DEPARTMENT OF AGRICULTURE

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August 14, 2017

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Project: Water Quality Enhancements in Corn Cropping Systems through Optimization of Cover Crop Establishment Technologies

Dear Chris:

Here is complete copy of the final report submitted to the Minnesota Department of Agriculture Pesticide and Management Division. The electronic copy was emailed to you on August 14, 2017.

I am submitting only one print copy. This report was prepared by the contractor and according to the project manager is not mandated by law.

Please contact me at (651) 201-6196 if you have questions.

Sincerely,

*Kam Carlson*

Kam Carlson
Contracts & Grants Coordinator
Pesticide & Fertilizer Management Division
Minnesota Department of Agriculture
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Enclosures: One copy of final report for project listed above

WATER QUALITY ENHANCEMENTS IN CORN CROPPING SYSTEMS THROUGH OPTIMIZATION OF COVER CROP ESTABLISHMENT TECHNOLOGIES

Final Report to the Minnesota Department of Agriculture

Prepared by Reagan L. Noland and M. Scott Wells

CLEAN WATER FUND RESEARCH AND EVALUATION PROGRAM

PROJECT ID: 76919


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## OVERVIEW

Cover crops can provide ecological services and improve the resiliency of annual cropping systems. Particularly, they have potential to mitigate the effects of agricultural practices on water quality. However, cover crop use is low in corn-soybean rotations in Minnesota due to challenges with establishment. This research project was designed and carried out to: 1) identify appropriate cover crop species and establishment methods for interseeding in corn at the seven leaf collar stage, 2) estimate ecological impacts through the use of models and interpretations of our findings, and 3) conduct a comprehensive, research-based educational program to deliver important findings and information to farmers, agricultural professionals, the scientific community, and the general public.

## INTRODUCTION

Management practices for annual crops in the upper Midwest often result in periods of increased risk for soil erosion and off-site movement of nutrients. Corn and soybean are the most widely grown crops in Minnesota, planted on a total area of 6.48 million hectares (16 million acres) in 2016 (USDA-NASS, 2017). These crops are extremely important to the economy of the state and the upper Midwest; however, their widespread production under conventional cropping practices has resulted in environmental challenges. Summer-annual crops are actively growing in the field for only a few months out of the year; therefore, the remainder of the year becomes a window of vulnerability for soil erosion and nutrient loss via surface runoff, leaching, and tile-drain discharge (Randall et al., 2003; Strock et al., 2004). Off-site movement of nitrogen is a primary concern. Since inorganic N is water-mobile, it can move rapidly and ultimately contribute to excessive nitrate loading in surface and ground waters, resulting in public health and environmental issues both here in Minnesota as well as downstream.

Cover crops can be integrated into annual cropping systems to use excess soil N and reduce these losses (Feyereisen et al., 2006; Qi and Helmers, 2010; Blanco-Canqui et al., 2015), and can also protect soil from erosion and improve overall soil health through increased organic matter (Reicosky and Forcella, 1998; Dabney et al., 2001). Although cover crops offer many benefits, they are not commonly used in corn-soybean rotations in the upper Midwest (Singer et al., 2007). The main limitation to establishing cover crops following corn harvest in northern climates is the lack of adequate time and favorable conditions for establishment before winter. An alternative strategy is to interseed cover crops into standing corn, which can allow adequate time for establishment (Wilson et al., 2013; Belfry and Van Eerd, 2016). In the past, some growers have interseeded cover crops into corn via aerial broadcast from an airplane or helicopter. These methods have not produced consistent results though, due to seed getting caught in the corn canopy, poor seed-soil contact, and seed predation by rodents and insects. New interseeding methods, such as high-clearance drills, have been developed to deliver cover crop seed directly between the rows of a standing crop.

Suitable cover crop species and reliable establishment methods need to be identified to develop viable cover cropping strategies that provide environmental benefits while maintaining productivity in Minnesota’s corn-soybean rotations. This research and outreach project, funded by the Minnesota Department of Agriculture – Clean Water Fund Research and Evaluation Program, was designed to identify suitable cover crops and planting methods for interseeding into corn and to deliver research-based outreach and education to farmers, crop advisors, extension educators, the scientific community, government agencies, and the general public. The objectives of this project were to:

1. Assess potential ground water quality improvements resulting from advanced cover crop establishment using a calibrated model (NLEAP) and estimate reductions in soil erosion associated with increased ground cover (i.e., cover crops) using the Revised Universal Soil Loss Equation (RUSLE).
2. Evaluate cover crop establishment methods and cover crop species/mixture in a grain corn system.
3. Conduct a comprehensive educational program to disseminate research findings and demonstrate cover crop establishment technologies, enabling growers and agricultural professionals to make marked improvements in cover crop establishment and water quality while maintaining the profitability of commodity crop production.

## FIELD EXPERIMENTS

Field experiments were conducted in 2014 through 2016 at the University of Minnesota Southern Research and Outreach Center at Waseca, MN and at the University of Minnesota Southwest Research and Outreach Center at Lamberton, MN. Both field sites were in primary corn production areas of the state, and were situated in the Canon River and Cottonwood River watersheds, respectively, which drain into the Minnesota River and are ultimately part of the greater Mississippi River Basin. All field sites were fertilized according to University of Minnesota recommendations for corn production (Kaiser et al., 2016) so nutrients were not limiting to crop growth. Corn (‘Pioneer P0193AM’) was planted on a 76-cm row spacing at 86,500 seeds $ha^{-1}$ (35,000 seeds $ac^{-1}$) at both locations between 28 April and 5 May in each year. To avoid soil-residual herbicide effects on cover crop establishment, weeds were controlled using only glyphosate prior to corn planting, and again prior to cover crop interseeding.

**Table 1.** Cover crop species and seeding rates.

| Common name | Scientific name | Functional group | Seeding rate (kg $ha^{-1}$) |
|---|---|---|---|
| Cereal rye | *Secale cereale* L. | Grass / small grain | 168 |
| Field pennycress | *Thlaspi arvense* L. | Oilseed brassica | 9.9 |
| Medium red clover | *Trifolium pretense* L. | Legume | 13.4 |
| Hairy vetch | *Vicia villosa* Roth | Legume | 35.1 |
| MIX (oat, field pea, and tillage radish) | *Avena sativa* L.<br>*Pisum sativum* L.<br>*Raphanus sativus* L. | Grass, legume, brassica | 140 |

Five different cover crop options (Table 1) were planted via three planting methods, resulting in a total of 15 treatments and a no-cover crop check plot. These plots were replicated six times at each location in each year. Cover crops were interseeded into corn at the seven leaf collar stage (Figure 1) in late-June (Table 2). All legumes were inoculated with the appropriate rhizobia species at the time of planting.

Cover crop planting methods included:

- Direct broadcast of seed into the inter-row (DBC)
- Directed broadcast into the inter-row with light soil incorporation (DBC+INC)
- Direct-drilling a high-clearance no-till drill (3-in-1 InterSeeder$^{TM}$) (DRILL)

To simulate the directed broadcast planting method (DBC), cover crops were broadcast directly by hand into the three inter-rows of each plot with no soil disturbance. The broadcast with incorporation (DBC+INC) planting method was achieved by modifying the high-clearance no-till drill. The drill units were raised so that the seed fell onto the soil surface, followed by custom-made incorporation units installed on the drill. These units consisted of a light closing chain followed by a harrow-tine rake to achieve light soil disturbance (Figure 2). The DRILL treatment had three drill units evenly spaced and centered within each of three inter-rows per plot. In each replication, the experimental control was a no-cover crop check plot (CHK). Following cover crop emergence, soil moisture sensors were installed at depths of 30 and 60 cm in DRILL-planted winter rye and in the CHK plots. Data loggers were programed to record volumetric water content on 1-hr intervals through the duration of the corn-soybean cropping cycle.

**Table 2.** Field tasks in cover crop establishment experiments at Lamberton, MN and Waseca, MN (Cycle 1: 2014-2015, Cycle 2: 2015-2016)

| Task | Date | |
|---|---|---|
| | Lamberton | Waseca |

| | | |
|---|---|---|
| Cycle 1 | | |
| Planted cover crops (corn growth stage V7) | 6/23/14 | 6/25/14 |
| Installed soil moisture sensors | 7/7/14 | 7/3/14 |
| Assessed cover crop fall biomass | 9/29/14 | 9/25/14 |
| Harvested corn stover (R6) | 9/30/14 | 9/26/14 |
| Harvested corn grain | 10/27/14 | 10/20/14 |
| Soil sampled | 10/28/14 | 10/31/14 |
| Visual cover crop assessments (winter survivability) | 3/16/15 | 3/15/15 |
| Assessed cover crop spring biomass | 5/13/15 | 5/8/15 |
| Soil sampled | 5/13/15 | 5/8/15 |
| Terminated cover crops (glyphosate) | 5/19/15 | 5/12/15 |
| No-till planted soybeans | 5/22/15 | 5/28/15 |
| Downloaded all data and dug up soil moisture sensors | 10/9/15 | 10/2/15 |
| Harvested soybean grain | 10/20/15 | 10/6/15 |
| Cycle 2 | | |
| Planted corn | 4/30/15 | 4/28/15 |
| Planted cover crops (corn growth stage V7-V8) | 6/26/15 | 6/25/15 |
| Installed soil moisture sensors | 7/13/15 | 7/16/15 |
| Sampled cover crop biomass | 9/28/15 | 9/25/15 |
| Harvested corn stover (R6) | 9/28/15 | 9/25/15 |
| Harvested corn grain | 10/19/15 | 10/27/15 |
| Soil sampled | 11/2/15 | 11/4/15 |
| Assessed cover crop spring biomass | 5/17/16 | 5/6/16 |
| Soil sampled | 5/17/16 | 5/6/16 |
| Terminated cover crops (glyphosate) | 5/20/16 | 5/16/16 |
| No-till planted soybeans | 5/24/16 | 5/19/16 |
| Downloaded all data and dug up soil moisture sensors | 10/13/16 | 10/13/16 |
| Harvested soybean grain | 10/21/16 | 10/14/16 |

**Figure 1.** (Above) Planting cover crops into V7 corn using a high-clearance InterSeeder™ at Lamberton, MN on 23 June 2014.

**Figure 2.** (Left) Incorporation units consisting of a harrow-tine rake and light closing chain, installed with drill units lifted above the soil surface to simulate directed broadcast interseeding with light incorporation.

Cover crop biomass and N content were measured at corn maturity, and in the spring prior to termination (Table 2). Corn grain, stover, and cob biomass were also sampled and analyzed for N content at maturity. At the corn grain harvest, the combine header was kept directly below the height of the ears to reduce the amount of stover deposited on cover crops and to serve as a snow catchment for improved winter survival. Cover crops were terminated with glyphosate in the spring (Table 2) and soybean (ASGROW 'AG1733') was no-till planted at 395,000 seeds $ha^{-1}$. Soil was sampled to a depth of 1.2 m and analyzed for nitrate-N content following corn harvest in the fall, and immediately prior to cover crop termination in the spring (Table 2). Red clover and hairy vetch cover crops were not completely terminated with the first application of glyphosate so a second application of glyphosate at the same rate and formulation was applied following soybean emergence (Table 2). Unfortunately, some of the hairy vetch survived at

Lamberton in both years and remained under the soybean canopy where it was protected from additional herbicide applications.

## OUTCOMES (OBJ. 2) *(Noland et al., 2017)*

Air temperatures were similar (within 2°C) to 30-year averages throughout the growing season in each site-year, except September 2015 which was slightly warmer (4°C) than normal. Precipitation totals (April–September) were above average in all site-years with a few excessively wet periods during June or July (Table 3). In all experiments, 5 to 23 mm of precipitation occurred within 7 days after cover crop planting and 10 to 38 mm occurred within 10 days.

**Table 3.** Monthly total precipitation in 2014, 2015, and 2016 and departures from the 30-yr (1984-2013) averages at Lamberton, MN and at Waseca, MN.

| Month | Lamberton | | | Waseca | | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| | ------------- mm ------------- | | | | | |
| January | 17.5 (3) | 11 (-4) | 8 (-7) | 36 (4) | 19 (-13) | 11 (-20) |
| February | 13.0 (0) | 5 (-8) | 18 (5) | 40 (15) | 19 (-6) | 22 (-4) |
| March | 25 (-16) | 10 (-31) | 51 (10) | 35 (-29) | 29 (-35) | 56 (-7) |
| April | 87 (11) | 31 (-44) | 85 (9) | 141 (60) | 70 (-12) | 50 (-31) |
| May | 46 (-37) | 139 (57) | 141 (59) | 73(-27) | 121 (21) | 95 (-5) |
| June | 188 (82) | 128 (23) | 66 (-40) | 328 (210) | 194 (74) | 121 (2) |
| July | 30 (-65) | 96 (1) | 176 (81) | 30 (-82) | 188 (76) | 227 (115) |
| August | 94 (1) | 113 (20) | 135 (41) | 81 (-40) | 152 (32) | 297 (177) |
| September | 154 (70) | 87 (3) | 134 (49) | 59 (-34) | 149 (56) | 376 (283) |
| October | 12 (-40) | 41 (-11) | 72 (19) | 35 (-33) | 31 (-37) | 79 (11) |
| November | 13 (-21) | 84 (50) | 47 (13) | 28 (-27) | 101 (46) | 41 (-13) |
| December | 25 (6) | 34 (15) | 29 (10) | 18 (-20) | 88 (50) | 54 (16) |

Cover crop biomass in the fall was generally greater with planting methods that increase seed-soil contact, using a high-clearance drill, compared to broadcast seeding (Figure 3). Pennycress was the only cover crop not affected by planting method. It should be noted that rainfall was above-average during the growing season in all site-years of this study, which likely influenced the success of the broadcast planting methods. Under drier conditions, similar establishment would not be expected of broadcast planting with no incorporation (Wilson et al., 2013). Corn grain and silage yields were not affected by cover crop species or planting method, indicating that the interseeded cover crops did not interfere with corn production when planted at the V7 growth stage.

Spring cover crop biomass was greater overall with the DRILL and DBC+INC planting methods (average 641 kg ha$^{-1}$) compared to DBC (514 kg ha$^{-1}$). Within species, the DBC method resulted in less red clover and hairy vetch biomass compared to other planting methods, but rye and pennycress spring biomass were not affected by planting method (Figure 3). Similar relationships were found for spring cover crop N uptake (Table 4), with rye resulting in the greatest overall N uptake (average 24.5 kg N ha$^{-1}$). Soybean yields were only reduced with the hairy vetch cover crop at Lamberton, compared to the pennycress and MIX treatments. Otherwise, soybean yield was similar across the remaining treatments at Lamberton and all treatments at Waseca.

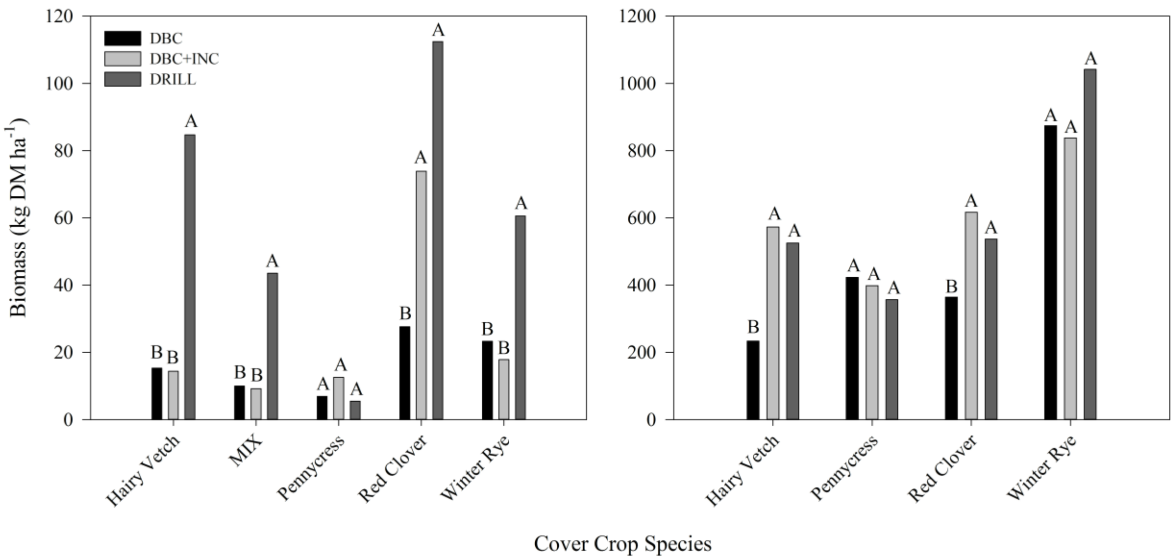


**Figure 3.** Cover crop species and planting method effects on cover crop biomass in fall (left) and spring (right) at Lamberton, MN and Waseca, MN. DBC, direct broadcast; DBC+INC, direct broadcast with light incorporation; DRILL, high-clearance no-till drill. MIX, mixture of oat [*Avena sativa* L.], pea [*Pisum sativum* L.], and tillage radish [*Raphanus sativus* L.]. Means presented are back-transformed from log-transformed model estimates. Within cover crops, means with the same letter are not significantly different at $P \leq 0.05$ (Noland et al., 2017).

The primary finding for Objective 2 is that cover crops can be successfully established via interseeding into corn at the seven leaf collar stage in Minnesota (Figures 4-8) without affecting corn yield; however, effective termination of cover crops is important to avoid risk of reducing soybean yield. Overall, planting methods with increased seed-soil contact demonstrated more consistent establishment. All cover crop species were successfully established, although rye and red clover were consistently among the greatest in spring biomass and N uptake.

**Table 4.** Cover crop species effects on tissue N content in spring at Lamberton, MN and Waseca, MN (Noland et al., 2017).

| | Tissue N Content† | | | |
|---|---|---|---|---|
| Planting Method | Hairy Vetch | Pennycress | Red Clover | Winter Rye |
| | ------------------ kg N $ha^{-1}$ ------------------ | | | |
| DBC‡ | 6.7b§ | 11.7a | 11.7b | 21.7a |
| DBC+INC | 14.9a | 11.6a | 19.4a | 25.8a |
| DRILL | 18.9a | 10.8a | 21.1a | 26.0a |

‡ DBC, direct broadcast; DBC+INC, direct broadcast with light incorporation; DRILL, high-clearance no-till drill.

§ Within a column, means with the same letter are not significantly different at $P \leq 0.05$ according to Fisher's LSD.

**Figure 4.** Winter rye cover crop interseeded with a high clearance drill into V7 corn.


**Figure 5.** Red clover interseeded into corn at V7 growth stage. Photo taken at corn maturity at Waseca, MN in 2015.


**Figure 6.** Hairy vetch cover crop at corn maturity, planted via directed broadcast (left) vs. directed broadcast with incorporation (right) at corn growth stage V7.

**Figure 7.** Red clover planted by directed broadcast with incorporation at corn growth stage V7. Photo taken at corn maturity in Waseca, MN.

**Figure 8.** Interseeded red clover cover crop in the spring, prior to termination at Waseca, MN in 2016.

*Management Efficiency (Noland, 2017)*

The efficiency of cropping practices was measured as the cover crop species or planting method that achieved the greatest benefit (spring biomass) at the lowest cost, and at the fastest rate. In addition to cover crop productivity, this analysis accounted for factors such as seed cost and equipment limitations. In practice, interseeding cover crops at a specific growth stage limits the farmer to a narrow window of time. The fastest planting method was DBC, as this can be achieved with a wider implement traveling at greater speeds than a drill or a broadcast seeder that is dragging incorporation units. Between cover crop species, seed cost per acre was greatest for hairy vetch and least for pennycress and red clover (Figure 9). Hairy vetch also averaged the lowest benefit, making it a less efficient option than red clover, pennycress, and rye. The greater biomass achieved with rye was offset by a slightly greater cost than red clover and pennycress, resulting in similar overall efficiency between these cover crops.

Between planting methods, DBC was most efficient and DRILL was the least efficient (Figure 9). This difference is primarily due to the speed of planting, as there were only slight differences in cover crop biomass in the spring (benefit) and planting costs. Environmental conditions often necessitate speed when interseeding into corn at the seven leaf collar stage, as this is a narrow timeframe to plant a large area. On average, only 3.3 days in the last week of June are suitable for in-field farm operations (USDA-NASS, 2017b). In this study, precipitation generally occurred shortly before and after planting. Therefore, the requirement for ample time with suitable field conditions would have limited the potential acreage to be interseeded, and speed of planting would have determined the most efficient interseeding option.

Under wet conditions, aerial broadcast planting may be a more appropriate method while the corn canopy is still open. This method is not limited by field-workability, and can be successful if the soil is wet or rain occurs shortly after planting (Wilson et al., 2013). Planting methods that achieve greater seed-soil contact may be more successful under drier conditions (Boyd and Van Acker, 2003; Hakansson et al., 2013), although environmental conditions in this study did not demonstrate this potential. A national survey of farmers (SARE-CTIC, 2016) identified cover crop establishment and time/labor required for planting and management as the top perceived challenges to integrating cover crops. This study and efficiency analysis provide a frame of reference for comparing both the speed and benefit of different establishment methods.

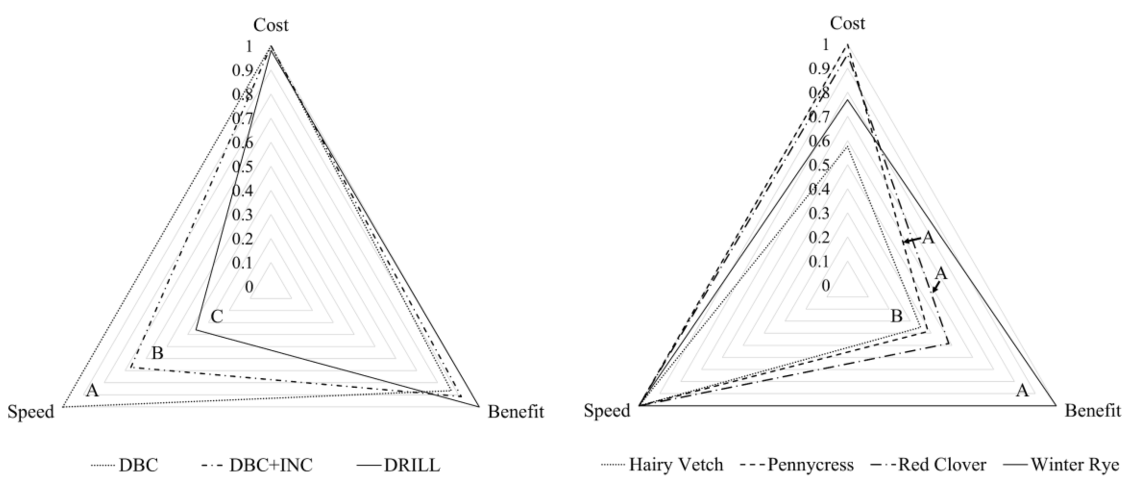


**Figure 9.** Comparison of cost, speed, and benefit (spring cover crop biomass) of three cover crop planting methods (left) and four species (right): hairy vetch, winter rye, red clover, and pennycress. Means are normalized on a 0 to 1 scale. Management efficiency is scored as the area of the triangle. Within panels, triangles with the same letter are not significantly different according to Fisher’s LSD at $P \leq 0.05$.

## OUTCOMES (OBJ. 1)

### *Soil Loss Modeling*

Cover crop biomass data and cropping practice information were applied to the Revised Universal Soil Loss Equation 2 (RUSLE2) to gauge cover crop effects on soil security. For presentation at the national ASA meetings, this work was combined with cover cropping data from other studies to assess the function and efficacy of the equation. The overall findings indicated that RUSLE2 generally over-estimated soil loss compared to empirical measurements. However, RUSLE2 estimations were valuable to inform relative comparisons between cropping practices and environments.

For this study, cover crop biomass from all species was considered, as well as the differences in soil disturbance created by two of the planting methods. For example, the high-clearance drill would create a greater disturbance than the broadcasted planting method. The drill also generally resulted in greater cover crop biomass, and these effects appeared to balance each other out as no differences were shown between planting methods within the cover crops that overwintered (Figure 10). As the MIX did not over-winter, the greater disturbance from the drill was not offset by spring biomass; therefore, this treatment resulted in greater theoretical soil loss than the no-cover check. All other cover cropping treatments reduced soil loss compared to the no-cover check.

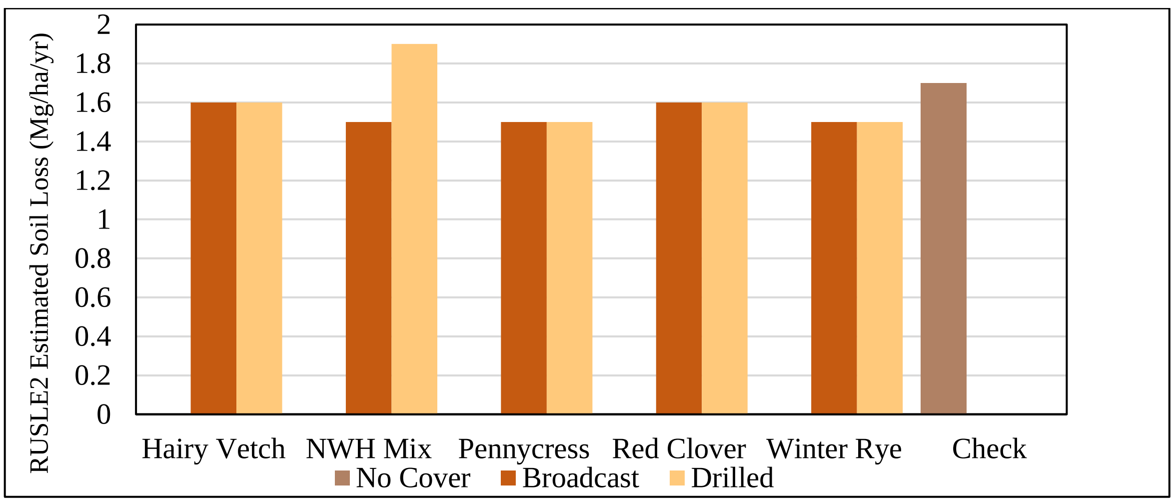


**Figure 10.** Estimated soil loss according to the Revised Universal Soil Loss Equation (RUSLE2) as affected by five cover crop species interseeded via two different planting methods into V7 corn.

### *Soil Nitrate N and Water Content (Noland et al., 2017)*

Cover crops did not affect soil nitrate N content in the fall. This is explained by the low biomass accumulation and corresponding low N uptake (average 1.3 kg N ha$^{-1}$) in the fall. In the spring, however, soil nitrate N was reduced by rye cover crops at Lamberton compared to other treatments, and by rye, hairy vetch, red clover, and pennycress at Waseca compared to the MIX and CHK treatments (Table 5). An important finding is that differences in spring soil nitrate N coincided with spring cover crop biomass production. In all cases where spring soil nitrate N was reduced, spring cover crop biomass was greater than 390 kg DM ha$^{-1}$. Furthermore, increasing spring cover crop biomass was negatively correlated ($R$ = -0.70; $P$ = 0.003) to the differences in soil nitrate N compared to the no cover CHK. This supports that cover crop biomass can serve as an indicator for ecological services in the reduction of excess soil nitrate N. In this study, the greatest effect was from the interseeded rye cover crops, which reduced spring soil nitrate N compared to the no cover crop check by 53 kg $NO_3$-N $ha^{-1}$ at Waseca and by 39 kg $NO_3$-N $ha^{-1}$ at Lamberton.

Rye cover crops also reduced volumetric soil water content compared to the no-cover CHK at the time of cover crop termination at Waseca in 2015 (Figure 11). Although the rye cover crops did not affect measured soil moisture in other site-years. At Waseca in 2015, rye biomass was greater than at Lamberton, and cumulative precipitation in the spring was less than in 2016. These factors help explain why similar reductions were not observed in other site-years.

**Table 5.** Effects of interseeded cover crops on spring soil $NO_3$-N at Waseca, MN and Lamberton, MN.

| Cover crop species | Soil $NO_3$-N content | |
|---|---|---|
| | Lamberton | Waseca |
| | ----------- kg $NO_3$-N $ha^{-1}$ ----------- | |
| No cover crop | 75a† | 109a |
| Winter rye | 37b | 56b |
| Pennycress | 70a | 74b |
| Red clover | 79a | 69b |
| Hairy vetch | 75a | 64b |
| MIX‡ | 67a | 102a |

† Within columns, means with the same letter are not significantly different at $P \leq 0.05$.

‡ MIX, mixture of oat, pea, and tillage radish.

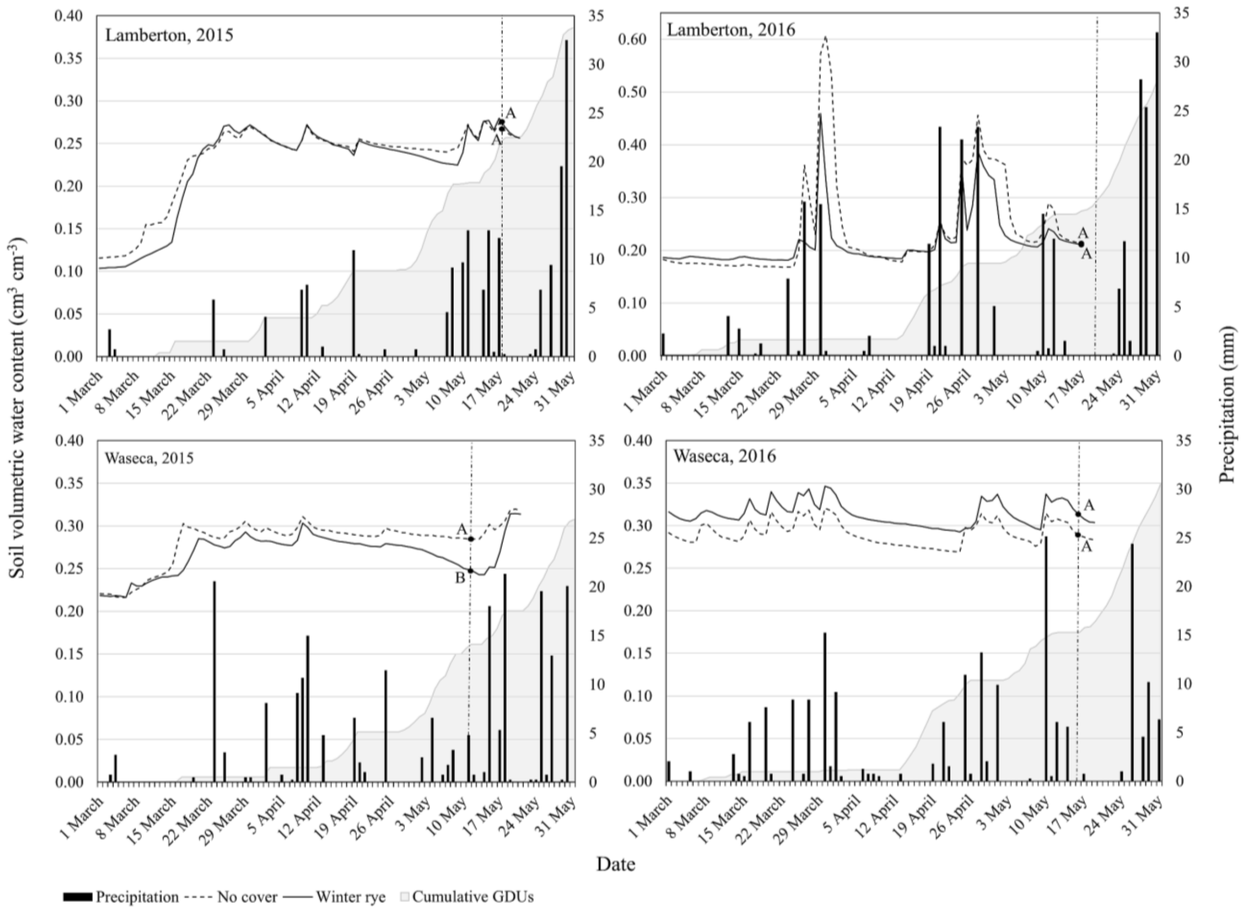


**Figure 11.** Cover crop effects on volumetric soil water content, precipitation, and cumulative growing degree units (GDUs) at Waseca, MN and Lamberton, MN in the spring of 2015 and 2016. Within each panel, soil water values with the same letter are not significantly different at $P \leq 0.05$.

## *Projected Environmental Impact*

To estimate the potential benefit to Minnesota waters, theoretical projections were made based on currently available information. The MDA reports water treatment costs for 5 municipalities in Minnesota with nitrate levels exceeding the acceptable threshold. These range from $0.97 to $5.71 per 1000 gallons and average $2.75. For the purposes of this comparison, we assume that the nitrate-N entering the water supply from agricultural fields with no cover crops results in a contamination level equal to the health threshold of 10 ppm. We also assume that reductions in soil nitrate-N are proportional to reductions in water nitrate-N leaving the field. Given these parameters, and that soil nitrate-N was reduced by 45.5 kg N ha$^{-1}$ with rye cover crops in this study, the projected average cost of treatment would be reduced to $1.39 per 1000 gallons. Table 6 uses this value to project the impact of increasing cover crop acreage on the percent reduction in water treatment costs. According to this projection, if 50% of corn acres were cover cropped, water treatment costs could be reduced by 25%. This illustration is speculative, but provides insight to the impact these cropping practices could have.

**Table 6.** Projected impact of increasing cover crop acreage on the cost of water treatment for excess nitrates (not empirical data, these values are speculative and theoretical).

| Proportion of cover crop acreage | Water treatment cost reduction (%) |
|---|---|
| No cover crops | 0.00 |
| Cover crop (1.8%) | 0.9 |
| Cover crop (10%) | 5.0 |
| Cover crop (20%) | 9.9 |
| Cover crop (50%) | 24.7 |

## OUTCOMES (OBJ. 3)

*Outreach and Extension*

This grant supported two field days specifically geared toward integrating cover crops in existing agricultural systems in Minnesota (Figures 11-12). Furthermore, these findings were presented at six additional field days and 64 educational programs, including workshops, grower meetings, and symposia, directly reaching a combined audience of 3200 stakeholders (producers, landowners, crop advisors, government personnel, and the general public). Findings from this project were also presented at 5 scientific conferences and symposia, including three presentations at the American Society of Agronomy National Meetings. Findings have also been disseminated in online crop news blogs, extension publications, as part of a Ph.D. dissertation and a scientific article that is currently in review with Crop Science. Through these outlets, this information will be accessible by scientific communities, locally, nationally, and globally.

*Personnel Impacts*

This project has also directly supported 6 different student workers, including 4 international students through the MAST (Minnesota Agricultural Student Trainee) program. Through this project, these students were provided with valuable experience and necessary skills as future agricultural professionals and researchers. The project also funded the graduate education (Ph.D.) of Reagan Noland. In addition to the direct implications of this work on regional cropping systems and agronomic understanding, this project has provided Reagan opportunities to develop research skills in conservation agriculture, as well as exposure and involvement with the corresponding extension programming.

*Extended Research Impacts*

Findings from this work were directly leveraged in proposals for expanded and continued research on interseeding cover crops in Minnesota. Three major grants were awarded to the program as a result of these efforts. One was a USDA-NRCS Conservation Innovation Grant to further demonstrate these cover cropping technologies to farmers and expand the scope of the project across multiple planting dates. Another grant, through the Minnesota Department of Agriculture is screening a wide range of cover crop species in mixtures interseeded in both corn and soybean systems, and is tracking the movement of nitrate-N through the soil with high temporal resolution. The third grant is through MDA via the Forever Green Initiative and has provided for the purchase of a fully-adjustable, high-clearance tractor that has become a critical part of the cover crop research program.

**Figure 12.** Reagan Noland (Ph.D. student) discussing the high-clearance InterSeeder with a group of farmers at a field day at Rosemount, MN in 2015.

**Figure 13.** Reagan Noland speaking with a group about the high-clearance Avenger cover crop planter at a field day in Rosemount, MN in 2016.

## CLOSING REMARKS

The primary findings of this research were that cover crops were successfully established via interseeding into corn at the seven leaf collar stage without affecting corn yield. Subsequent soybean yield was also not affected by previous cover crops, with the exception of hairy vetch at Lamberton. Winter rye was consistently among the highest in spring cover crop biomass and N uptake, which consequently resulted in generally lower spring soil nitrate N. The DRILL planting method, which achieved the greatest seed-soil contact, resulted in greater cover crop biomass in the fall compared to DBC for all species except pennycress, and spring cover crop biomass was increased with DRILL and DBC+INC for hairy vetch and red clover. Spring soil water content was reduced by the interseeded rye cover crop in only one of four site-years, when sufficient rye biomass was present and spring precipitation was less. Cover crops that produced $\geq$390 kg DM ha$^{-1}$ in the spring reduced soil nitrate N compared to the no cover crop check, providing a direct improvement to water quality downstream. Overall these findings support that 1) cover crops can be interseeded into corn at the seven leaf collar stage in the upper Midwest without risk of reducing corn yield, 2) interseeded cover crops can sequester excess soil nitrate N in the spring, and 3) cover crops should be completely terminated prior to no-till planting soybean to avoid potential yield reductions. Establishment was generally improved with greater seed-soil contact, and this effect is expected to be greater under drier conditions. However, planting methods achieving the greatest seed soil contact are also the slowest, which should be considered regarding the size of the target area and field conditions at the desired time of planting.

Further research will be required to build complete recommendations; however, we have identified some broad suggestions and important considerations based on the findings of this work. If farmers are interested in interseeding cover crops, we advise they start with a small area as a test. Select a uniform acre or two of the field split it into test strips. Winter rye is relatively cheap and has shown to be one of the most hardy and productive cover crop options. Rye is also easily terminated with glyphosate. If legumes such as red clover and hairy vetch are tested, a sound termination plan needs to be developed, as theses species were difficult to terminate with glyphosate alone. To keep tests at a low cost, farmers can adapt their own broadcast and incorporation mechanism to a high clearance tractor. Alternatively, some custom operators in Minnesota are interseeding cover crops and could potentially plant a small area at low cost to the farmer. These tests would best be done in swaths the same width as the farmer’s combine, so that any effects on main crop yield can be detected. Strips should be replicated at least four times in a field to obtain a good average.

In addition to the agronomic findings of this research, this work supports that cover crops can provide an improvement to water quality issues in Minnesota by reducing the amount of water-mobile N in the soil during otherwise fallow periods. Altogether, this MDA Clean Water Research grant has facilitated improved knowledge and understanding of cover crop interseeding options in Minnesota, supplied invaluable educational opportunities to all students and collaborators involved, and has provided a platform for a rapidly growing and highly productive research and education program. The findings and outcomes of this work will continue to have an impact on agricultural systems and future research and education efforts.

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