Evaluation of seeding methods of cover crops interseeded into organic corn

Final report

Submitted to Organic Farming Research Foundation

February 29, 2024

Principal Investigator
Axel Garcia y Garcia
Associate Professor
University of Minnesota
Southwest Research and Outreach Center
23669 130th Street
Lamberton, MN 56152
507-766-5618

Co-Principal Investigator
Emily E. Evans, M.S.
Researcher 3
University of Minnesota
Southwest Research and Outreach Center
23669 130th Street
Lamberton, MN 56152
507-430-0269

Key Cooperator
Ryan Batalden
Owner/Operator Batalden Farms
39474 County Road 11
Lamberton, MN 56152
507-220-1036

Table of Contents

Abstract

Inclusion of cover crops continues to be a priority for organic farmers, but many struggle with successful establishment in long-season cash crops, especially in the upper Midwest. Typical practices of aerial seeding into standing corn and drilling after fall harvest have yielded inconsistent results leading to low adoption rates. Past research has shown that seeding cover crops between V2-V7 corn stages can produce significant biomass without affecting corn yield; however, seeding methods typically involve high-clearance equipment or modified grain drills that are expensive or difficult to obtain. Alternative and affordable methods to achieve similar results may lie in a combination of broadcast seeding timed with routine weed control practices to mimic seed placement from drilling. Farmer ingenuity has fueled many independent investigations that spark interest, but questions about timing, species selection, and methods must be answered to make the outcomes repeatable and consistent. Replicated research trials were conducted on certified organic acres at the University of Minnesota Southwest Research and Outreach Center (SWROC) in Lamberton, MN (site 1) in 2022 and 2023, and on the farm of a cooperating organic producer (site 2) in 2022. Four cover crop treatments were tested; red clover (*Trifolium pratense* L.), annual ryegrass (*Lolium multiflorum* Lam), winter rye (*Secale cereale* L.), and tillage radish (*Raphanus sativus* L.) at site 1 and red clover, annual ryegrass, tillage radish and a multispecies pollinator mixture at site 2. Each cover crop species/mix was broadcast around two routine weed control events at site 1: before tine-weeding and after final field cultivation. At site 2, the cover crop treatments were broadcast after final cultivation. At each of these events, the cover crops were also drilled to equally compare establishment and growth. In 2022, there was little cover crop growth in all treatments at both sites. In 2023 at site 1, seeding method affected the establishment of the cover crop at the earlier seeding around the flex-tine weed control operation, and this was species-dependent. The red clover crop established better when broadcast and incorporated with the flex-tine implement, and winter rye established better when drilled compared to the broadcast method. Both planting methods yielded similar establishment outcomes with the annual ryegrass and tillage radish cover crops. We found that the majority of the tillage radish population, however, did not survive beyond the first half of the growing season. When the four cover crop treatments were planted after

the final cultivation, seeding method made no difference in total cover crop biomass collected at the end of the season.

While cover crop establishment using routine weed control passes and equipment was comparable to that when planted with a high-clearance grain drill, further experimentation is needed to show how these methods compare over several growing seasons to make this practice truly repeatable. Furthermore, more research needs to be done to determine whether seeding into standing corn, regardless of the method, produces enough biomass to make the practice agronomically and economically valuable.

Rationale and Literature Review

It is well documented that cover crops increase rotational diversity, improve soil fertility, provide topsoil protection, reduce nitrate leaching, interrupt pest cycles, add organic matter to the soil, improve water and nutrient holding capacity, lower compaction, and improve water infiltration and aeration[1,2,3]. Planting cover crops with annual small grains and in between other short-season cash crops is common in almost all organic rotations throughout the United States; yet, the "narrow window of opportunity" has been identified as the primary challenge of cover crop management[3,4]. Furthermore, attempts at seeding a cover crop after harvesting a long-season cash crop in the upper Midwest have especially left farmers frustrated due to the small window for establishment. This usually results in poor stands in the fall and limited regrowth in the spring of winter-hardy species[5,6,7]. Without a clear economic or agronomic justification for the practice, farmers tend, for the most part, to abandon planting cover crops after corn harvest.

Growers have not lost sight of the need for a cover crop after corn. In many parts of the upper Midwest and Canada, strong winter winds and heavy spring rains displace fertile topsoil, with recent estimates of A-horizon soil loss in 1/3 of the midwestern Corn Belt[5]. Persistent spring rain events, coupled with snowmelt, are also responsible for the displacement of nitrogen (N) and phosphorus (P) from the rooting zone and polluting surface and groundwater. Well-established winter hardy cover crops not only cover the soil but can scavenge available spring soil N, which would otherwise be leached, and make it available to a following cash crop.

Additionally, there is great potential for a well-established cover crop to provide weed control (a) in-season between corn rows and (b) post-season for the following cash crop. A Canadian study testing interrow tillage followed by diverse cover crops, including several legume species, consistently reduced weed biomass compared to the non-weeded control, though their efficacy was diminished in conditions of heavy weed infestations [8]. Other studies have also shown that with adequate fall establishment, annual ryegrass generates enough spring biomass to reduce winter annual weeds when seeded between V2-V5 stages[9].

Recent attempts at seeding *into* a standing corn crop, however, have yielded inconsistent results. For instance, a successful establishment of cover crops by aerial seeding is dependent on many factors, including wind speed and direction, seed weight, field topography and shape, and height of seed drop making the practice considerably risky[10]. Furthermore, seed loss to predation after aerial or broadcast seeding has been estimated at up to 18% daily[11], and as much as 98% total loss one week after seeding[10]. On the other hand, drilling cover crop seed when the corn is between V2-V10 development stages has produced consistent stands. Studies have shown that when cover crops are drilled after the corn reaches the V2 stage, many species establish well and produce robust stands with no corn yield loss[8,9,12,13,14,15]. Alternatively, it is also been shown that cover crops seeded after V10-V12 do not generate enough biomass to serve their intended purpose[10,11]. It is generally accepted that drilling between V2-V10 increases the chance of establishing a vigorous stand and limits the risk of corn yield drag. In the upper Midwest and Canada, however, drilling cover crops into standing corn typically involves high-clearance equipment and/or modified grain drills that are expensive or difficult to obtain. Farmer ingenuity has fueled many independent investigations that involve a combination of broadcast seeding times with routine weed control practices to mimic seed placement from drilling. Questions about species selection, timing, and methods must still be answered to make the outcomes repeatable and consistent.

This research served the Production Priority Areas 1 and 2. Adding a cover crop in a corn-based rotation, especially winter hardy types early in the growing season can greatly improve soil health. This is because these cover crops produce large amounts of biomass, which helps capture more carbon and increase soil organic matter. Additional benefits include nutrient cycling within the agroecosystem and increased biodiversity. This practice could also reduce the need for multiple tilling operations to manage weeds.

The seeding methods that were chosen for this study were suggested by local producers, and are based on equipment and practices commonly followed for weed control. Incorporation of seed by a tine weeding disturbance (treatment 1) and broadcast seeding immediately after deep interrow cultivation (treatment 3) were thought to increase seed-to-soil contact compared to broadcast seeding alone, thus enhancing germination and establishment. Cover crop species selected for this experiment were based on recommendations from local farmers and have been historically successful in our region. Additionally, the species selected are purposely dynamic in size and shape, potentially affecting how the seeds are incorporated into the seed bed. The cooperating farmer chose which species he would like to test. His selection was based on weed control potential, soil protection, the ability to attract pollinators, and how well they will enhance fertility and overall soil productivity.

Objectives

Objective 1: *Evaluate seeding method on cover crop establishment and growth.* We tested four species of cover crops, seeded by two methods at two planting times to better understand best management practices for each species. We conducted field studies at two locations to generate a larger data set to help with general recommendations. Because of an atypically dry year and little cover crop growth, we repeated the experiment (on site 1 only) a second year.

Objective 2: *Determine the effects of interseeded cover crops on yield of organic corn.* We quantified growth and yield differences in organic corn when planted with and without cover crop to determine if there was an economic risk associated with yield drag.

Objective 3*: Evaluate soil protection potential of cover crop strategies before winterkill.* The first year had very little living biomass at the end of the season, therefore percent cover was evaluated only in the second year at site 1.

Objective 4: *Evaluate weed control potential of cover crops at 60 days after interseeding (DAI), winterkill, and spring termination.* Weed biomass was measured on site 1 only in both 2022 and 2023. At site 2, there was very little weed or cover crop biomass throughout the study in 2022.

Objective 5: *Evaluate soil nitrogen status before and after cover crop*. Evaluation of soil N was done to determine if the cover crop filled an intended niche (contribute or scavenge nitrogen) or negatively affected corn yield.

Materials and Methods

Three integrated activities were employed to complete our objectives: (1) a replicated on-station research trial at the SWROC, (2) a replicated on-farm research trial at a local organic farm, and (3) an outreach program to disseminate research results to educate producers.

Three hypotheses were developed and tested with our experiments:

Hypothesis 1: Cover crop establishment preceding and following tillage disturbances will be similar to that following drilled method.

Hypothesis 2: Cover crop biomass will be higher in earlier planting compared to later planting.

Hypothesis 3: Corn yield will not be affected by cover crops across timing/seeding methods.

Site description and history:

Site 1: The University of Minnesota's Southwest Research and Outreach Center (SWROC) is home to Elwell Agroecology Farm (EAF), a 120-acre farm that has been used to study organic and transitional farming practices since 1998. The EAF is located 1.5 miles west of Lamberton on Highway 14, in the southwest corner of the state. The predominant soil types found on the farm are Clarion loam, Nicollet loam, and Webster silty clay loam. Together these soils represent around 60% of the cropland in southwest Minnesota. The research plots were located on land that has been certified organic since acquisition in 1998 and farmed without any use of synthetic chemicals before 1998. Organic rotations and management practices at the EAF reflect typical best management organic practices in the region for the last 25 years. In both 2022 and 2023, the experiment was established in 2 different locations, following three years of alfalfa to ensure adequate fertility and minimal weed competition to better support the study.

Site 2: Ryan Batalden farms 350 acres of land that is located adjacent to the SWROC and has been certified organic since 2012. Ryan practices an extended rotation of seed crops and grains, tofu-grade soybeans, field corn, and popcorn. He routinely includes cover crops for soil-building, fertility, and weed suppression, and uses manure from neighboring livestock operations as a nutrient source. The site for the research plots was established following a tillage radish crop harvested for seed in the prior growing season.

Experimental design and treatments. At both sites, experimental plots were set up using a RCBD with 4 replicates. At site 1, four cover crops (Table 1) were both broadcast (treatments 1 and 3) and drilled (treatments 2 and 4) at the weed management cultivation done when corn was at V2 and V6 stages (Table 2). Two control treatments were included to compare plots with the same weed control methods with no cover crop for the V2 and the V6 seeding treatments. At this location, a split block design was used to effectively manage the different weed management and seeding method treatments. At site 2, four cover crop species (Table 1) were broadcast-seeded and drill-seeded into standing corn at the final field cultivation at the V6 stage only (treatments 3 and 4, Table 2), plus a control treatment with no cover crop planted to compare.

Tillage implements used were a Flex-tine weeder at V2 and an interrow cultivator at V6. Weed control operations aligned with best management practices in all treatments up until seeding of the cover crop, then ceased after the cover crop was seeded. (See Figure 1 for timing of all early-season field operations.) Cover crops were seeded using a Multipurpose Cover Crop InterSeeder™ Model 10 (InterSeeder Technologies, Woodward, PA). For drilled treatments, seed depth was adjusted according to recommendations by the Sustainable Agriculture Research and Education program (SARE) [1]. For the broadcast seeding treatments, the equipment was adjusted to simulate a drop seeder to be used for surface placement of all seed types. Legume cover crops were inoculated with appropriate inoculant to ensure adequate nodulation.

Table 1. Cover crop treatments at sites 1 and 2.

Site 1	Site 2
Medium red clover (*Trifolium pretense* L.)	Medium red clover
Annual ryegrass (*Lolium multiflorum* Lam.)	Annual ryegrass
Tillage radish (*Raphanus sativus* L.)	Tillage radish
Winter rye (*Secale cereale* L.)	Pollinator Multispecies mixture (PollinatorMAX CC13; Albert Lea Seed, Albert Lea, MN)

Table 2. Seeding method treatments. Site one tested treatments 1-5. Site 2 tested treatments 3-5.

Treatment	Corn Stage	Weed control Implement	Seeding Method
1	V2	Flex-tine	Broadcast before flex-tine
2	V2	Flex-tine	Drilled after flex-tine
3	V6	Interrow Cultivator	Broadcast after final cultivation
4	V6	Interrow Cultivator	Drilled after final cultivation

Sampling. Cover crop and weed above-ground biomass were sampled in all plots at 3 points: (1) in-season to determine differences in establishment, (2) immediately before winterkill to determine total biomass accumulation, and (3) in the plots with winter hardy cover crops (winter rye and red clover) before spring termination. Because of poor cover crop growth, biomass was not measured before winterkill at site 2.

Corn biomass was collected at physiological maturity from all plots. Corn yield was obtained with an Almaco SPC 40 plot combine.

Baseline soil samples were taken by replicate prior to cover crop planting using a 1” probe at 0-6” and 6-12” depths. Soil was sampled in each treatment after corn harvest and analyzed for available N, total N, and total C to help explain any differences in corn yield, and/or how the treatments impact soil fertility.

To assess the soil protection potential, the percent living cover was measured in the fall before the first frost at site 1, in year 2 only. Pictures were taken in each plot in a 0.50 m^2 area and images were analyzed for percent living cover through the Canopeo App[16].

Data was subjected to analysis of variance (ANOVA) using SAS software to test the effect of the seeding methods on cover crop biomass, soil fertility, weed incidence, soil cover, and corn yield. Tukey tests for means comparisons were performed on treatments that were significant ($P <$ 0.05).

Results and Discussion

Timeline. Because the timing of each cover crop seeding was based on weed control operations, field management before cover crop planting varied from site to site and year to year (Fig. 1). Decisions were made based on best management practices, field history, weed emergence, soil conditions, and present and forecasted weather.

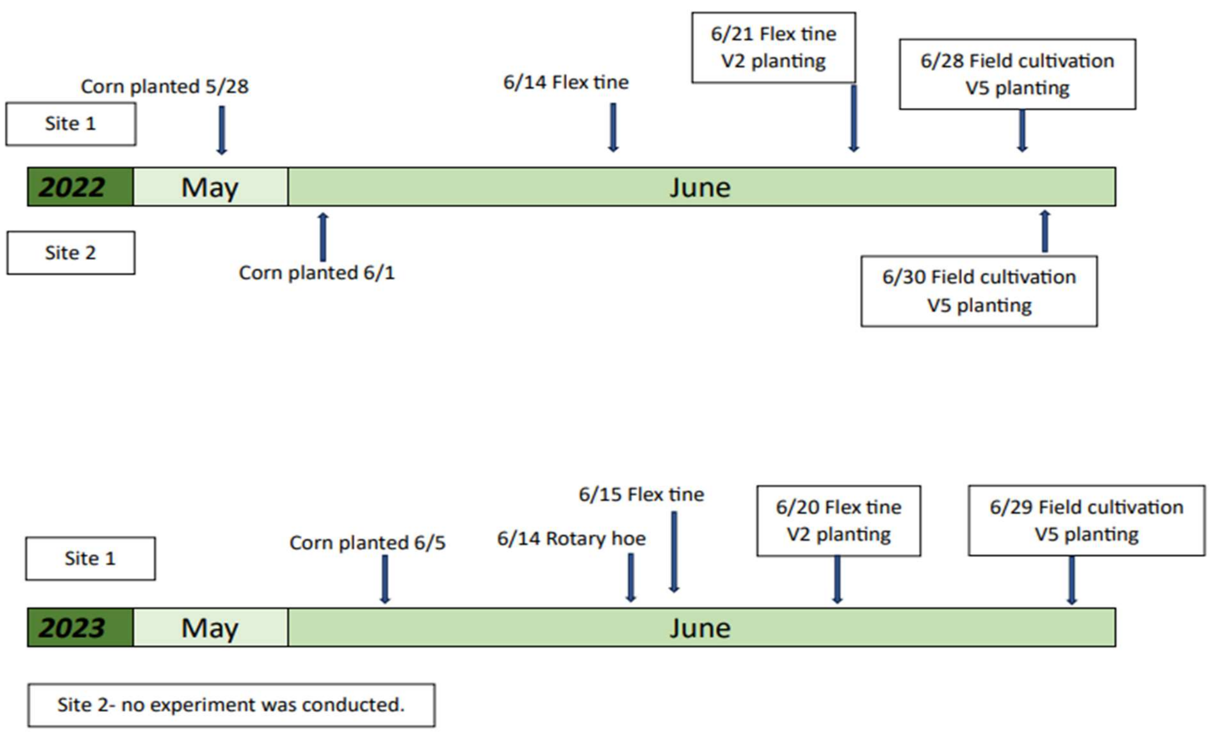

Figure 1. Timing of field operations at sites 1 and 2 in 2022, and site 1 in 2023.

Weather Observations. Weather data were collected at two SWROC weather stations located within 0.25 miles of both sites. Both the 2022 and 2023 growing seasons presented challenges for many Minnesota farmers as rain totals were significantly less than the historical averages, especially in the southern half of the state. However, the early season soil moisture conditions were very different each year. Unlike 2022, the spring of 2023 had above-average precipitation from May 8th - July 24th (figure 2), during the time in which the cover crops were planted. Nevertheless, rainfall totals from June 1 through October 31 for both years fell below the 30-year historical average of 16.3”. Precipitation totals were 6.65” and 12.2” in 2022 and 2023, respectively. By the end of October 2022, Redwood County was categorized as being in “extreme drought” conditions according to the National Drought Mitigation Center (University of Nebraska-Lincoln, Lincoln, NE). In 2023, we did not experience drought conditions despite very little precipitation from mid-July to mid-October, because of both early- and late-season rain events.

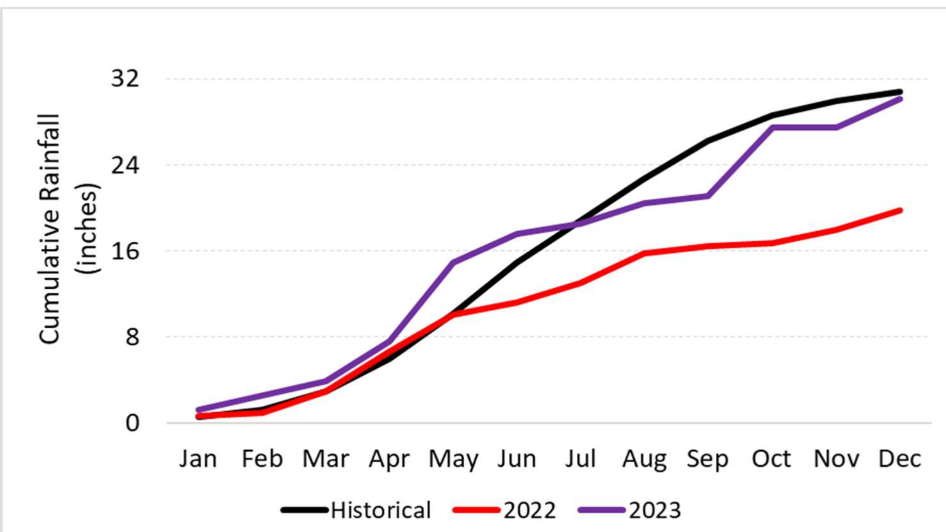

Figure 2. Cumulative rainfall in years 2022 and 2023 compared to the 30-year historical average.

Site 1:

Cover crop establishment and growth. The in-season cover crop sampling measurements were used as an indicator of how well each of the cover crops established. We had originally planned to collect the in-season sampling at 60 days after cover crop planting. However, because of the extremely dry conditions, we collected the biomass on July 28th in 2022 (38 and 31 days after the V2 and V6 plantings). At this point, it was apparent that the majority of the plants that had germinated had already died, so we sampled the remaining living plants from all plots. When treatments were compared statistically, we saw no differences in the establishment of the cover crops based on seeding method or species. Winter rye had the highest biomass totals; yet, biomass of all species was underwhelming. By the end of the growing season, we observed that very few cover crop plants were still alive when we collected the final biomass. As a result, the end-of-season biomass of all species was considerably lower than the reported results from other studies, including those conducted in Lamberton (Table 3). Once more, our results showed no statistically significant differences in total biomass due to timing and method of seeding or cover crop treatment. The following spring, we had planned to collect biomass from the two overwintering cover crops, red clover and winter rye. Red clover did not produce any measurable regrowth so plots were not sampled. The winter rye plots were all sampled. At both the V2 and V6 plantings, regrowth in the drilled plots was higher than the broadcast (100 and 46 lb/A at V2 and 136 and 81 lb/A at V6 for the drilled and broadcast plots, respectively). These differences were not statistically significant.

Because of unfavorable growing conditions and poor cover crop establishment in 2022, we repeated the experiment in 2023 on site 1. The in-season biomass sampling was collected August 16. Average dry biomass across all species measured 78 lb/A at the in-season sampling in 2023. Tillage radish had the highest totals, averaging 169 lb/A. Winter rye totals averaged 131 lb/A. Red clover and annual ryegrass stands were sparse, and totals averaged only 10 lb/A and 4 lb/A, respectively.

At the V2 seeding of the cover crops, planting methods had a statistically significant effect on the establishment of red clover and winter rye (Table 4). Red clover yielded 10 times the amount of biomass when it was broadcast seeded and incorporated with a flex-tine as opposed to when it was directly drilled. This may suggest that the lighter “incorporation” by the flex-tine was advantageous compared to the drilling method in which precise seed depth is harder to control with smaller seeded species. In contrast, winter rye established better when drilled as opposed to broadcast at V2, producing more than 5 times the amount of biomass. This may suggest that the flex-tine incorporation did not offer the same advantageous seed-to-soil contact as drill seeding for winter rye.

For tillage radish, both broadcast and drilling produced the same amount of dry biomass at both the V2 and the V6 planting. We did see a statistical difference in biomass production when the seed was incorporated with the flex tine implement at V2 compared to when it was broadcast after the final cultivation at V5. The V2 broadcast seeding produced more than 6 times the biomass than the V6 broadcast seeding ($p<0.05$), and though not statistically different, the V2 drilling produced almost double the biomass compared to the drilling at V5. (Table 4). Annual ryegrass was the only cover crop that had established equally across all seeding method treatments, however, the average dry biomass harvested was very little, averaging only 3.7 lb/A across all planting methods. There were no statistical differences in the establishment of all four species at the V6 planting (Table 4).

Table 3. Total cover crop dry biomass (lb/A) collected at the end of the season.

Cover Crop	2022		2023		Potential biomass §
Red Clover	5†	a	8	b	2000-3500
Annual Ryegrass	20	a	5	b	2000-5500
Tillage Radish	12	a	24	b	4000-5500
Winter Rye	59	a	92	a	3000-6500

§ Source: Managing Cover Crops Profitably. 2012, 3rd Edition, College Park, MD. Data is based on published research results throughout the United States.

† Within a column, values with the same letters are not significantly different at $p < 0.05$. No stats for 2022?

Table 4. Cover crop biomass (lb/A) collected in 2023 for the in-season sampling. Treatments were separated for interactions, sliced by cover crop treatment to test for system effects.

Seeding Method	Red Clover		Annual Ryegrass		Tillage Radish		Winter Rye	
V2 broadcast	27	a†	3	a	243	a	55	b
V2 drilled	2	b	6	a	260	a	293	a
V6 broadcast	6	b	1	a	38	b	54	b
V6 drilled	5	b	5	a	133	ab	120	b

† Within a column, values followed by the same letter are not statistically significant at $p < 0.05$.

In contrast to the in-season sampling, the final cover crop biomass sampling at the end of the growing season revealed that total biomass production was not affected by the timing (V2 vs V6) or method of seeding (broadcast vs drilled). Among cover crops, winter rye yielded significantly higher total biomass compared to all other cover crops (Table 3). However, like the 2022 results, the total biomass production was much lower than what past studies have reported. It has been shown that the magnitude of almost all services and disservices of cover crops are positively correlated with biomass production[17]. In terms of the minimum amount for certain ecosystem services, there are several examples in literature. For example, Ruis et al found that a minimum of 3 Mg/ha (2680 lb/A) of winter rye biomass was needed to have any effect on several soil health parameters[18]. Hively et al. found that at least 1 Mg/ha of cover crop biomass is needed to control erosion[19]. Studies in upstate New York estimate that red clover will contribute 25 lb of nitrogen for every 1000 lb of aboveground biomass incorporated into the soil[20]. The end-of-season biomass totals in the two years of this study, however, are far below what is considered necessary to fulfill any of these intended ecosystem benefits, and likely most other known ecosystem benefits.

<u>Weed management</u>. In both 2022 and 2023, there was relatively low weed pressure, a likely result of the weed suppression benefits of the preceding 3 years of alfalfa in both experimental locations. In 2022, total weed biomass averaged across all treatments was 145 lb/A with high variability within a treatment, attributed to a noticeable thistle [*Cirsium arvense* (L.)] infestation in 2 of the 4 replications. In 2023, total weed biomass was much lower: 5 lb/A average of all plots. No statistically significant differences were found in both years. At such small amounts, it isn’t surprising that weed effects on both the cash crop and the cover crop are imperceptible. Similarly, the cover crop effects on weed incidence are difficult to distinguish in such low weed populations.

<u>Corn yield</u>. At site 1, corn yields for both 2022 and 2023 exceeded the 15-year historic average for UMN-SWROC bulk corn acres by over 20 bu/A, with an average of 148 bu/A in each year. There was no significant difference in corn yield in either year based on seeding method at both V2 and V6 growth stages. Corn yield was similar across all cover crop species, and not significantly different than the control treatments.

In 2023, however, the plots that were planted with a cover crop at the V2 corn stage yielded 16 bu/A less than those planted with a cover crop at the V6 corn stage ($p < 0.01$). Corn biomass in those plots that were planted with a cover crop at V2 also had significantly lower corn biomass ($p < 0.01$) compared to those that were planted at V6. The plots that were planted at V6 were cultivated twice before they were planted 10 days after the plots that were planted at V2. This was a concern raised by farmers during the planning of this project: potential weed competition because of not being able to do any tillage after the cover crop was planted at V2 corn, however, the two control treatments (V2 and V6) were statistically similar in both corn yield and corn biomass. This, plus the very low weed populations, suggests the yield drag was likely not due to weed pressure.

Soil protection. The soil protection potential of the cover crops was determined by measuring the percentage of the soil that was covered by the living cover crop after the corn crop was harvested. In 2022, it was difficult to find any cover crop growing in any of the plots, therefore the soil had no cover crop protection. In the 2023 trial, there was enough living cover crop to do the measurements. No significant differences were found based on the seeding method of the cover crops. Winter rye, however, had significantly more living biomass than the other 3 cover crop species; yet, only covered 2-5% of the soil. Each of the other three species covered less than 0.5%. It should be noted that, in both years, the remaining corn residue provided substantial soil protection.

Soil fertility. All cover crops were relatively similar in their effect on soil nitrogen levels post-harvest, with tillage radish having the highest recorded nitrogen level and annual ryegrass the lowest. However, in both sites and years, differences in total soil N among cover crop treatments were not statistically significant (Table 5).

Table 5. Total available soil N ($mg*L^{-1}$) from post-harvest sampling.

Cover Crop	2022†		2023	
Red Clover	34.5	a	10.6	a
Annual Ryegrass	30.0	a	10.7	a
Tillage Radish	36.9	a	12.1	a
Winter Rye	35.7	a	10.9	a

† Within a column, values with the same letters are not significantly different at $p < 0.05$

Site 2:

The trial on site 2 was conducted in 2022 only. Similar to the 2022 experiment at site 1, there was very little cover crop growth, as well as very little weed pressure. Biomass was only collected at the in-season sampling on August 1. Seeding method did not affect the establishment of the monocrop cover crops. The polyculture, however, produced twice the amount of biomass when drilled, compared to broadcast after the final field cultivation ($p<0.0001$). Similar to the 2022 study at site 1, the cover crop biomass totals at this sampling were very low, averaging 0.53 lb/A, 2.0 lb/A, 7.0 lb/A, and 18 lb/A for annual ryegrass, red clover, tillage radish, and the polyculture, respectively. By the end of the growing season, there were no living cover crops in any of the single species plots, and very few scattered living plants in the polyculture plots. Biomass was not collected in the fall. The average corn yield across all plots was 186 bu/A, with individual plots recording yields as high as 225 bu/A. Yields did not differ significantly between treatments, and not surprisingly, we saw no treatment differences in the soil analyses done on the soil samples collected after corn harvest.

A note about the trial at site 2: This field was chosen based on anecdotal information from the cooperating farmer. He consistently notices that the weed pressure is extremely low in corn when it follows a tillage radish crop that has been harvested for seed. Because of this, he typically follows a tillage radish crop with corn and has been very successful with high corn yields and few weed “escapes”. The 2022 year proved to be no different with similar low weed pressure and high corn yields. Unfortunately, without a successful cover crop establishment, we could not determine if the seeding method had any effect on stand establishment.

Conclusion

The two seeding methods used in this experiment aimed to mimic the seed placement achieved with a grain drill but allowed for seeding into standing corn without the need for expensive high-clearance equipment. Except for one instance (seeding winter rye during the flex-tine weeding event at the V2 corn stage), the cover crop stands were either comparable or even superior (e.g., red clover planted at the V2 corn stage) to those achieved through drilling.

However, the total biomass produced by all cover crops in this study was much lower than the averages reported in other studies and well below the minimum required to provide their intended environmental benefits. This discrepancy makes it challenging to justify the adoption of these practices when the anticipated benefits of cover crops may not be achieved. Further research across multiple growing seasons is needed to firmly determine whether seeding cover crops into standing corn is a viable addition to an organic rotation in regions like ours. Additionally, it is key to investigate whether achieving sufficient biomass to fulfill intended environmental benefits comes at the cost of reduced corn yields.

Outreach:

July 19th 2022: **Minnesota County Agricultural Inspectors tour.**

July 27th 2022: **University on the Prairie**. Field tour of the plots was given to 17 High School students who participated in University on the Prairie. This was a group of students who participated in a day-long STEM program. The focus of that section was to explore alternative methods for improving soil health and fertility.

August 1st 2022: **SWROC Website Update**. Comparisons of seeding methods were posted on the Facebook page and SWROC website (Images 3 and 4).

August 18th 2022: **Cover Crop Field Day: Setting up for Success**. Field tour of the plots was given to 57 participants. The audience was a mixture of farmers and agronomy professionals.

September 14th, 2022: **Diversifying the Agroecosystem**. Field day consisted of a field tour for 22 participants who toured the plots. Preliminary establishment data was presented to the group.

February 23-25, 2023: **Poster Presentation at 34th Marbleseed Midwest Organic Conference**. Poster presented with 2022 data. Inclement weather prevented in-person presentation, however, the poster was presented on-line with recorded narration.

Upcoming Outreach events:

June 27th 2024: **Cover Crop Academy.**

July 1st 2024: **Fact sheet and online presentation completed including data collected in spring 2024. Both will be uploaded to the SWROC website.**

Financial Accounting:

Organic Farming Research Foundation- Final Financial Report						
Research Grant: Evaluation of seeding methods and timing of cover crops interseeded into organic corn						
PI: Axel Garcia y Garcia						
Institution: Univeristy of Minnesota, Southwest Research and Outreach Center						
Project dates: 5/1/22-3/1/24						
Description	**Class**		**Budget**	**Expenses**	**Available Balance**	**Notes**
Salaries:	P&A		$ 225.00	$ 138.23	$ 86.77	
Fringe:	P&A		$ 83.00	$ 51.15	$ 31.85	
					$ -	
Salaries:	Civil Service		$ 3,343.00	$ 4,690.11	$ (1,347.11)	
Fringe:	Civil Service		$ 1,070.00	$ 1,534.93	$ (464.93)	
					$ -	
Salaries:	Labor Rep		$ 205.00	$ 199.64	$ 5.36	
Fringe:	Labor Rep		$ 65.00	$ 66.88	$ (1.88)	
					$ -	
Salaries:	Temp/Casual		$ 650.00	$ 442.50	$ 207.50	
Fringe:	Temp/Casual		$ 54.00	$ 35.92	$ 18.08	
	Salary and Fringe Totals		$ 5,695.00	$ 7,159.36	$ (1,464.36)	
General Supplies			$ 115.00	$ 115.00	$ -	Labels, postage, paper supplies
Lab Supplies			$ 8,000.00	$ 8,485.64	$ (485.64)	Vials, pipette supplies, reagant for analysis, seed
Gen Services			$ 100.00	$ 100.00	$ -	
Lab Services			$ 5,000.00	$ 3,140.00	$ 1,860.00	MVTL services, plot fees
Travel			$ 90.00		$ 90.00	
Professional Services			$ 1,000.00	$ 1,000.00	$ -	Farmer stipend
			$ 14,305.00	$ 12,840.64	$ 1,464.36	
			$ 20,000.00	$ 20,000.00	$ -	

References cited:

1. Clark, A. (ed.) 2012. Managing cover crops profitably. Sustainable Agriculture Research and Education (SARE) program, College Park, MD.
2. Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Comm. In Soil Sci. and Plant Anal. 32(7):1221-1250.
3. Moncada, K. and C. Scheaffer. 2010. Winter cover crops. In: Moncada, K. and C. Scheaffer (eds.), Risk Management Guide for Organic producers. Univ. of Minnesota, St. Paul.
4. MCCC-USDA. 2015. Integrating cover crops in soybean rotations. Midwest Cover Crops Council, United States Department of Agriculture.
5. Thaler, E.A., I.J. Larsen, and Q. Yu. 2021. The extent of soil loss across the US Corn Belt. Proc. Natl. Acad. Sci. Unit. States Am., 118:9. doi:10.1073/pnas.1922375118
6. Baker, J.M and T.J. Griffis. 2009. Evaluating the potential use of winter cover crops in corn soybean systems for sustainable co-production of food and fuel. Agric. Forest Meteorol. 149:2120-2132. doi:10.1016/j.arformet.2009.05.017
7. Basche, A.D., S.A. Archontoulis, T.C. Kaspar, D.B. Jaynes, T.B. Parking, and E.E. Miguez. 2016. Simulating long-term impacts of cover crops and climate change on crop production and environmental outcomes in the Midwestern United States. Agric., Ecosys. & Environ. 281:95-106.
8. Abdin, O.A., X.M. Zhou, D. Cloutier, D.C. Coulman, M.A. Faris, D.L. Smith. 2000. Cover crops and interrow tillage for weed control in short-season maize. Euro. J. Agron. 12:93-102.
9. Brooker, A.P., K.A. Renner, and C.L. Sprague. 2020. Interseeding cover crops in corn. Agron. J. 112:139-147. doi:10.1002/agj2.20046
10. Wilson, M.L., D.L. Allen, and J.M. Baker. 2014. Aerially seeding cover crops in the norther US Corn Belt: Limitations, future research needs, and alternative practices. J. Soil Water Cons. 69(3):67A-72A. doi:10.2489/jswc.69.3.67A
11. Davis, A.S. and M. Liebman. 2003. Cropping system effects on giant foxtail demography: Green manure and tillage timing. Weed Sci. 51:919-929.

12. Baributsa, D.N., E.F. Foster, K.D. Thelen, A.N. Kravchenko, D.R. Mutch, and M. Ngouajio. 2008. Corn and cover crop response to corn density in an interseeding system. Agron. J. 100(4):981-987.
13. Belfry, K.D., and L.L Van Eerd. 2016. Establishment and impact of cover crops intersown into corn. Crop Sci. 56:1245-1256.
14. Curran, W.S., R.J. Hoover, S.B. Mirsky, G.W. Roth, M.R. Ryan, V.J. Ackroyd, J.M. Wallace, M.A. Dempsey, and C.J. Pelzer. 2018. Evaluation of cover crops drill interseeded into corn across the Mid-Atlantic region. Agron. J. 110:435-443. doi:10.2134/agronj2017.07.0395
15. Noland, R.L., M.S. Wells, C.C. Sheaffer, J.M. Baker, K.L. Martinson, and J.A. Coulter. 2018. Establishment and function of cover crops interseeded into corn. Crop Sci. 58:863-873.
16. Patrignani, A. and T.E. Ochsner. 2015. Canopeo: a powerful new tool for measuring fractional green canopy cover. Agron J., 107(6), 2312-2320. doi:10.2134/agronj15.0150
17. Finney, D.M., C.M. White, and J.P. Kaye. 2016. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Org. Agric. & Agroeco. 108(1): 39-52.
18. Ruis, S. J., H. Blanco-Canqui, P.J. Jasa, G. Slater, and R.B. Ferguson. 2023. Increasing rye cover crop biomass production after corn residue removal to balance economics and soil health. Field Crops Research, 302, 109076. doi: 10.1016/j.fcr.2023.109076
19. Hively, W.D., M. Lang, G.W. McCarty, J. Keppler, A. Sadeghi, and L.L. McConnel. 2009. Using satellite remote sensing to estimate winter cover crop nutrient uptake efficiency. J. Soil Water Cons. 64(5), 303-313. doi: 10.2489/jswc.64.5.303
20. Ketterings, Q, J. Kingston, K. Cyzmmek, B. Caldwell, C. Mohler, and G. Goodwin. 2011. Nitrogen Credits from red clover as cover crop between small grains and corn. Cornell Coop. Ext. Fact Sheet 60. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet60.pdf

Photos

Image 1. Ryan Batalden, farmer cooperator standing in the corn trial at Site2, July 7, 2022.

Image 2. Field tour for Minnesota Agriculture Inspectors spotlighting cover crop research in 2022.

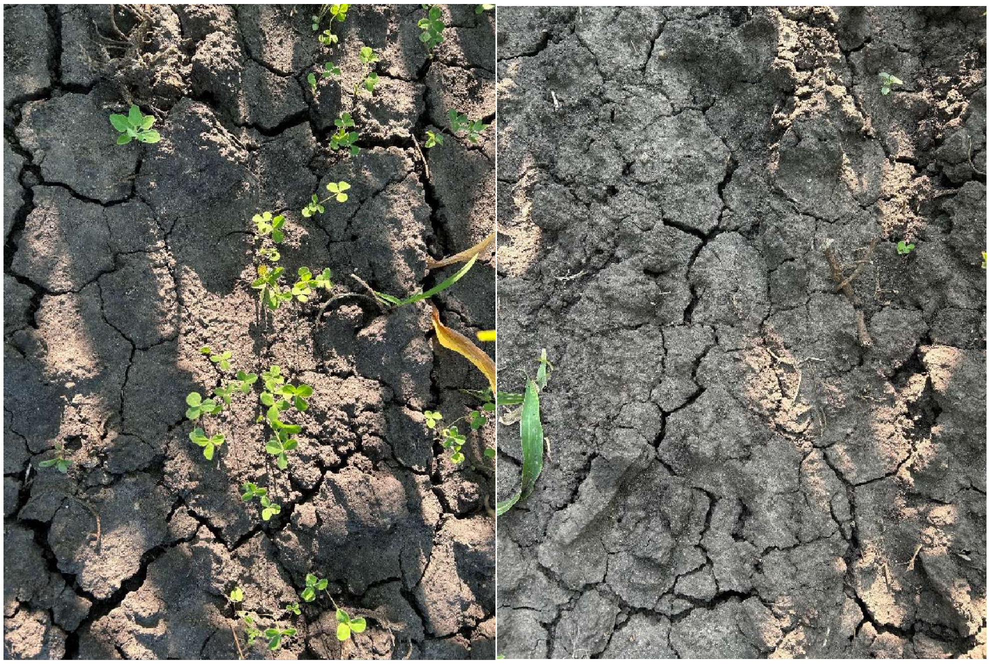

Image 3. Red clover, seeded at the corn V2 stage (left: broadcast and incorporated with flex tine, right: drilled with high clearance grain drill). Pictures taken at 34 days after seeding on site 1 in 2023.

Image 4. Winter rye, seeded at the corn V2 stage (left: broadcast and incorporated with flex tine, right: drilled with high clearance grain drill). Pictures taken at 34 days after seeding on site 1 in 2023.