauses until the corn is harvested.

The overall goal of this project is to increase the acres of effective cover crops in northern climates to improve soil health and crop health and reduce nonpoint source nutrient pollution to watersheds. This project utilizes the use of innovative technologies and cropping system approaches that helped expand the acreage of effective cover crops. The purpose of this project is to identify modification to corn production practices that will increase interseeded cover crop success. Modifications of corn production practices from typical farmer management to management that could result in higher cover crop establishment and more cover crop growth without impact cash crop yield included changes to the herbicide program, corn variety, corn population, and corn planting methods.

Objectives

1. Work with farmers to compare their typical practices with modified corn/cover cropping strategies.
2. Determine the impact of modifications on weed control and cover crop establishment.
3. Determine effect of field management modifications on silage corn yield

Accomplishments

At project initiation in 2020, there were 30 participating farmers. Although participating farmers remained actively engaged throughout the project, due to farms being sold, there were a total of 24 active participants by the end of the project. During the length of this three year on-farm project, over 134 fields and 2,134 acres were enrolled. At each farm, fields were identified to implement modified cropping system methods. Herbicide programs were modified to decrease residual impact on cover crops. Corn varieties were chosen with more vertical leaf architecture to reduce obstruction of sunlight to the cover crop. Corn populations were slightly lowered to decrease canopy cover without impacting yield. A corn seeder was modified to plant with skips in the rows to create a window within the corn canopy for sunlight to penetrate and encourage cover crop growth.

Methods

From each of the participating farms, one field was chosen as a control (typical methods) and another was chosen as a trial (modified methods). For some farms, the control field had fall

planted cover crops following corn harvest. For other farms, the control field was not cover cropped using any method. Soil health samples were taken in the spring and sent to Cornell Soil Health Lab for analysis. In 2020 and 2021, cover crops, weed biomass, and corn yields were monitored for each farm's control and trial field. In the third and final year of the project (2023), it was left to the farmers to implement modifications at their own cost as they work toward adaptation of modified cropping practices.

Results

Across years and between years, there was no statistical difference among the control and trial project fields' soil health scores. Average cover crop and weed biomass on the trial field was higher in 2020 than 2021. This may have been more favorable weather conditions contributing to higher plant growth. Normalized difference vegetation index (NDVI), a measure of green ground cover, data was collected in the fall. In 2020, NDVI was significantly higher in the trial fields than the control fields. In 2021, there was no statistical difference. In 2020, corn yields were significantly higher in the Control fields than the Trial fields. This may be due to a difference in corn populations or variety. In 2021, there was no significant difference in corn yield. This may have been due to overall poor weather conditions limiting growth, difference in corn variety, or corn populations. As soil health scores were in the high or very high functioning range, the limiting factor for cover crop growth or corn yield success was not overall soil health.

Recommendations

The goal of this project was to modify practices, corn variety, populations, and herbicide program for improved cover crop establishment without harming yields. In many cases, the weather had the greatest impact on the cover crop establishment and corn yield.

Herbicide management is essential to success. If herbicides are custom applied the farmer needs to communicate what fields will have cover crops interseeded and appropriate low-residual herbicides need to be selected. Additional considerations and adjustments to the herbicide program should be made when interseeding cover crops in to corn following sod.

In Vermont, cover crop mixtures helped to provide diversity each season. However, more importantly some cover crop species were more successful in certain years, soil types, and conditions than others. Having a mixture can help to hedge risk from year to year and field to field. Overall, a mixture that contains both winter terminated and over wintering species help provide both fall and spring soil cover.

Some differences in cover crop establishment and corn yield may have been driven by field conditions, corn variety, or a combination. In the future, to better compare field practices and their impact on cover crop establishment and corn yield, the corn variety should be kept constant. However, ultimately the goal of this project was to compare farmer practices with a new combinations of field practices chosen for their potential for improving cover crop stand success. Regardless, successful interseeding should not compromise corn yields. Hence, cover crop and corn variety selection may need to be tailored to specific soil types and environments to increase cover crop establishment success and crop yields.

Project Goals and Objectives

Objectives

1. Work with farmers to compare their typical practices with modified corn/cover cropping strategies.
2. Determine the impact of modifications on weed control and cover crop establishment.
3. Determine effect of field management modifications on silage corn yield

Task 1. Identify and secure project participants. This project worked with 30 farmers across Vermont to document the current corn silage system they were using and then made necessary changes to the system to improve the potential for robust establishment of cover crops (Figure 1).

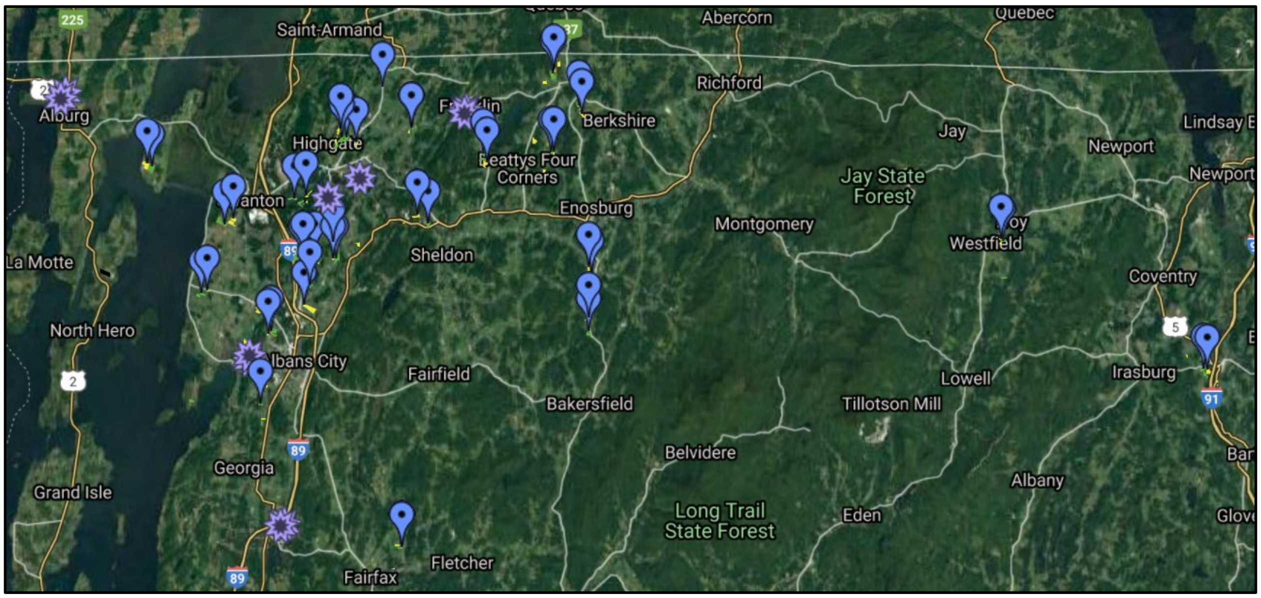

Figure 1. Map of participating farms.

Task 2. Gather baseline field characteristics and management data. UVM Extension staff met with farmers and designed a survey to collect field management data. Stafff developed a database system which documented baseline information on the current corn-cover crop management system and soil type.

Task 3. Acquire weather stations, portable scales, and seeding implements. Weather stations were placed at each farm and detailed weather data was kept to help explain variations in results between farms. UVM Extension purchased a portable scale system to help producers accurately measure yields. In order to plant cover crops successfully at participating farms, two new implements were required. UVM acquired one six-row crop conservation planter and a third six-row interseeder to facilitate the interseeding of the cover crops. See Project Methods for a complete description.

Task 4. Identify corn varieties that meet cover crop growing needs. UVM Extension compiled a list of corn varieties which meet our criteria and list of herbicides that were used to prepare the selected fields for cover cropping. This was done with extensive consultation with academic researchers and private sector service providers.

Task 5. Meet with farmers to plan implementation. UVM Extension staff held planning meetings with producers and developed planting plans and contingency plans regarding corn varieties and planting details. UVM helped farmers with the planting of their corn to ensure project objectives were met. A cover crop plan was developed for each farm meeting the goals of the farm. UVM Extension staff worked closely with farmers to make sure equipment and seed were utilized at the correct time to maximize cover crop establishment opportunities. When feasible cover crop timing was correlated to pending moisture events and field operation dates were recorded.

Task 6. Develop field specific herbicide programs. UVM Extension worked with herbicide applicators and farmers to ensure that weed issues in fields were adequately addressed while making sure herbicide residuals that could damage the interseeded cover crop were avoided. In some instances, there were other opportunities to manage weed pressure such as flame weeding.

Task 7. Collect soil health data. Baseline, first-year, and final soil health metrics were collected using standards outlined in NRCS's Soil Health and Technical Notes No. 450-03 (May 2019). Each year during the On-Farm Trials, soil samples at V-4 to V-6 corn growth stages were taken to measure soil moisture and plant available nitrogen. See project methods for a complete methods description. NRCS RUSLE2 tools were used to assess the potential reduction in erosion difference between cover crop and not cover crop practices on soils typical of the area.

Task 8. Collect corn and cover crop data. UVM Extension staff collected crop and cover crop data on the trial and control fields throughout the growing season. Changes were documented with on-the-ground pictures and normalized difference vegetation index (NDVI). Fields were monitored for weed emergence. Observations on pest damage and disease pressure were recorded at V4 flowering, and harvest. Canopeo was used post-harvest in the fall before the first hard frost and pre-termination in the spring to document percent canopy cover of the cover crop. In the fall of 2020-2022, Normalized Difference Vegetation Index (NDVI) data was used to determine the percentage of the entire field covered with cover crop. Before first killing frost, aboveground cover crop biomass was collected from each Trial field and analyzed for C:N ratios by University of Vermont (UVM) Agricultural and Environmental Testing Laboratory (AETL). Interseeded cover crop was often not winter hardy so there were not cover crop biomass samples to collect in the spring. Corn yield and quality were measured yearly to determine the impact of cropping method on crop yields. See Project Methods for a complete methods description.

Task 9. Analyze and report findings. UVM Extension staff compiled the data and provided farm and project summary data back to each participating farm at the end of each growing season. The NRCS Cover Crop Economic Calculator was populated for cover crop and no cover crop scenarios. UVM hosted farmer meetings with all the participants to discuss findings and strategize modifications if needed. This was a critical part of the process because all conservation practices need farmer buy-in and keeping them involved in the process is critical to achieving and increasing adoption rates. UVM Extension hosted two field days with this project as the focus each year of the project. This provided an opportunity for other farmers to learn about the methods used in this project and the results.

Project Background

As fuel, grain, and herd sizes increase, more acres of annual row crops (corn silage, grain, and soybeans) are being grown to meet farm feed needs. Although the integration of row crops into cropping systems has increased productivity and efficiency, lack of rotation out of annual crops has led to a number of potentially detrimental economic and environmental consequences, including increased use of pesticides, increased cost of production, decreased yields, rapid erosion of topsoil, and reduced soil health. Extensive research has found that cover cropping increases the overall health of agricultural systems by scavenging excess nutrients, increasing water infiltration, reducing surface runoff, reducing compaction, building soil tilth, increasing biodiversity, and building organic matter. Furthermore, cover cropping can help enhance the benefits of other farming practices, such as no-till planting, creating synergies that increase farm financial and environmental sustainability. Cover cropping therefore, when implemented effectively, creates a more resilient agricultural system that is able to produce consistent yields across more diverse weather patterns while reducing environmental impacts. This function is especially crucial given today's often erratic climate. The Northeastern U.S. region continues to experience more drastic weather conditions, especially heavier rainfall events (Figure 2). Cover cropping therefore provides farmers with an essential tool for protecting and increasing soil health, the key to our future financial and environmental sustainability.

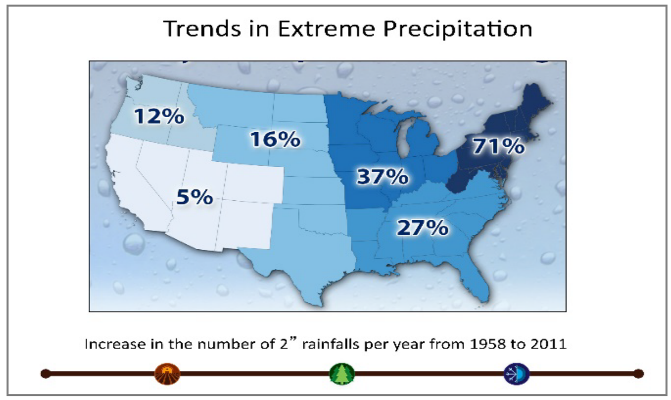

Figure 2. Trends in extreme precipitation

Over the past decade adoption of cover cropping has substantially increased throughout North America. In Vermont there has been a concerted effort by NRCS, the Vermont Agency of Agriculture, UVM Extension, and the farmers themselves, to integrate cover crops into their cropping systems. According to NRCS data, Vermont farmers planted a record-setting 25,727 acres of cover crops on more than 2,000 fields in 2016. This equates to 25% of all annual cropland in Vermont. This is a 58% increase in the acres with winter cover crops compared to 2015. Although this increase is substantial, it has become apparent that proper establishment of cover crops continues to be particularly challenging in our region for the following reasons. Vermont's

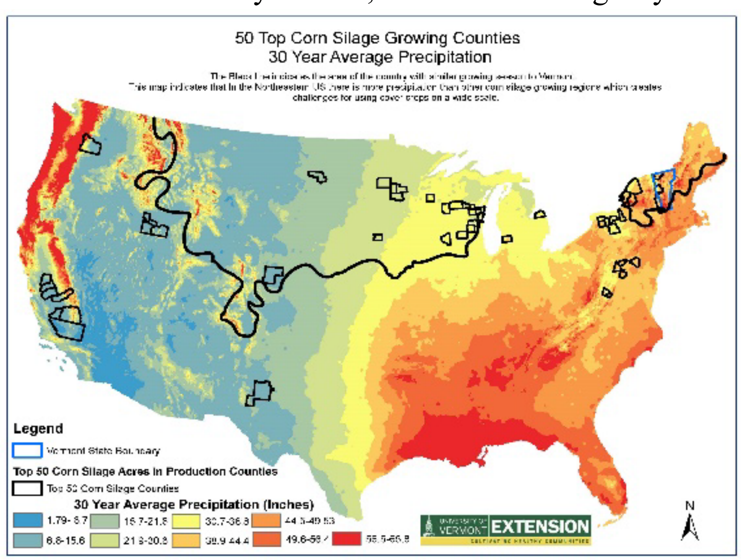

Figure 3. Corn silage production versus precipitation.

agricultural landscape predominantly consists of dairy operations which rely heavily on the production of corn silage. Silage corn varieties typically require 2200-2800 growing degree units (GDUs) to reach maturity. In northern climates, the total GDUs accumulated across the entire growing season is typically between 1800 and 2800 depending on location. This leaves very little time to adequately establish cover crops following corn harvest. If cover crops are not effectively established, the soil may only be protected from degradation by the minimal residue left after corn silage harvest which typically covers 10% or less of the soil surface. Furthermore, during this time, this region also often experiences high rainfall, further complicating farmers' abilities to access fields to plant cover crops in a timely manner (Figure 3).

Interseeding is a relatively new practice, which involves the sowing of cover crop seed in with the cash crop to achieve early establishment and better long-term results. There are several interseeding methods that can be used, each with its own challenges and advantages. These methods include aerial application, highboy application, broadcast application (with fertilizer spreader), and drilling with interseeders such as the Interseeder Technologies interseeder or a Dawn Interseeder.

Through numerous research and outreach projects over the last five years, including a Natural Resource Conservation Service Conservation Innovation Grant (NRCS CIG) (#69-3A75-14-273), UVM Extension has evaluated all these methods extensively on thousands of acres of row crops across Vermont. Through this work we have determined that interseeding can be an effective tool for farmers to establish successful cover crops that protect our soils from degradation, our waterways from nutrient and sediment pollution, and support farm productivity and economics. However, we have also identified several key factors which lead to successful establishment of interseeded cover crops including herbicide program selection, crop varietal selection, and planting conditions and timing. With a better understanding of these factors, their impacts on cover crop establishment, and their relationships with one another, we can better educate and assist farmers in addressing these barriers on their farms to increase cover crop adoption, cover crop establishment success, and ultimately environmental and economic impacts.

Project Methods

Task 1. Identify and secure project participants. Before project funding, Extension staff had already identified 30 farmers interested in participating in this project. In the winter of 2020, UVM capitalized on these existing relationships and worked with partners to secure fields from farmers willing to participate in the program. Participation was targeted and prioritized for farms located in critical source areas.

Task 2. Gather baseline field characteristics and management data. UVM Extension staff met with farmers and developed a database system which documented baseline information on the current corn-cover crop management system. This documentation included information about field attributes like soil type, erosion factors, and other characteristics as well as field management decisions like tillage practices, planting equipment setups, fertilization schedules and amounts, herbicide programs, harvest data including dates and historical yield data, and current cover cropping strategies. Every farm had at least one control field which did not have modified management practices. For some farms, the control field had fall planted cover crops. For other farms, the control field was not cover cropped using any method.

Task 3. Acquire weather stations, portable scales, and seeding implements. Weather stations were placed at each farm and detailed weather data was kept to help explain variations in results between farms. UVM Extension purchased a portable scale system to help producers accurately measure yields.

To plant cover crops successfully at participating farms, two new implements were required. UVM acquired one six-row crop conservation planter and a third six-row interseeder to facilitate the interseeding of the cover crops. The planter was used to assist farmers that currently use four or eight row planters or do not have planters with seed plates.

This innovative cover crop interseeding method begins with the corn planter. To create space for sunlight to penetrate through the corn canopy through the growing season, the corn planter planting wheel was modified by blocking or otherwise plugging four of the seed spaces (Image 1) This creates areas or skips in the rows where a corn seed is not planted. Cover crops are interseed when the corn is between growth stages V2-V3 (Image 2). The skip rows create space in the field for a corn crop 'window' where sunlight can reach the cover crop throughout the season (Figure 4). The in-row skip method cannot be done with finger pickup seed meters. It is critical that the planting pattern match the interseeding pattern or corn yields will suffer due to damaged crops in the non-matching rows (the interseeder will knock down corn if planter and interseed do not have the same rows). Farmers that had plate seeders were provided a set of modified seed plates which created the row spacing needed for this project. Each planter was fitted with these modified plates.

Image 1. Seed spaces blocked on wheel to plant corn with 'skip rows.'

Image 2. Interseeding cover crop with Dawn Duoseeder.

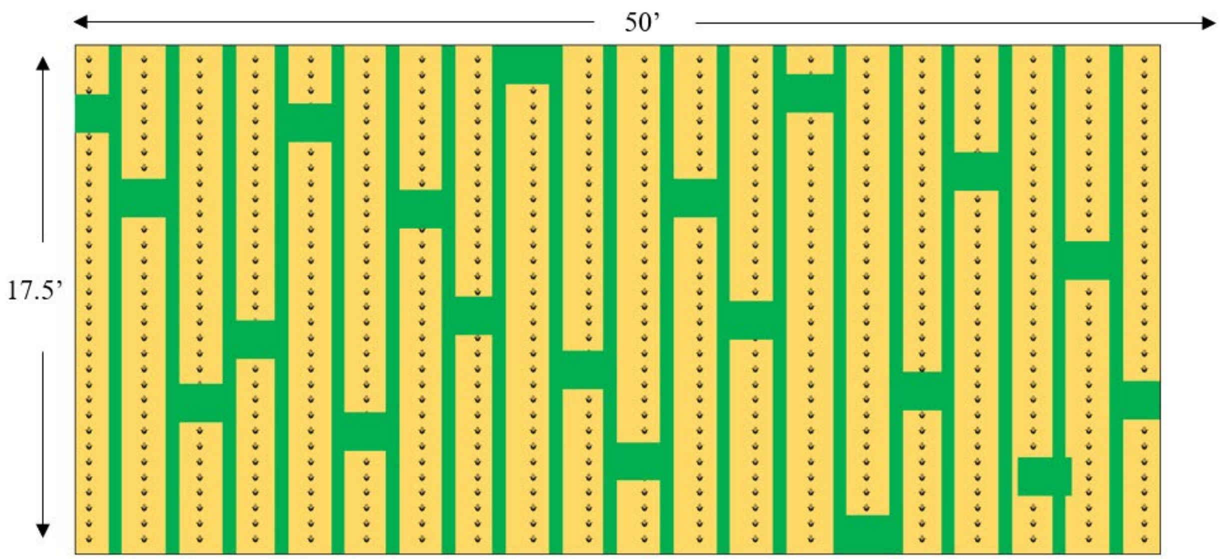

Figure 4. Diagram of 'skip rows.'

Task 4. Identify corn varieties that meet cover crop growing needs. UVM Extension compiled a list of corn varieties which met our criteria and list of herbicides that were used to prepare the selected fields for cover cropping. This was done with extensive consultation with academic researchers and private sector service providers.

Task 5. Meet with farmers to plan implementation. UVM Extension staff held planning meetings with producers and developed planting plans and contingency plans regarding corn varieties and planting details. UVM helped farmers with the planting of their corn to ensure project objectives were met. A cover crop plan was developed for each farm meeting the goals of the farm. UVM Extension staff worked closely with farmers to make sure equipment and seed were utilized at the correct time to maximize cover crop establishment opportunities. When feasible, cover crop timing was correlated to pending moisture events and field operation dates were recorded.

Task 6. Develop field specific herbicide programs. UVM Extension worked with herbicide applicators and the farmers to ensure that weed issues in fields are adequately addressed while making sure herbicide residuals that could damage the interseeded cover crop were avoided. In some instances, there were other opportunities to manage weed pressure such as flame weeding.

Task 7. Collect soil health data. Soil health samples were taken in the spring of 2020, 2021, and 2022. Samples were collected using methodology from the Comprehensive Assessment of Soil Health – The Cornell Framework[1]. NRCS's Soil Health and Technical Notes No. 450-03 (May 2019)[2] methodology were used at Cornell's Soil Health Laboratory for soil health analysis. Soil organic matter dynamics were measured by analyzing soil samples for soil organic matter using loss on ignition. To measure potential food sources for soil biological life, active carbon was assessed with permanganate oxidizable carbon. Bioavailable nitrogen as proteins were measured with autoclaved citrate extractable (ACE) protein index. Presence of biological life was measured with soil CO_2 respiration. Soil structural stability was measured with the Cornell sprinkle infiltrometer. General nutrients were measured with a routine soil test using Modified Morgan's solution. Samples were gently mixed in a bucket, placed in Ziploc bags, and stored on ice or in a refrigerator until packaged for shipping to the Cornell Soil Health Laboratory.

Soil samples for Presidedress Nitrate tests (PSNT) were taken in mid-July at V-4 to V-6 corn growth stages. PSNT soil samples were taken from 15 random locations to a depth of 12" in each field. Samples were gently mixed in a bucket, placed in Ziploc bags, and stored on ice during transportation to the AETL. The AETL follows standard protocols to process the soil sample for analysis with a Lachat QuickChem 8500 Flow Injection Analyzer. The NRCS Cover Crop Economic Calculator was populated for cover crop and no cover crop scenarios.

Task 8. Collect corn and cover crop data. UVM Extension staff collected crop and cover crop data on the trial and control fields throughout the growing season. Changes were documented with written observations, on-the-ground pictures, and NDVI data.

Twice during the growing season, percent ground covered by cover crops and weeds was counted using a modified version of the NRCS line transect method, also known as the beaded-string method.[3] In the spring before cover crop termination, cover crops and weeds were counted where they crossed the six-inch marks on a 30-foot string. This process was repeated 10 times. In mid-summer after cover crop germination and before corn canopy closure, cover crops and weeds were counted where they crossed the one-inch marks on a 25 inch string. A shorter string was used after

[1] Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, K.S.M Kurtz, D.W. Wolfe, and G.S. Abawi, 2016. Comprehensive Assessment of Soil Health – The Cornell Framework, Edition 3.2, Cornell University, Geneva, NY.
[2] Stott, D.E. 2019. Recommended Soil Health Indicators and Associated Laboratory Procedures. Soil Health Technical Note No. 450-03. U.S. Department of Agriculture, Natural Resources Conservation Service.
[3] NRCS. National Agronomy Manual (190-V-NAM, Second Ed., March 1988).

corn establishment to capture the cover within the 30-inch corn rows. This process was repeated randomly throughout the field 10 times.

Observations on pest damage and disease pressure were recorded at V4, flowering, and harvest. using protocols developed by the Certified Crop Advisor methodology.

Percent cover with Canopeo was taken in the spring before cover crop termination, mid-summer after cover crop emergence, and in the fall before the first hard frost. Canopeo is a phone application that uses a picture to analyze the green pixels of a picture to generate percent cover of ground cover by plants. Ten pictures were randomly taken through the field at each time point. Canopeo methodology and application can be found here: https://canopeoapp.com/

In the fall of 2020-2022, Normalized Difference Vegetation Index (NDVI) data was used to determine the percentage of the entire field covered with cover crop. The NDVI data was acquired from the website: https://wp.agromonitoring.com/. The data was collected using Landsat 8 or Sentinel-2 satellite platforms with 10-meter resolution.

Before first killing frost, 10 samples of aboveground biomass within a 0.25 m^2 quadrat were collected from each Trial field. The biomass was separated by cover crop and weeds. Then dried at 105° F until a stable weight was reached which was used to determine dry matter biomass and C:N ratios by UVM AETL.

Corn yield and quality were measured yearly to determine impact of cropping method on crop yields. Corn was harvested using equipment available to each farm and yield was measured by counting loads and an average weight of each load was calculated using measurements from portable truck scales. A subsample (about 500 grams) was collected then dried at 105° F until a stable weight was reached which was used to determine dry matter and quality. Corn quality was measured by UVM E. E. Cummings Crop Testing Laboratory using standard protocols for near-infrared analysis based on Dairy-One calibrations. The Laboratory uses standardized and widely accepted methods from Association of Official Analytical Chemists International, scientific journals, manufacturer's proprietary procedures, and major universities. The Dairy One Forage Laboratory employs a four-part QC and QA program to ensure the integrity of analyzed results. A list of analytical methods with corresponding references can be found on their web site at https://dairyone.com/services/forage-laboratoryservices/analytical-service-packages/.

Task 9. Analyze and report findings. UVM Extension staff compiled the data and provided farm and project summary data to each participating farm at the end of each growing season. The NRCS Cover Crop Economic Calculator was populated for typical cover cropping scenarios (no cover crop, fall planted cover crop, and interseeded cover crop). UVM hosted a farmer meeting with all the participants to discuss findings and strategize modifications if needed. This was a critical part of the process because all conservation practices need farmer buy-in and keeping them involved in the process is critical to achieving and increasing adoption rates. UVM Extension hosted two field days with this project as the focus each year of the project. This provided an opportunity for other farmers to learn about the methods used in this project and the results.

Project Results

In 2019, the project began with 30 active participating farms. By the end of the project, there were 24 participating farms. The reduction in participation reflects farms going out of business or otherwise consolidating. The following selected results reflect the farms that planted corn silage (i.e., not snaplage or grain corn).

Soil Health

Soil health samples were collected from Trial and Control fields before project initiation for a baseline measurement. Soil samples were collected in 2021 and 2022 before corn planting to assess the impact of cover crop management on soil health and submitted to Cornell's Comprehensive Assessment of Soil Health for analysis (Figure 5). Across years and between years, there was no statistical difference among the Control and Trial project fields' soil health scores. Average soil health scores were in the high category (60-80% soil health score) or very high soil health category (>80% soil health score) indicating that, on average, field operations on project fields were conducive to building or maintaining good soil health.

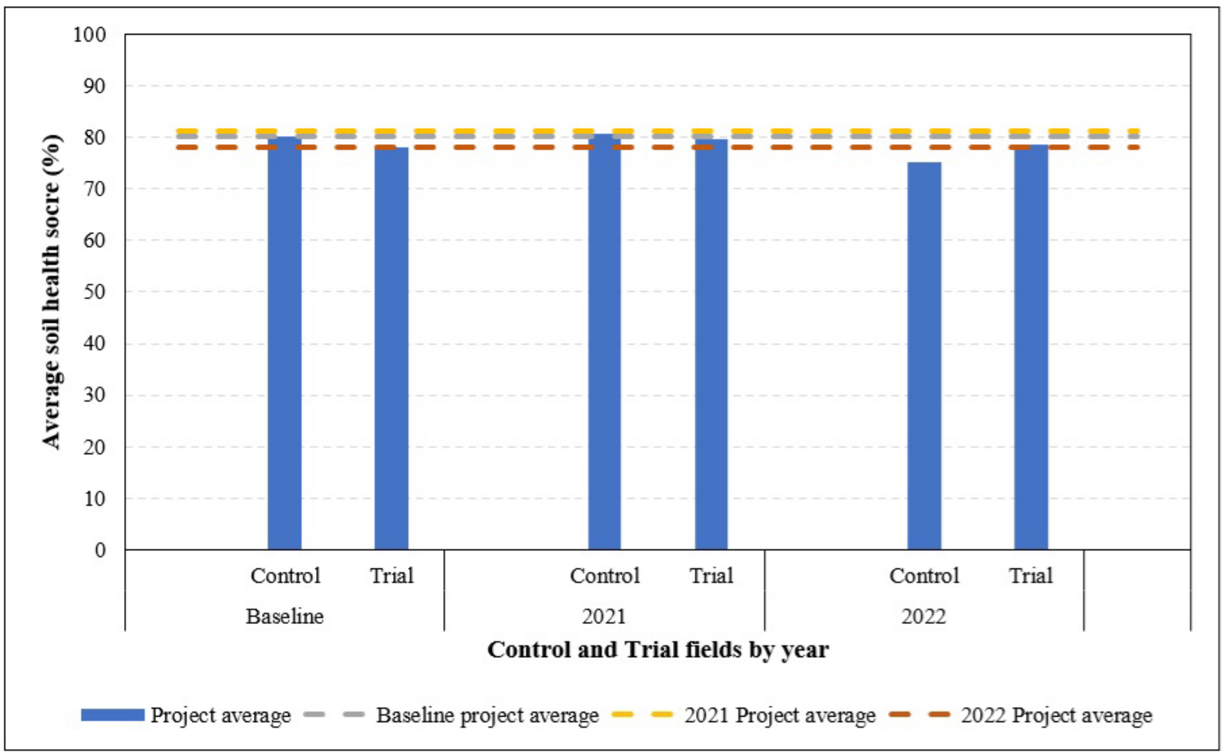

Figure 5. Average project annual soil health scores for Control and Trial fields, 2020-2022.

Pre-Sidedress Nitrate Tests (PSNT)

Soil samples were collected from both the Trial and Control fields to evaluate nitrate concentrations in late June in both years and submitted to UVM's AETL for analysis. Across all the farms in the project in 2020 and 2021, there were no differences in PSNT results among the project Trial and Control fields (Figure 6). All 2020 PSNT sample results and 75% of 2021 PSNT sample results were above the nitrogen recommendation threshold (25 ppm), meaning that no additional nitrogen fertility was needed to meet the farm yield goals. Dry conditions in both years during the growing season resulted in low levels of nitrogen loss from the production system likely yielding ample nitrate for the corn crop.

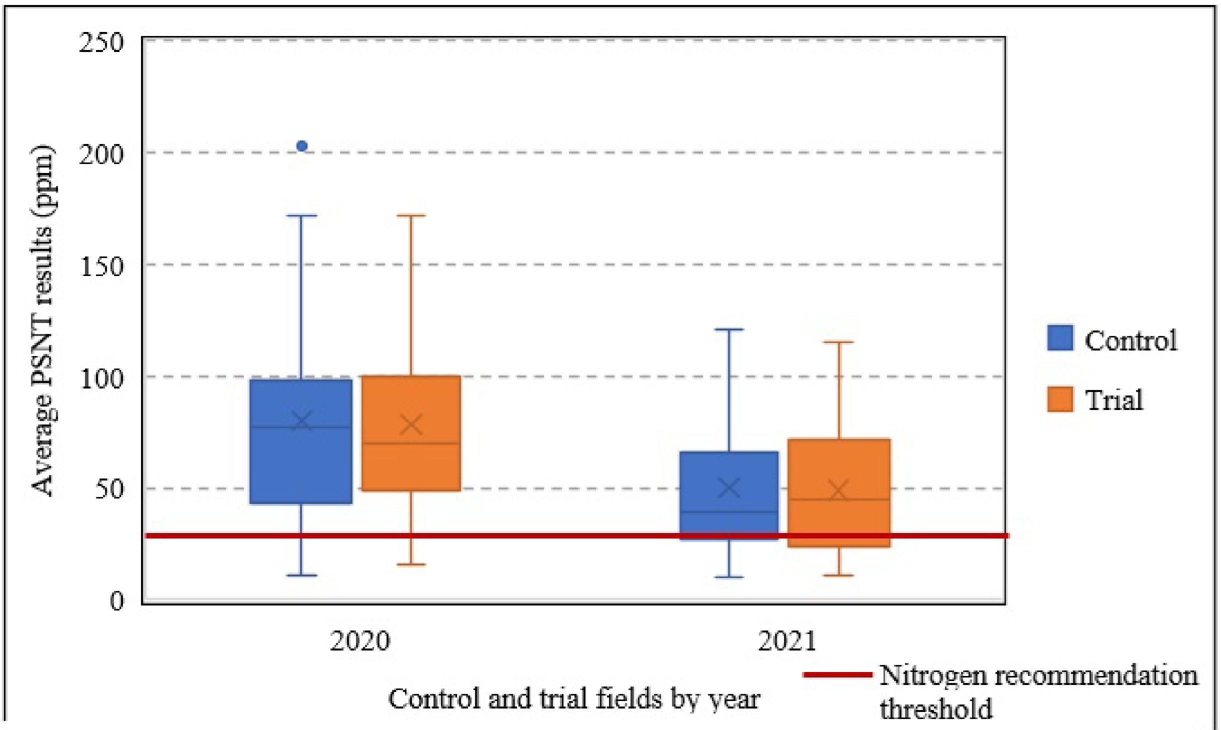

Figure 6. Average annual PSNT results for Control and Trial fields and nitrogen recommendation threshold, 2020 and 2021.

2020 Results

Cover Crop Assessment

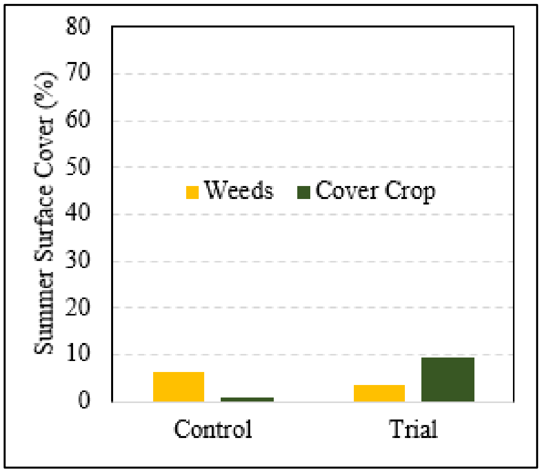

Figure 7. Average summer surface cover for Control (n=22) and Trial (n=22) fields, 2020.

Summer Percent Surface Cover

Average surface cover by weeds was 2.8% higher in the Control (6.3%) than the Trial (3.5%) fields (Figure 7). The average cover crop surface cover was 2.7X that of weeds in the Trial fields. In the two Trial fields that were in their first year of hay rotated from sod, modifications to herbicide program were successful with greater than 10% weed surface cover. There were three Control fields that were interseeded hence providing some level of cover during the season. Only in one Trial field did cover crops not establish. In six Control fields and seven Trial fields, surface cover by weeds was 0%. In five Trial fields, weed surface cover exceeded cover crop biomass.

Fall Percent Surface Cover and Biomass

Fall percent surface cover and biomass were highly variable (Figure 8). Median percent surface cover was 36.5%. Percent cover was taken between 22-Oct and 27-Oct and, depending on the farm, varied between 16.5% to 63.6%. The cover crop biomass median was 1,243 lbs of dry matter (DM) acre^{-1}. However, there was a wide range of growth observed across all the fields ranging from 386 to 5,486 lbs acre^{-1} DM.

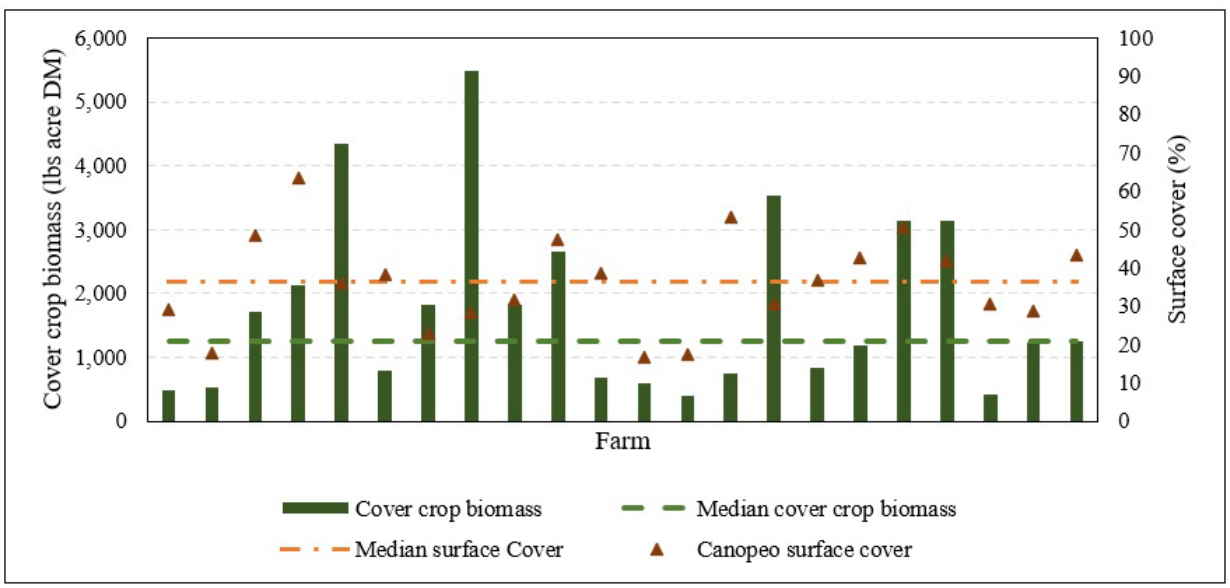

Figure 8. Average fall cover crop biomass composition in Trial fields (n=22), 2020.

Fall Trial Cover Crop Biomass

When averaged across all Trial fields, the dominant cover crop was radish (88%), with some ryegrass (12%) and no clover or weeds (Figure 9).

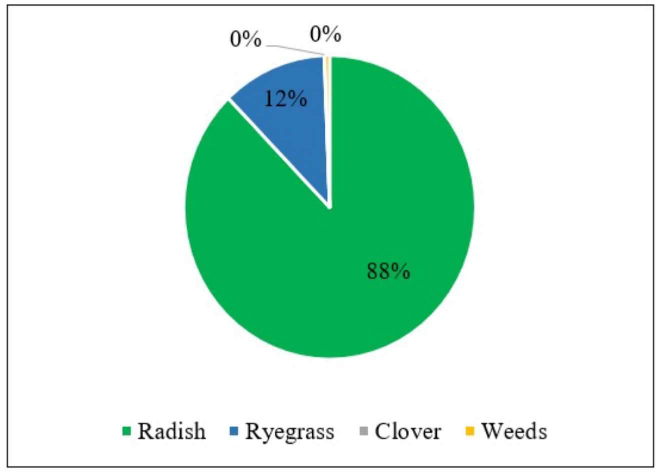

Figure 9. Average fall cover crop biomass composition in Trial fields (n=22), 2020.

Corn Yield Assessment

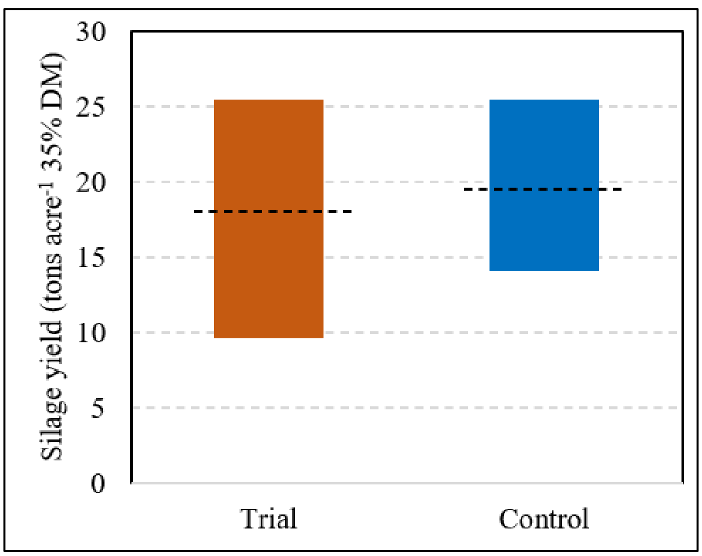

Figure 10. Average corn silage yields for Control (n=22) and Trial (n=22) fields, 2020.

<u>Corn Silage Yields</u>

Average corn silage yields were 2.2 tons acre^{-1} higher in the Control fields than the Trial fields (Figure 10). Although, this is negligible, there was a lot more yield variability in the Trial fields than the Control fields. Some yield differences may be due to different varieties or seeding rates. The lowest yield (9.6 tons acre^{-1}) suffered from poor weed control and poor field conditions.

2021 Results

Cover Crop Assessment

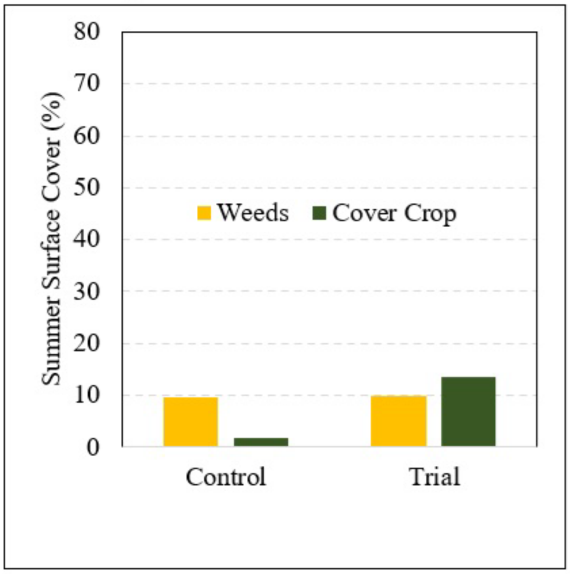

Figure 11. Average summer surface cover for Control (n=28) and Trial (n=28) fields, 2021.

Summer Percent Surface Cover

Average surface cover by weeds was 0.3% higher in the Trial (10.0%) than the Control (9.7%) fields (Figure 11). Average cover crop surface cover was 1.3X that of weeds in the Trial fields. Five of the seven weediest fields were Control fields. Two farms had both their Trial and Control fields in the six top weediest fields. In four Control fields and two Trial fields, surface cover by weeds was 0%. There were three Control fields that were interseeded hence providing some level of cover during the season. One of the interseeded Control fields had half surface cover by weeds and half surface cover by cover crops (16.0%). The other two interseeded Control fields had low surface cover by weeds (0.8% and 1.2%).

In two Trial fields, cover crops had not yet established and in one of these fields there was no surface cover by weeds indicating that the herbicide program was aggressive. An additional seven Trial fields had less than 5% surface cover by cover crops. In twelve Trial fields, weed surface cover exceeded cover crop biomass.

Fall Percent Surface Cover and Biomass

Fall percent surface cover and biomass were highly variable from field to field (Figure 12). The median percentage of surface cover provided by the cover crop was 26.8%. Percent cover was taken between 27-Oct and 9-Nov and, depending on the farm, varied between 1.76% to 74.3%. The cover crop biomass median was 700 lbs of dry matter (DM) acre^{-1}. However, there was a wide range of growth observed across all the fields ranging from 19.1 to 3,186 lbs acre^{-1} DM.

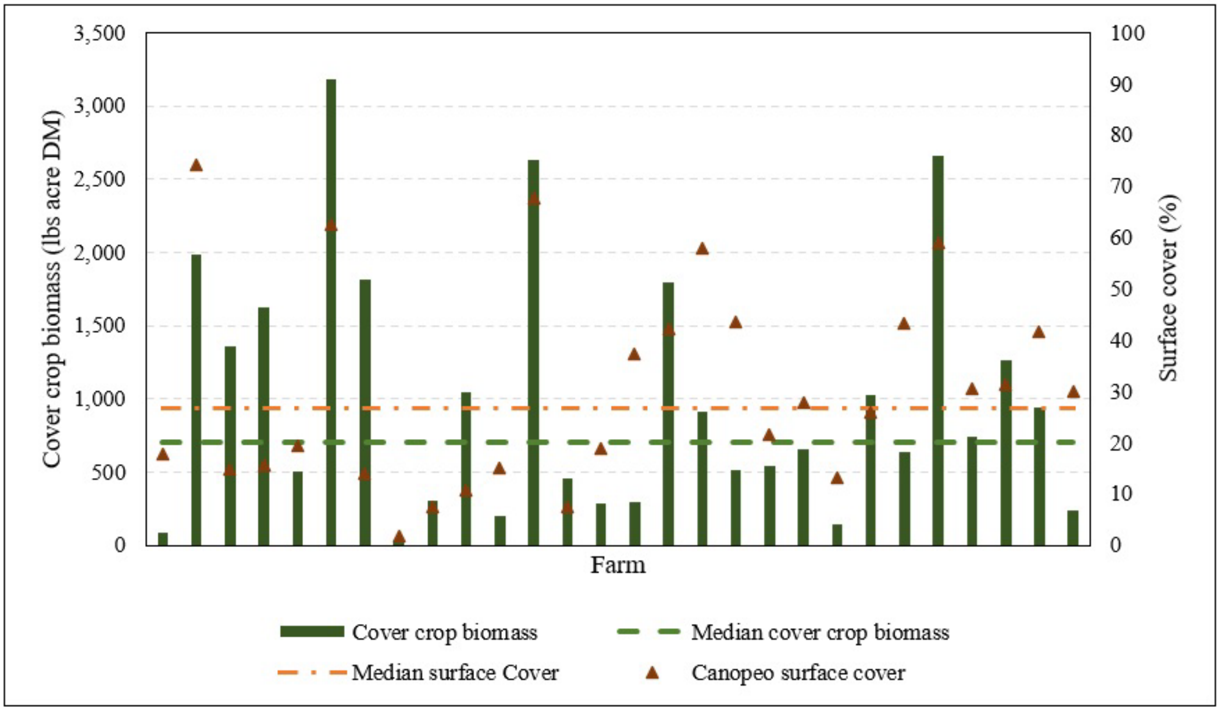

Figure 12. Average fall cover crop biomass composition in Trial fields (n=22), 2021.

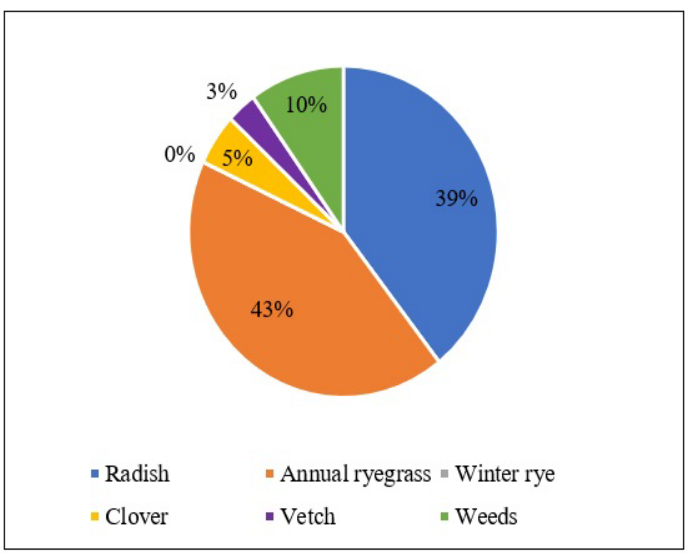

Figure 13. Average fall cover crop biomass composition in Trial fields (n=28), 2021.

Fall Trial Cover Crop Biomass

When averaged across all Trial fields, the dominant cover crops were annual ryegrass (43%) and radish (39%) with some clover (5%) and vetch (3%) (Figure 13). The average weed biomass was 10%. Winter rye did not establish in any of the fields. Winter hardy cover crops were planted post-harvest on 18 Control fields.

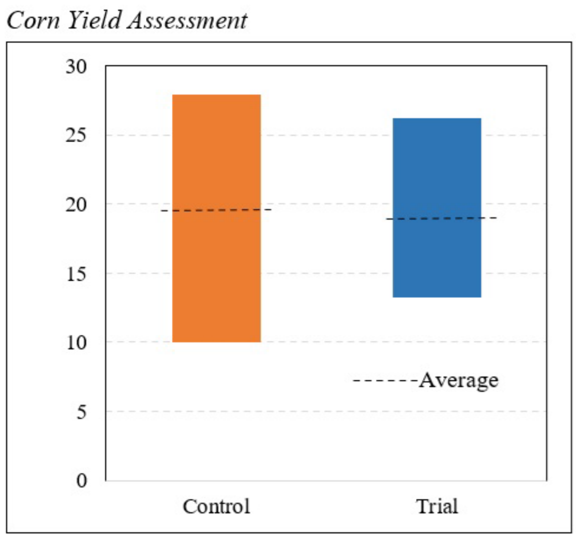

Figure 14. Average corn silage yields for Control (n=25) and Trial (n=24) fields, 2021.

Average corn silage yields were 0.8 tons acre^{-1} higher in the Control fields than the Trial fields (Figure 14). Some yield differences may be due to different varieties or seeding rates. The lowest yield (10.0 tons acre^{-1}) suffered from poor field conditions.

RUSLEII Rotation Analysis

We ran RUSLEII analysis on typical soil types to look at the reduction of erosion risk between cover cropped and non-cover cropped fields for the average of the first four years in corn after hay (Table 1). On loamy fine sand soil (e.g., Enosburg) and fine sandy loam (e.g., Copake) cover crops reduced potential soil loss by 46% i.e. potential erosion was 1.8x higher without cover crops than with. On clay soil (e.g., Kingsbury) cover crops reduced potential soil loss by 30% i.e. potential erosion was 1.4x higher without cover crops than with.

Soil Type	**Loamy fine sand**			**Fine sandy loam**			**Clay**		
Cover Crop (CC)	**None**	**%**	**CC**	**None**	**%**	**CC**	**None**	**%**	**CC**
Average 4-year RUSLEII tons/acre/year of soil loss	1.48		0.80	2.53		1.78	2.65		1.43
Difference between cover crop and no cover crop		46%			30%			46%	
Amount potential erosion was higher in no cover crop than cover crop	1.8X			1.4X			1.8X		

Table 1. RUSLEII results for typical soil types with and without cover crops.

NRCS Cover Crop Economic Calculator

Using the NRCS Cover Crop Economic Calculator (CCEC), we ran typical cover crop scenarios. The interseeded cover crop scenario represents the trial scenario with modified corn practices. The fall cover crop and no cover crop represent the control scenarios with typical farmer management. For long term analysis constants of 25-year lifespan, 2% discount rate, 3% current soil organic matter (SOM), and 7% estimated of maximum potential SOM. For both cover crop scenarios, the estimated number of years of management change to increase SOM by 1% was 10 and for the no cover crop scenario, the estimated number of years of management change to increase SOM by 1% was 50. Because there was relatively little difference among the project trial and control yield averages within years, baseline yields were kept constant (Table 2).

Overall, for both short term and long-term analysis, the greatest economic loss is fall cover crops, followed by interseed cover crops with the least loss in the no cover crop scenario. The biggest driver of economic loss is cover crop cost. Government cost-share programs often off-set this cost. The greatest benefit was with the interseeded cover crop scenario as this scenario includes input reduction (herbicide, fungicide, and insecticide), erosion reduction, and water storage. The fall cover crop scenario had a slightly higher erosion benefit as it typically has longer living cover but did not have input reduction and had the same water storage benefit. In the no cover crop scenario, there were economic losses because the benefits of cover crops were not realized (no input reduction, erosion reduction, or water storage). However, because there were no cover crop expenses, it appears to be economically neutral in the long-term. One caveat not captured in these scenarios is the public relations benefit that cover crops can entail. One farmer quantified this at $10 per acre.

Cover crop	Scenario	Interseeded	Fall cover crop	No cover crop
Rotation info	Baseline yield (ton acre^{-1})	20	20	20
	Crop value ($ ton^{-1})	$40	$40	$40
Cost summary	Cover crop cost ($ acre^{-1})	-$72.50	-$70.00	$0.00
Benefits summary	Input reduction ($ acre^{-1})	+$11.25	$0.00	-$12.50
	Erosion reduction ($ acre^{-1})	+$20.50	+$25.00	-$15.00
Short term analysis	Total cost ($ acre^{-1})	-$72.50	-$70.00	$0.00
	Total benefit ($ acre^{-1})	+$31.75	+$25.00	-$27.50
	Net benefit ($ acre^{-1})	-$40.75	-$44.50	-$27.50
Long term benefit analysis	Water storage ($ acre^{-1} year^{-1})	+$8.43	+$8.43	$0.00
	Net benefit ($ acre^{-1} year^{-1})	-$32.32	-$36.07	$0.00

Table 2. NRCS Cover Crop Economic Calculator typical cover cropping scenario results.

Discussion

Average baseline, 2020, and 2021 soil health scores were high functioning or better in the Trial and Control fields. The high ratings indicate that on average, farmers are managing their fields to maintain good soil health. Soil health metrics like predicted water capacity, aggregate stability, organic matter, ACE soil protein index, and active carbon were all high functioning or better. However, soil health metrics like soil respiration could be improved with additions of organic matter through manure or cover crops and/or rotation with sod. Sub-optimal soil hardness may be the result of taking penetrometer measurements in dry ground. However, targeted tillage or planting of strategic cover crop varieties may alleviate compaction. It is possible that there may have been too little time passing between the sampling dates for measurable accumulated changes.

Across all project farms and fields, median cover crop biomass was higher in 2020 (1,243 lbs $acre^{-1}$) than in 2021 (700 lbs $acre^{-1}$). This may be a result of planting different cover crop mixes. However, in both years cover crop biomass was highly variable. In 2020 the field with the lowest biomass had 386 lbs $acre^{-1}$ and the field with the highest had 5,486. In 2021, the field with the lowest biomass had 19.1 lbs $acre^{-1}$ and the field with the highest had 3,186 lbs $acre^{-1}$. Weed cover at time of establishment had little effect on fall biomass, indicating that weed competition may not have been the sole cause of low cover crop biomass nor was soil health.

Across all the farms in the project, in 2020 and 2021, there were no differences in percentage of weeds among the project Trial and Control fields. However, across all farms and fields, percent weed surface cover was 5.63% in 2020 and slightly higher in 2021 with 9.87% percent weed cover. The difference in weed pressure between 2021 and 2020 could be the result of more favorable weather conditions in 2021 which resulted in better growing conditions for crops and weeds alike. In addition, there was on average, lower cover crop establishment in 2021. This may have resulted in less competition with weeds and hence less weed suppression.

In 2020, across all project fields, there was significant differences in NDVI among the Trial and Control fields. On average, the project Trial fields had 5.4% higher NDVI than the project Control fields. In 2022, across all farms and fields there were no differences in NDVI among project Trial and Control fields. This may have been the result of more fall cover cropped control fields in 2022.

Corn yield data is difficult to assess because of variability in variety, seeding rate, and management practices. In 2020, across all farms, on average the project Control fields produced 2.16 tons/acre more than the Trial fields. However, in 2021, across all farms, the difference between project Control and Trial fields was negligible (0.79 tons/acre). This may be due to overall poor weather conditions limiting growth or corn variety. Overall, 2021 was dryer and cooler than 2020.

Given the variability in cover crop establishment and corn crop yields, weather may have been the driving force in success. Poor weather at the beginning of the growing season and through the summer may have impacted corn yields. Weather and field conditions in the middle of the summer could have impacted cover crop establishment.

Regardless, RUSLEII results show that planting cover crops has a higher potential to reduce erosion loss and subsequent nutrient loading to water ways across typical Vermont soils. This is a benefit that the community receives that is not necessarily captured in the NRCS CCEC.

Furthermore, in the CCEC, we did not assign ecosystem service values for carbon capture or potential reduced flooding with improved soil health. These are benefits the community receives and the farmer is not directly paid for. There is an economic advantage to not planting cover crops, even when benefits from cover crops are subtracted as potential costs. When considering benefits of planting cover crops, the cost of planting far outweighs the potential economic return to the farm as cover crop benefits. The NRCS CCEC clearly illustrates the need for cover crop cost share.

Conclusions

- Overall, there was good participation from collaborating farmers and interseeding on most fields was successful if best practice was followed.

- Soil health scores for low cover crop biomass fields were in the high to very high performing range. This indicates that soil health was not a limiting factor for cover crop establishment and suggests that there is room for improvement in cover crop establishment planting methodology.

- RUSLEII results indicate that cover crops reduce erosion potential and subsequent nutrient loading on typical Vermont soil types.

- It is hard to quantify other cover crop benefits like improving public relations or increasing ecosystem services in the NRCS CCEC. However, results indicate that cost share programs have the potential to significantly decrease cover crop establishment costs.

- Weather had the greatest impact on interseeded cover crop establishment.

- The herbicide program used in the Trial fields could use some adjustment when interseeding cover crops in corn after sod.

- Results indicate that modifying corn production practices can lead to better establishment of cover crops and some fields may need more management modifications to provide more consistent establishment success.

- In the future, to better compare field practices and their impact on cover crop establishment and corn yield, the corn variety should be kept constant. However, ultimately the goal of this project was to compare farmer practices with a new combinations of field practices chosen for their potential for improving cover crop stand success.

Project Outputs

For each year of the project (2020, 2021, and 2022) participating farms received individual reports with a comparison of average project results and their farm-specific results (weather, soil health, percent weed cover, percent ground cover by Canopeo and NDVI, cover crop biomass by species, and corn yields). There is an example report in Appendix 1.

A Guide to Interseeding Cover Crops into Corn Systems in the Northeast was also created and shared with other technical service providers and farmers. The guide and other cover crop resources can be found at uvm.edu/extension/nwcrops. The guide can be found at:

*https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/Articles_and_Factsheets/Guide_to_interseeding_cover_crops_in_northern_New_England.pdf?_gl=1*9ntbu8*_gcl_au*MTc0OTUwODkwNS4xNzE4ODE3Njg3*_ga*MjA0NDY0NTU4My4xNjM1MjY1Njgz*_ga_G3S3K4BJ32*MTcxODgxOTc1OS4xMjEuMS4xNzE4ODE5NzY0LjU1LjAuOTExNjc5Mjc4&_ga=2.147921841.72327215.1718817687-2044645583.1635265683*

Project information was shared with 285 farmers at 3 field day events held in June, July, and September 2022. Farmers and stakeholders in attendance were able to see the research plots and see the data collected thus farm. Farmers were also able to see the interseeder operate. During 3 winter events in 2023, an additional 425 stakeholders learned of project results and were also provided applications to sign-up for interseeder use in 2023. Over 75 farms expressed interest and were provided with additional information on requirements for interseeding. During the spring and summer of 2023, the interseeder was used to implement over 1000 acres of cover crops on 18 new farms. In July of 2023, there were 185 attendees at the UVM Annual Crop and Soil Field Day where project results and interseeding was highlighted. A total of 895 stakeholders learned about new strategies to improve cover crop interseeding, 48 farmers were able to access new interseeding equipment, and over 3,000 acres were interseeded with new practices.

Project Impacts

The main focus of this project was to increase successful cover crop establishment (NRCS Standard 340). During the length of this three year on-farm project, 30 farmers enrolled with over 134 fields and 2,134 acres. In 2020 and 2021, modified corn practices were implemented on 1, 350 acres. In 2022, at the farmer's discretion, modified corn practices were implemented on nearly 1,000 acres. Farmers continued implementation using the UVM equipment and new knowledge in 2023.

Overall, through this project new interseeding standards were created focused on modifying the way corn is grown to encourage cover crop establishment. Outreach materials and technical knowledge were shared with 895 stakeholders through the project period. Farmers gained knowledge and access to equipment. Finally, cover crop interseeding was performed on over 3,000 acres in VT.