Maximizing cereal rye cover crop management for multiple benefits: Cover crop-based organic no-till soybean production

OSCIA Tier 2 Final Report

Highlights:

- Cover crop-based organic no-till soybean production was evaluated at 22 locations (13 observational sites and 9 replicated trial sites) in 2019, 2020 and 2021.
- Across all replicated trial sites, cover crop-based organic no-till soybeans yielded 32.4 bushels/acre, which was 21.1 bu/ac less than soybeans grown with either tillage or herbicides used for weed control. No-till soybeans at observational sites averaged 38.7 bu/ac. Where soybean stands and weed suppression was adequate, yield reductions are believed to be due to a combination of soil moisture depletion and stunting from thick rye mulch.
- Cover crop-based organic no-till soybean production can be done successfully in Ontario, but it is not yet recommended on a large scale. Benefits include reduced labour requirements and soil improvement but yield reductions relative to standard production are significant. Interested growers should assess the system on a small acreage and follow best practices outline at the end of this report.
- Further research is needed to identify opportunities for yield enhancement.

Purpose:

The overall objective of this two-year project was to determine methods to manage a cereal rye cover crop to achieve multiple benefits, while minimizing any negative effects on crop yield. The project had two components: 1) to evaluate spring rye termination timing and its effects on nutrient uptake, weed abundance and soybean development and yield, and 2) to evaluate a cover crop-based organic (or herbicide-free) no-till soybean production system using a roller crimper to terminate cereal rye. This report includes information on the second component. For information on the first, refer to *"Maximizing cereal rye cover crop management for multiple benefits: Spring termination timing"*.

Cover crop-based organic no-till soybean production has been popularized by the Rodale Institute in Pennsylvania. The system uses a roller crimper, a drum with chevron-shaped metal attachments (Figure 1), which crimps the stems of rye (or another suitable plant) once it has reached anthesis and kills it. Soybeans are then typically seeded into the mulch, which, if thick enough, provides season-long weed suppression. The cover crop-based organic no-till system offers advantages over tillage-based production in terms of labour savings and soil health improvements.

Figure 1. A front-mounted roller crimper being used to terminate cereal rye at anthesis in Ontario, June 2019

Research in states with similar climates to Ontario, including Wisconsin and New York, has found that the system can produce comparable yields to wide-row, tillage based organic soybean production. Trials had not been conducted in Ontario prior to this study, however, and on-farm experiences with the system have been mixed. The purpose of this trial was to evaluate cover-crop based organic no-till soybean production, using established best practices, across a range of Ontario soil and climate conditions.

Methods:

Replicated and randomized strips were used to compare cover crop-based organic no-till soybean production with standard production practices. Observational, full field sites of cover crop-based organic no-till soybeans were also monitored. Cereal rye and soybean seeding rates, dates and methods can be found in the results section. Cereal rye biomass, soybean population and seeding conditions, soil temperature and moisture and soybean development and yield were measured.

At the replicated, randomized strip trial sites (e.g. Figure 2), neither tillage nor herbicides were used to manage weeds in the roller crimped rye treatments, except Elora-2021, which received two in-season applications of glyphosate. Either tillage (primary and secondary tillage, tine weeding, inter-row cultivation) or herbicides (at Elora, Bornholm, Seaforth and Woodstock) were used to manage weeds in the no rye control treatment. Most sites were a two-treatment comparison: roller crimped vs. a no-rye control. Soybeans were seeded at a high rate in the roller crimped treatment as per best practice for organic no-till. No-rye control strips were generally seeded at the same time and rate to maintain consistency between treatments.

Figure 2. Aerial view of replicated and randomized plot at Drayton site, spring 2019.

At Bornholm in 2020, additional treatments were included to evaluate the impact of soybean seeding date, soybean seeding rate and cereal rye termination timing. The treatments were:

Rye	Planting date	Seeding rate (seeds/acre)
No rye (control)	May 23	300,000
Roller crimped rye	May 23	300,000
No rye (control)	June 9	300,000
Early terminated rye (sprayed April 27)	June 9	300,000
Roller crimped rye	June 9	300,000
Roller crimped rye	June 9	225,000

At Bornholm and Elora sites in 2021, the following treatments were compared to evaluate the impact of soybean seeding rate and added fertility. Soybean planting dates were the same for all treatments at each site.

Rye	Applied fertility	Seeding rate (seeds/acre)

No rye (control)	None	300,000
Roller crimped rye	None	175,000
Roller crimped rye	None	250,000
Roller crimped rye	None	300,000
Roller crimped rye	60 lbs P_2O_5/acre as monoammonium phosphate in fall 2020 (Elora only)	300,000
Roller crimped rye	60 lbs P_2O_5/acre and 60 lbs K_2O/acre as potash in fall 2020	300,000
Roller crimped rye	60 lbs P_2O_5/acre and 60 lbs K_2O/acre in fall 2020 plus 70 lbs N/acre as urea in April 2021	300,000

Observational sites did not involve different treatments; instead, they were either full or partial fields in which cover crop-based organic no-till soybean production was attempted.

Rye was seeded on an angle (greater than 20º) relative to the direction of crimping at all sites. Common rye was seeded at all sites. Background site information can be found in Table 1.

Table 1. Site descriptions, including soil type, soil test values and previous crop.

Site **Observational (O)** **Strip trial (ST)**	**Soil Type**	**Background Soil Fertility**	**Previous Crop**
2019			
Blyth (O)	Donnybrook sandy loam & Harriston loam	pH: 7.3 OM: 3.8% P (Olsen): 19 ppm K: 91 ppm	Red clover
Drayton-2019 (ST)	Huron & Brookston loam	pH: 6.6-7.6 OM: 4.2-5.2% P (Olsen): 85-86 ppm K: 287-312 ppm	Winter wheat
Elora-2019 (ST)	London loam	pH: 7.6 OM: 3.8% P (Olsen): 8 ppm K: 71 ppm	Silage corn
New Hamburg (O)	Huron silt loam	-	Winter wheat
St. Marys J-2019 (O)	Huron & Perth clay loam	pH: 7.8 OM: 6.8% P (Olsen): 38 ppm K: 211 ppm	Sweet corn (canning)

St. Marys M-2019 (O)	Huron clay loam	pH: 7.8 OM: 5.2% P (Olsen): 20 ppm K: 239 ppm	Sweet corn (canning)
2020			
Bornholm-2020 (ST)	Perth clay loam	pH: 7.3 OM: 2.7% P (Olsen): 16 ppm K: 116 ppm	Winter wheat
Drayton-2020 (ST)	Huron & Brookston loam	pH: 7.5 OM: 3.9% P (Olsen): 72 ppm K: 239 ppm	Mixed grain (barley and oats)
Elora-2020 (ST)	London loam	pH: 6.7 OM: 3.6% P (Olsen): 26 ppm K: 72 ppm	Corn silage
Seaforth (ST)	Perth clay loam	pH: 7.5 OM: 3.8% P (Olsen): 10 ppm K: 68 ppm	Oats
St. Marys D-2020 (O)	Huron clay loam	pH: 7.8 OM: 4.7% P (Olsen): 12 ppm K: 151 ppm	Sweet corn (canning)
St. Marys H-2020 (O)	Huron & Perth clay loam	pH: 7.8 OM: 4.7% P (Olsen): 21 ppm K: 151 ppm	Black beans
St. Marys J-2020 (O)	Huron & Perth clay loam	pH: 7.8 OM: 5.2% P (Olsen): 19 ppm K: 117 ppm	Sweet corn (canning)
St. Marys M-2020 (O)	Parkhill loam	pH: 7.3 OM: 5.4% P (Olsen): 21 ppm K: 213 ppm	Black beans

Woodstock Demo (O)	Guelph loam	pH: 7.5 OM: 2.5% P (Olsen): 9 ppm K: 87 ppm	Immature corn
Woodstock (ST)	Guelph loam	pH: 7.0 OM: 3.1% P (Olsen): 11 ppm K: 51 ppm	Oats / Soybeans
2021			
Bornholm-2021 (ST)	Perth clay loam	pH: 7.5 OM: 5.2% P (Olsen): 10 ppm K: 99 ppm	Winter wheat
Drayton-2021 (O)	Huron loam	-	Spring barley
Elora-2021 (ST)	London loam	pH: 7.4 OM: - P (Olsen): 9 ppm K: 54 ppm	Cereals (various)
St. Marys H-2021 (O)	Parkhill loam & Listowel silt loam	pH: 7.0 OM: 5.0% P (Olsen): 26 ppm K: 102 ppm	Sweet corn
St. Marys M-2021 (O)	Huron clay loam	-	Sweet corn
St. Marys R-2021 (O)	Perth silt loam & silty clay loam	-	Sweet corn

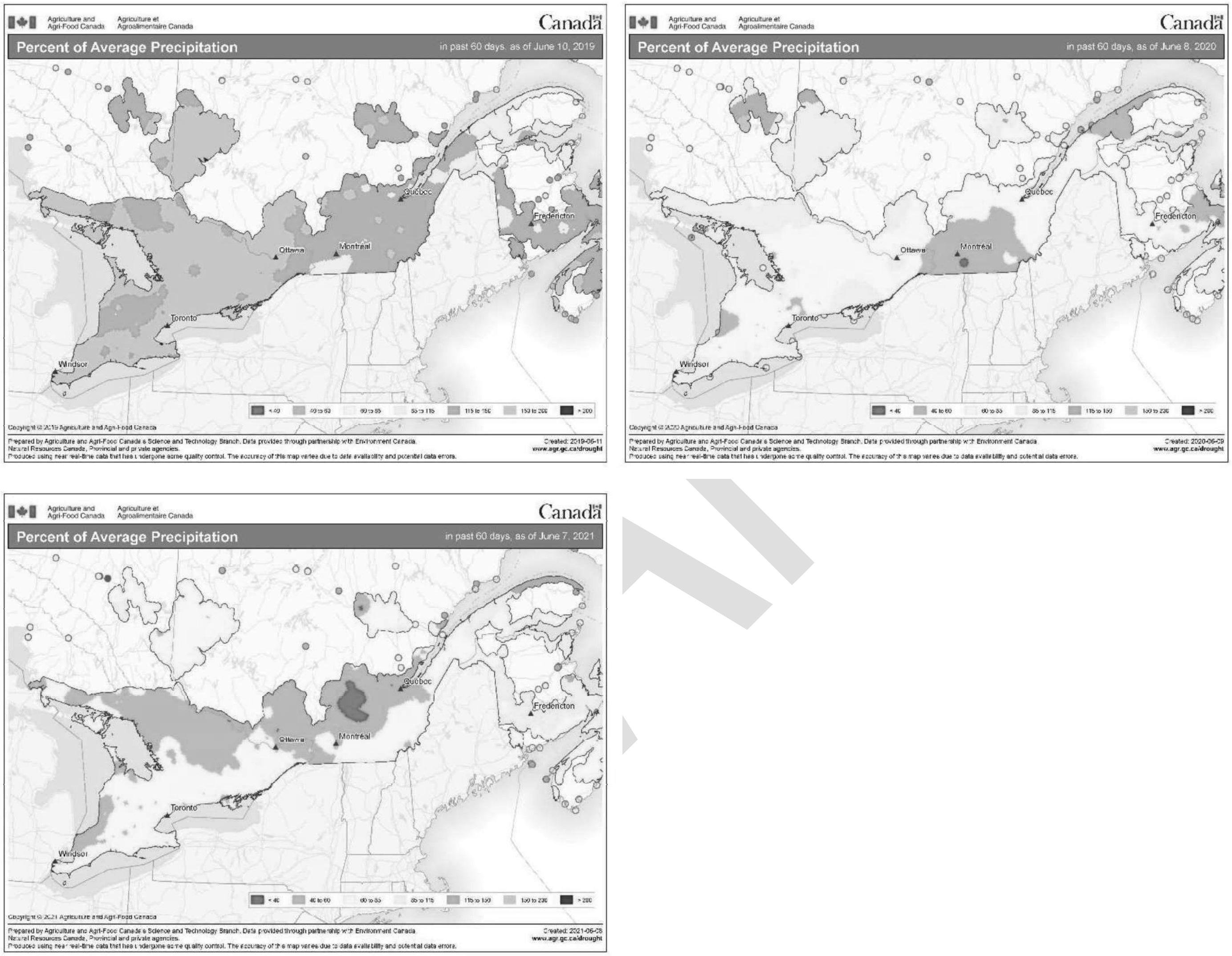
– no data

Weather

Over the three seasons of the trial, the weather varied significantly. Figure 3 shows the percent of average precipitation for the 60 days leading up to the approximate date of crimping (June 10, 2019; June 8, 2020; June 7, 2021). The spring of 2019 was wet, with 15-50% greater precipitation than normal in the trial region. 2020 and 2021 were the opposite, with the region receiving only 65-80% of normal rainfall in May and June both seasons (Figure 3). Temperature was slightly lower than normal from May 14-June 10 in 2019. In 2020 and 2021, temperature for the same period was slightly higher than normal (source: Agriculture and Agri-Food Canada, historic agroclimate conditions).

Rainfall for the remainder of the growing season varied by season. 2019 had average to slightly below average precipitation from mid-June to mid-August, while 2020 rainfall was average for this period. 2021 saw significant rainfall in July and trial locations received average to above average precipitation from mid-June to mid-August (source: Agriculture and Agri-Food Canada, historic agroclimate conditions).

Figure 3. Percent of average precipitation in the 60 days leading up to June 10 (2019), June 8 (2020) and June 7 (2021) for central Canada (Agriculture and Agri-Food Canada).



Site measurements and monitoring

All sites were monitored on a regular basis. At strip-trial sites, observations, measurements and samples were collected from multiple locations within each strip. At observational sites, geo-referenced locations (8-10 per field) were established and used throughout the season for data collection. Measurements included cereal rye biomass and carbon-to-nitrogen ratio at time of termination (Table 2), soil nitrate levels, soybean stands (Table 3), height and growth stage (Table 4) and soybean yield (Table 5). Cereal rye biomass values were estimated in 2021 due to a sample drying issue.

Soil temperature and moisture was measured at the Elora site (2-inch depth) in 2019 and the Bornholm site in 2020 (2 and 12-inch depths) in a minimum of three replicates using sensors and automatic data-loggers (Figure 4).

Figure 4. Soil temperature and moisture sensors installed at the Bornholm site in 2020 (left) and the Elora site, 2019 (right). Readings were logged hourly throughout the growing season.

Yield (adjusted to 13% moisture) was determined by weigh wagon or by combine scale at strip trial sites plots. Yield self-reported by cooperating farmers at observational sites. Statistical analysis was performed on yield data. Different letters indicate a significant difference ($P < 0.10$).

Results:

Cereal rye biomass

Across all sites, the average biomass achieved at the time of termination was just over 5,300 lbs/acre of dry matter (Table 2). According to research from regions such as southern Pennsylvania and North Carolina, a minimum of 8,000 lbs/acre biomass is required for sufficient weed suppression. More northern regions, however, such as upper New York state, have found 6,000 lbs/acre to be sufficient. Early spring growth is also critical for competition with weeds. The Drayton 2019 and 2020 sites had excellent early season canopy coverage (Figure 5a) and reasonable biomass, which contributed to strong weed control both seasons. Other sites, including Elora-2020, produced insufficient rye biomass to compete with and suppress weeds for the season (Figure 5b).

Figure 5. Thick cereal rye stand at Drayton-2020 site on April 30, 2019 (left) compared to a thin stand at the later-seeded Elora-2020 plot on May 1, 2020 (right)

Earlier seeded rye generally had a higher tiller count (Figure 6) and greater biomass (Figure 7). Based on 16-site years, seeding before September 22nd was critical for achieving greater than 5,500 lbs/acre dry; sites seeded after that date generally had low biomass.

Figure 6. Average tillers per square foot, as measured in April 2020, vs. rye seeding date for seven 2020 trial sites.

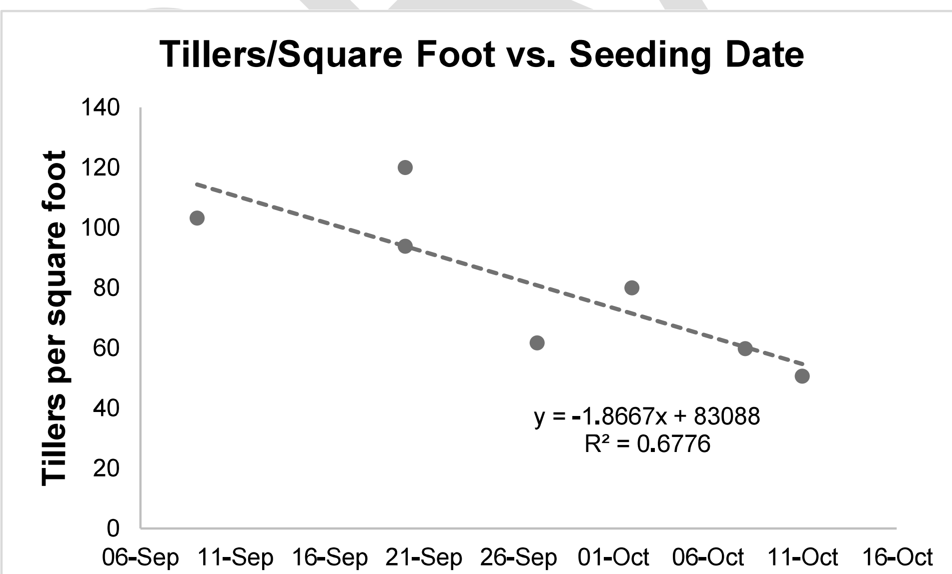
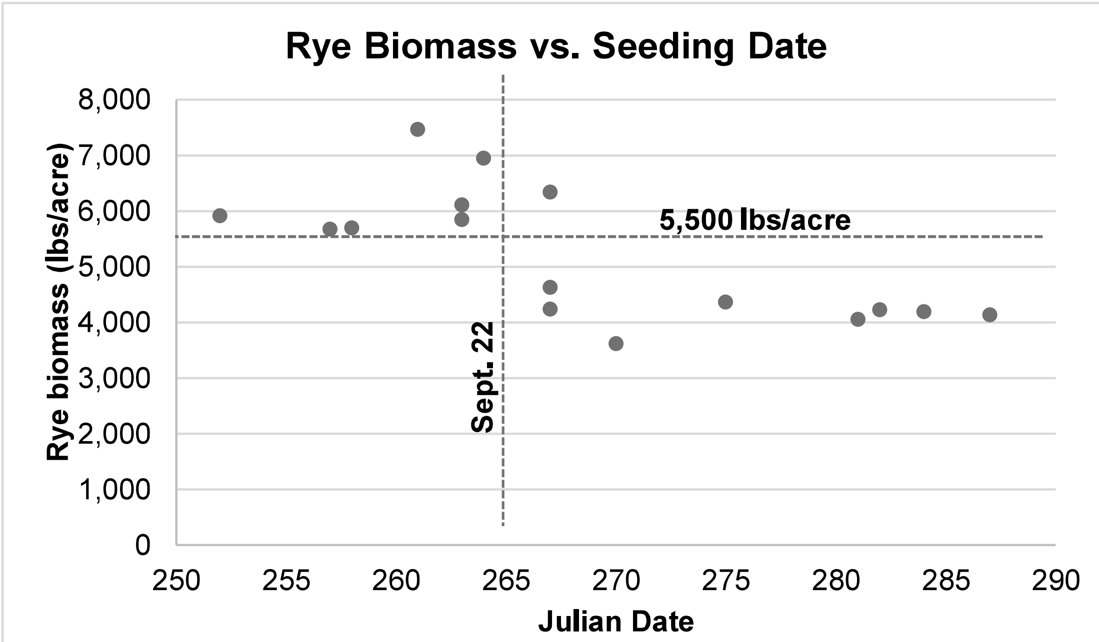


Figure 7. Cereal rye biomass at time of crimping relative to seeding date for 16 sites in 2019 and 2020.



Date of rye crimping varied by site and did not reflect exact timing of rye anthesis, though it gives a reasonable indication. Several sites in 2019 reached anthesis one week or more before crimping. Crimping occurred earliest in 2021 on average (June 4), likely due to warmer conditions in the month of May relative to 2019 and 2020. On average across all sites and all years, crimping occurred on June 8th (Table 2). The earliest date of full anthesis and crimping occurred at the St. Marys sites in 2021 on June 2nd.

Based on three years of data across a range of locations in southern Ontario, anthesis of common rye can be expected in the first or second week of June. Waiting until this time reduces yield potential relative to the more typical late May planting in tillage-based organic production. It is critical to crimp rye and plant soybeans in a timely fashion to capture as much growing season as possible. Seeding an earlier-flowering variety of rye may assist with achieving earlier planting.

It was not possible to determine the impact of rye seeding rate on biomass in this trial. In 2019, both rates resulted in very similar values (5,400 lbs/ac biomass for 168 lbs/ac rate and 5,000 for 100 lbs/ac rate). In 2020, sites seeded at 100 lbs/acre had very low biomass, but they were also all planted in October. Seeding rate should be based on seeding timing and background fertility. When seeding earlier in a high fertility field, the rate can be reduced. When seeding rye later or in a lower fertility field, rates should be increased to compensate for reduced tillering.

Carbon-to-nitrogen ratio of crimped rye at 2019 and 2020 sites varied from 28.2 to 73.3, with an average value of 49.8.

Table 2. Rye crimping date, biomass, carbon-to-nitrogen ratio and rye seeding date and rate across all six sites.

Site	Date of rye crimping	Average cereal rye biomass (lbs/acre dry)	Cereal rye carbon-to-nitrogen (C:N) ratio	Rye Seeding Date	Rye Seeding Rate (lbs/ac)
2019					
Blyth (O)	June 17	7,470	53.3	Sept. 19, 2018	168
Drayton-2019 (ST)	July 8*	5,680	51.4	Sept. 14, 2018	168
Elora-2019 (ST)	June 11** (& 19)	4,240	54.5	Sept. 24, 2018	168
New Hamburg (O)	June 19	5,700	73.3	Sept. 15, 2018	100
St. Marys J-2019 (O)	June 7	6,950	36.0	Sept. 21, 2018	100
St. Marys M-2019 (O)	June 8	4,640	48.6	Sept. 24, 2018	100
2019 Average	**June 12** (excluding Drayton)	**5,780**	**52.8**	**Sept. 20, 2018**	**134**
2020					
Bornholm-2020 (ST)	June 13	3,620	54.5	Sept. 27, 2019	168
Drayton-2020 (ST)	June 17	6,120	59.3	Sept. 20, 2019	168
Elora-2020 (ST)	June 16	4,370	60.9	Oct. 2, 2019	168
Seaforth (ST)	June 6 (& 8)	5,850	52.0	Sept. 20, 2019	168
St. Marys D-2020 (O)	June 8	4,230	42.0	Oct. 9, 2019	100
St. Marys H-2020 (O)	June 8	4,200	52.8	Oct. 11, 2019	100
St. Marys J-2020 (O)	June 8	4,060	28.2	Oct. 8, 2019	100
St. Marys M-2020 (O)	June 9	4,140	43.3	Oct. 14, 2019	100
Woodstock Demo (O)	June 5	5,920	50.4	Sept. 9, 2019	168
Woodstock (ST)	June 5 (& 8)	6,350***	35.7	Sept. 24, 2019	100

2020 Average	**June 9**	**4,886**	**47.9**	**Sept. 29, 2019**	**134**
2021					
Bornholm-2021 (ST)	June 7	4,000-5,500	-	September 12, 2020	160
Drayton-2021 (O)	June 25 (anthesis June 4)	6,000-7,000	-	September 12, 2020	180
Elora-2021 (ST)	June 4	3,500-4,500	-	September 25, 2020	168
St. Marys H-2021 (O)	June 2	6,500-7,500	-	September 24, 2020	120
St. Marys M-2021 (O)	June 2	4,500-5,500	-	September 24, 2020	120
St. Marys R-2021 (O)	June 3	4,500-5,500	-	September 27, 2020	120
2021 Average	**June 4** (excluding Drayton)	**4,833-5,917**	**-**	**Sept. 21, 2020**	**143**
Overall Average	**June 8**	**5,347******	**49.8**	**September 23**	**134**

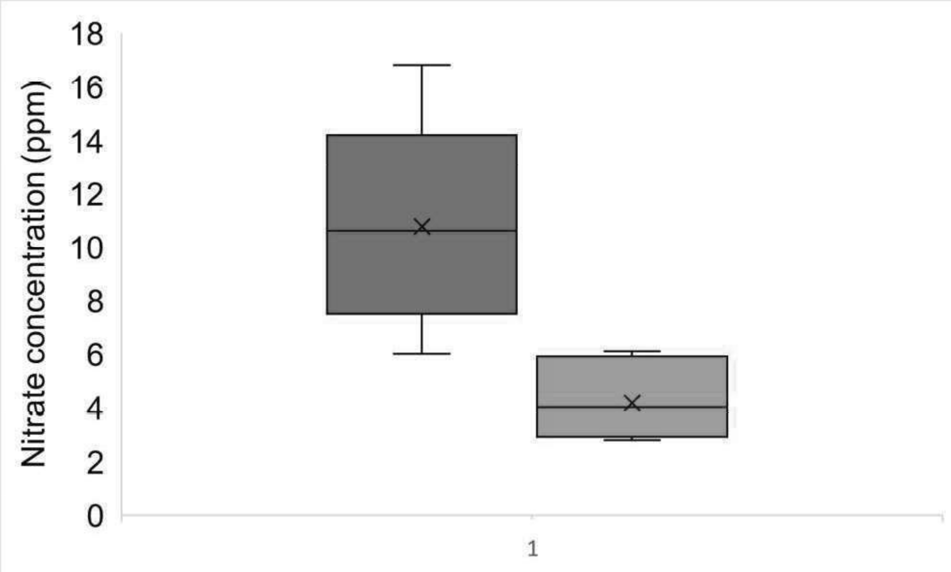
*Soybeans seeded on June 8, 2019. Cooperator unable to crimp until after emergence, so waited until V1-V2 for crimping to avoid negatively affecting soybean stand.
**Crimped too early – rye was at very early anthesis. Followed up with herbicide application and second crimping.
***Fertilized with 100 lbs/acre of nitrogen at green-up in the spring of 2020.
****Calculated using the midpoint of the range provided for 2021.
- no data

Soil nitrate levels

Soil nitrate samples (0-12 inches) were collected just after crimping across seven strip-trial sites in 2019 and 2020. The average soil nitrate level under roller crimped rye was 2.5-times less than under the no-rye control (Figure 8). The largest difference was observed at the Drayton-2020 site, where soil nitrate levels averaged 16.8 ppm under no rye and only 4.1 ppm under the roller crimped treatments.

The uptake of nitrogen by rye contributes to its weed suppression, particularly against weeds that thrive under high fertility conditions. The decrease in available nitrogen under the organic no-till system may also help explain the slow early-season soybean growth that was observed (see Soybean growth and development section).

Figure 8. Box and whisker plots showing the median and average (x) nitrate concentrations (0-12 inches) from 7 strip-trials in 2019 and 2020.



No rye (control) Roller crimped

Soybean stands

Seeding soybeans to a sufficient depth, closing the seed slot and achieving an acceptable stand is critical to the success of the system. It is recommended to seed soybeans at a higher rate than normal, anywhere from 225,000-300,000 seeds/acre in organic systems. All strip-trial sites were seeded at 300,000 seeds/acre in 2020 and 2021. Farmer cooperators at the St. Marys sites opted for much higher seeding rates in 2019 and 2020, in part to compensate for thin rye stands, which resulted in thicker soybeans stands on average. Averaged across strip-trial sites in 2020 and 2021 seeded at 300,000 seeds/acre, the average plant stand for the no rye control was 23% higher (240,000) than the roller crimper treatment (195,000) (Table 3).

No-till drills and planters equipped for high-residue conditions were used to seed soybeans. Generally, it is recommended to use a modified planter with sufficient down-pressure, sharp cutting coulters or openers and appropriate closing wheels. The drilled fields, on average, achieved acceptable stands; slot closure, however, was not achieved by any drill across five sites in 2019 due to moist conditions under the rye at seeding. Fortunately, ample rainfall after seeding across all sites ensured adequate germination and emergence. Dawn Gaugetine closing wheels were used with good success in 2020 and 2021 on the planter used at Elora, Bornholm and Woodstock sites to address this concern (Figure 9).

Figure 9. Dawn Gaugetine closing wheels used for seeding soybeans into rye mulch at project sites in 2020.

Table 3. Soybean population, seeding rate, method, variety and planting date.

Site	Plants per acre		Seeding rate (seeds/acre)	Seeding method	Soybean variety (relative maturity)	Planting date
	No rye (Std. Dev.)	Roller crimped (Std. Dev.)				
Blyth (O)	n/a	122,000 (58,100)	220,000	Drill, 7.5" and 15"	Colby (1.1)	June 17
Drayton-2019 (ST)	138,000 (13,700)	188,000 (–)	200,000 (no rye) 250,000 (crimp)	Drill, 7.5"	Panorama (0.3)	June 8
Elora-2019 (ST)	159,000 (22,000)	87,500 (65,500)	220,000	No-till planter, 15"	DKB04-41 (0.4)	June 12
New Hamburg (O)	n/a	153,000 (22,000)	200,000	Drill, 15"	OAC Strive (0.4)	June 13
St. Marys J-2019 (O)	n/a	175,500 (43,000)	312,000	Drill, 7.5"	OAC Strive (0.4)	June 7
St. Marys M-2019 (O)	n/a	248,500 (37,100)	427,000	Drill, 7.5"	Avatar (1.6)	June 8
2019 Average	**n/a**	**162,000**	**271,500**	**n/a**	**0.7**	**June 11**

Bornholm-2020 (ST)	207,000 (41,200)	119,500 (48,500)	300,000	Planter, 15”	S07-K5X (0.7) & S04-D3 (0.4)	May 23 & June 9
Drayton-2020 (ST)	206,000 (25,400)	185,000 (61,300)	200,000 (no rye) 270,000 (crimp)	Drill, 7.5”	Panorama (0.3)	May 24
Elora-2020 (ST)	246,000 (42,000)	175,500 (71,600)	300,000	Planter, 15”	DKB04-41 (0.4)	June 15
Seaforth (ST)	50,500* (23,000)	161,000 (48,700)	200,000 (no rye) 300,000 (crimp)	Drill, 7.5”	S07-M8 (0.8)	June 4
St. Marys D-2020 (O)	n/a	406,000 (67,700)	500-600,000**	Drill, 7.5”	Avatar (1.6)	June 2
St. Marys H-2020 (O)	n/a	473,500 (152,300)	500-600,000**	Drill, 7.5”	Avatar (1.6)	June 3
St. Marys J-2020 (O)	n/a	329,500 (162,400)	400-500,000**	Drill, 7.5”	S16-F5 (1.6)	June 1
St. Marys M-2020 (O)	n/a	340,500 (145,000)	~400,000	Drill, 7.5”	Avatar (1.6)	June 3
Woodstock Demo (O)	278,000 (11,000)	246,000 (8,100)	300,000	Planter, 15”	Altitude R2 (0.6)	June 5
Woodstock (ST)	260,000 (22,000)	240,000 (30,300)	300,000	Planter, 15”	Altitude R2 (0.6)	June 5
2020 Average	**239,000*** **	**193,000*** **	**372,000**	**n/a**	**1.1**	**June 3**
Bornholm-2021 (ST)	183,000 (46,400)	174,000 (30,000)	300,000	Planter, 15”	P07A18X (0.7)	June 7
Drayton-2021 (O)	–	185,000 (71,400)	300,000	Drill, 7.5”	Panorama (0.3)	June 7
Elora-2021 (ST)	263,000 (30,600)	216,000 (43,000)	300,000	Planter, 15”	P06A13R (0.6)	June 10
2021 Average	**223,000**	**192,000**	**300,000**	**n/a**	**0.5**	**June 8**
Overall average	**n/a**	**182,222**	**314,500**	**n/a**	**0.8**	**June 7**

– no data
* stand establishment issue due to cereal rye stubble and inadequate seed to soil contact
** seeding rate error by cooperating farmer. Intended seeding rate was 400,000.
*** data from St. Marys sites and Seaforth site excluded

Seeding and stand issues were most pronounced at the Blyth and Elora sites in 2019 and the Bornholm and Elora sites in 2020. At the Elora-2019 (Figure 10) and 2020 sites, as well as Bornholm, crimping after planting causes issues in emergence under tractor tire tracks. Seeds germinated but were not able to emerge underneath compacted surface soil. At the Blyth site, the drill's inability to cut through thick rye residue (Figure 10) resulted in stand gaps. In situations where high rye biomass is achieved, sharp, well-maintained equipment is critical.

Figure 10. An example of where the no-till drill was unable to cut through rye residue and place the seed into the soil at the Blyth site (left). On the right, a compromised soybean stand in a roller crimped strip at Elora in 2019.

Evaluation of seeding rates (2021)

Three different seeding rates were evaluated at the Bornholm and Elora small plot sites in 2021. Plant stands from each seeding rate are summarized below (Table 4). Given the late seeding dates (June 7th and 10th for Bornholm and Elora, respectively) and challenging seedling environment due to thick rye mulch, it is clear from these results that 175,000 is too low a seeding rate for the organic no-till system. At Bornholm, yield increased at each successively higher seeding rate (See yield section below for details). At Elora, 250,000 and 300,000 seeds/acre rates resulted in greater yields than the 175,000 seeds/acre rate. A final plant stand of 93,000-107,000 plants per acre was not enough to maximize yield.

Applying 70 lbs/ac nitrogen at rye green-up resulted in a thicker stand of crimped rye, which slightly reduced the soybean stands at both sites. Plant stands were greater at every seeding rate at Elora, due likely to higher soil moisture at planting.

Table 4. Soybean plant stands at various seeding rates and nitrogen treatments (rounded to the nearest 1,000).

Seeding rate (seeds/acre)	Soybean stand (plants/acre)		
	Bornholm	Elora	Average
175,000	93,000	107,000	100,000
250,000	135,000	166,000	150,000
300,000, 70 lbs/ac nitrogen	149,000	193,000	171,000
300,000, no nitrogen	174,000	216,000	195,000
300,000, no rye	183,000	263,000	223,000

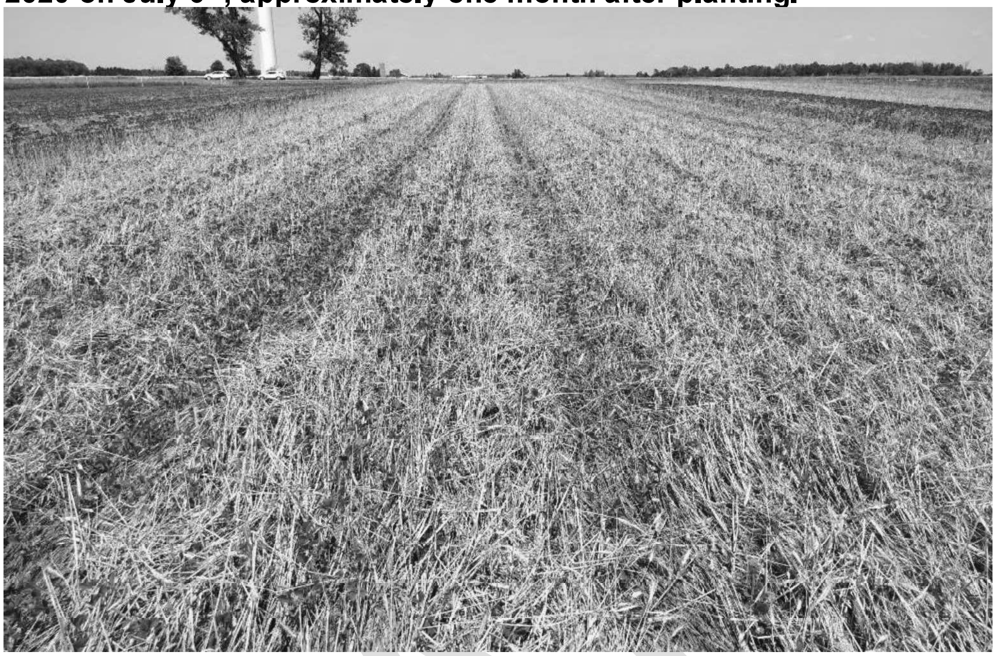
Soybean growth and development

At strip-trial sites, soybeans planted into roller crimped rye typically lagged one growth stage behind the no-rye control on average and were also much shorter (Table 5). Early season growth of soybeans in the rye mulch was very slow, as seen in Figure 11. At most sites, soybeans in crimped rye were two-thirds the height of no-rye soybeans right up until harvest. In the driest growing season (2020), soybeans in crimped rye attained only half the final height of the no-rye control soybeans at the Drayton strip-trial site. At the Elora site in 2019, which began with excess moisture, soybeans in crimped rye almost caught up to the no-rye control soybeans by late August (Table 5).

Table 5. Average soybean height and growth stage at various points throughout the season at the Drayton and Elora sites in 2019.

Date	Drayton-2019				Elora-2019			
	No Rye (Control)		Roller Crimped		No Rye (Control)		Roller Crimped	
	Height (cm)	Growth stage	Height (cm)	Growth stage	Height (cm)	Growth stage	Height (cm)	Growth stage
July 8	-	-	-	-	15.4	V2	9.2	VC-V1
July 22	48.4	R2	25.2	R1	-	-	-	-
August 20	72.5	R6	43.5	R5	59.5	R5	51.0	R4.5

Figure 11. Soybeans in a roller crimped treatment at the Seaforth site in 2020 on July 6th, approximately one month after planting.



Weed effects

Weed density counts were made at two sites in the 2020 season in June. At the Drayton-2020 site, the presence of crimped rye drastically reduced the density of the predominant species, pigweed and lamb's-quarters (Figure 12). Mechanical weed control by tillage effectively managed weeds on the no-rye control, while weed suppression by the rye mulch also proved effective throughout the season. By harvest, the crimped rye strips had some patches of Canada thistle coming through but were quite a bit cleaner than the no rye control (Figure 13).

Figure 12. Weed density, expressed as plants per square metre, at the Drayton-2020 site for five prominent weed species. Measured at the V1 stage for soybeans (June 12, 2020).

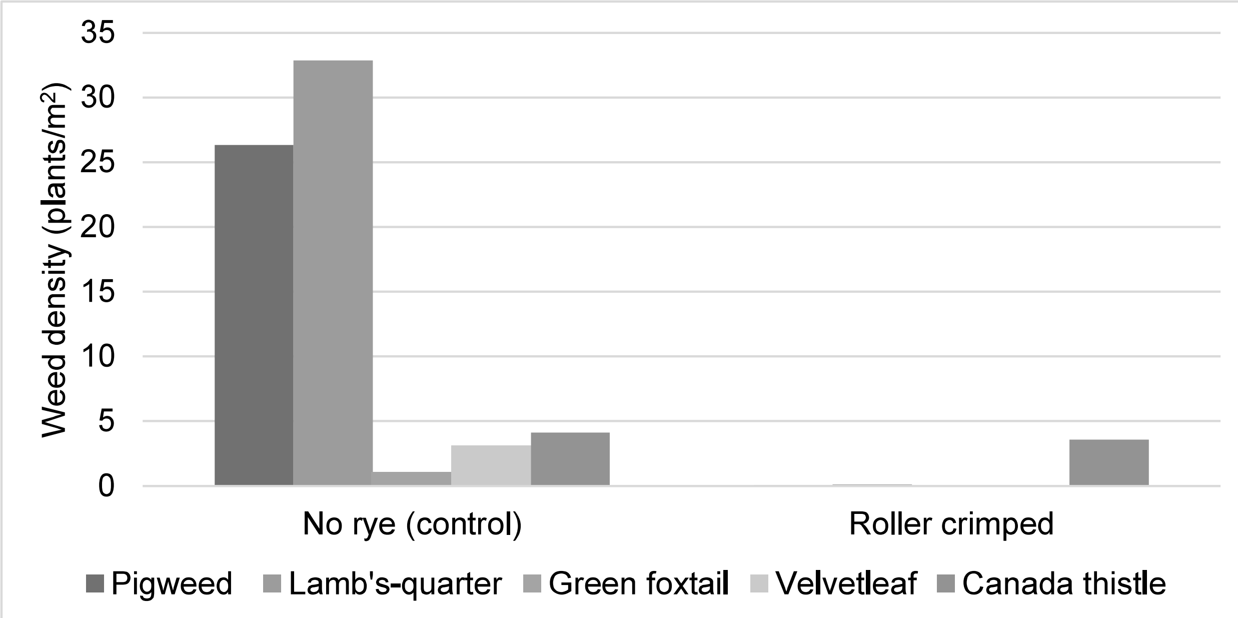


Figure 13. Presence of weeds by season's end at the Drayton-2020 site. Fewer weeds in the organic no-till rye strips (right) made for easier combining than in the no-rye control strips (left).

While the rye also greatly reduced weed pressure at the Elora-2020 site, it was not effective as a full-season weed suppressor. With a much higher weed density, the crimped rye strips still had 50 witchgrass plants/m^2 (Figure 14). Because the mulch was not thick enough to prevent light from reaching the soil, without supplementary weed control witchgrass outcompeted the soybeans as the season progressed (Figure 15).

Figure 14. Weed density, expressed as plants per square metre, at the Elora-2020 site for four prominent weed species. Measured at the unifoliate stage for soybeans.

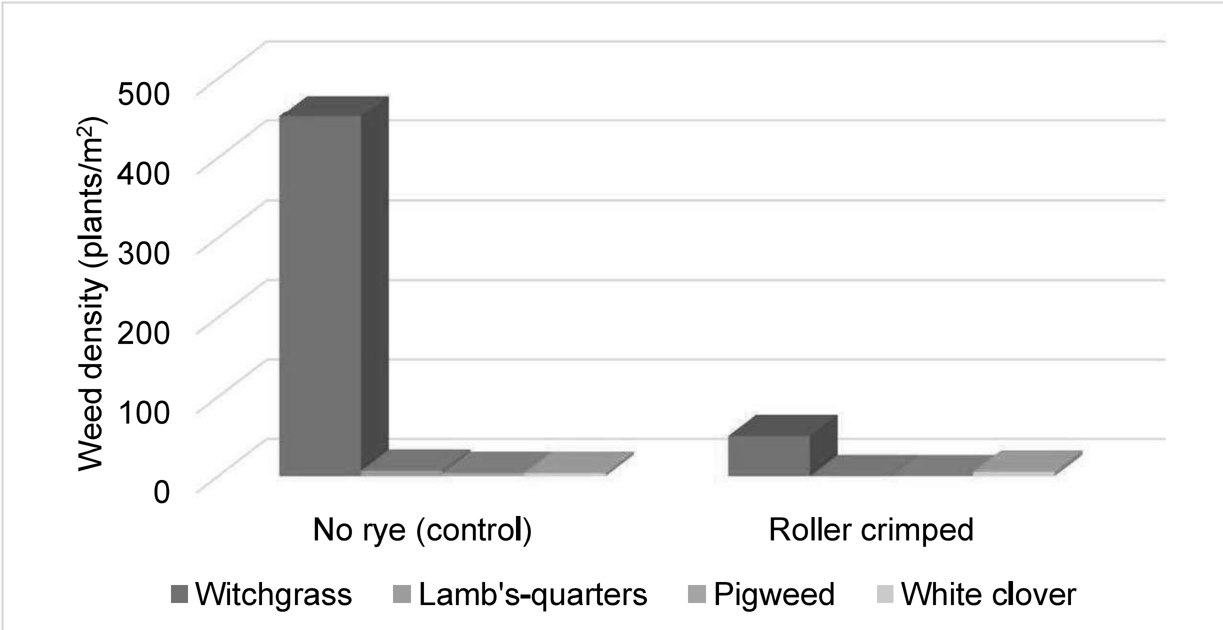


Figure 15. A comparison of a no-rye control vs. a roller crimped treatment at the Elora-2020 site on July 15th (left). The photo on the right shows the roller crimped treatment on September 3rd.

Soil moisture and temperature

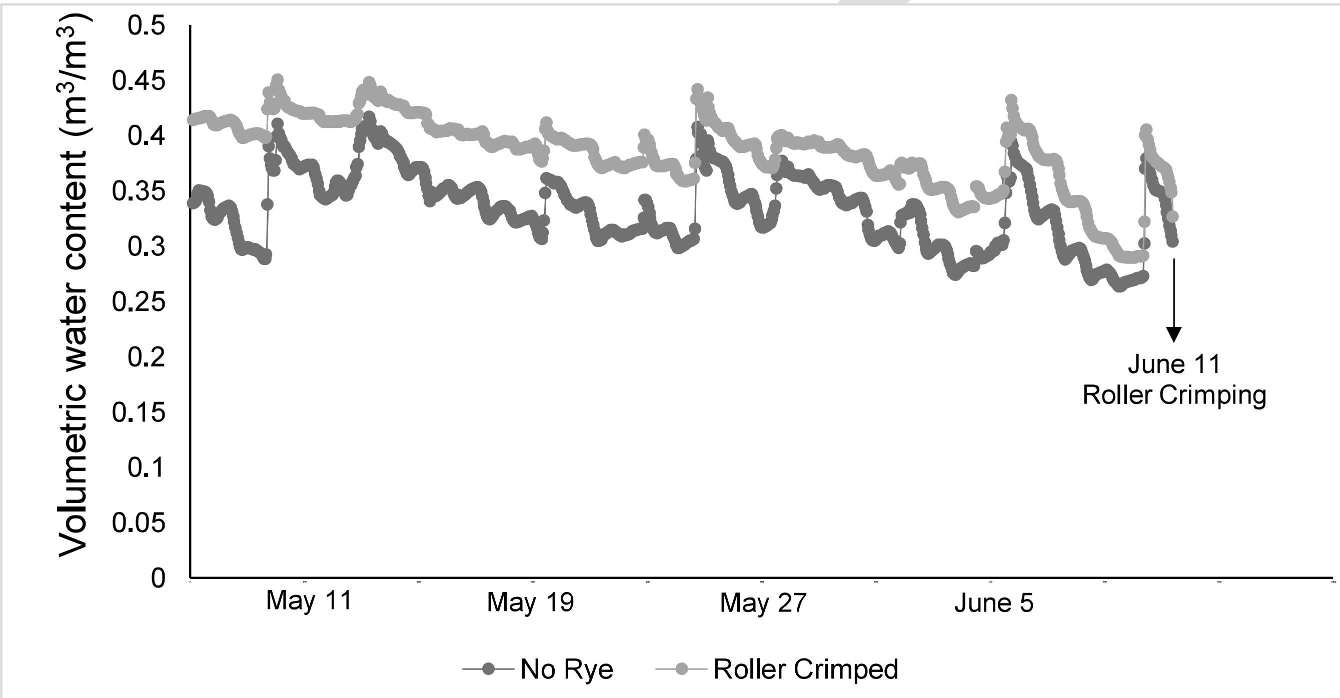
Spring

Soil moisture was measured at 2-inch depth, mid-row, in each of the treatments at the Elora-2019 site from late April until harvest. Figure 16 shows the difference in soil moisture from May 7th to June 11th. During this period, soil in the rye treatment was wetter than the no-rye control. The greatest difference in moisture occurred in early May and the gap lessened toward early

June. By the date of crimping, soil moisture was only slightly higher in the crimped rye treatment.

The difference in soil moisture was likely due to reduced evaporation from the soil underneath the rye during the wet spring of 2019. As the rye grew rapidly and headed out, however, it began transpiring much larger amounts of water, which helped dry out the soil.

Figure 16. Average soil moisture at the Elora-2019 site. Moisture at 2-inch depth in no-rye control treatment (blue) and roller crimped treatment (grey) from May 7 to June 11, measured hourly.



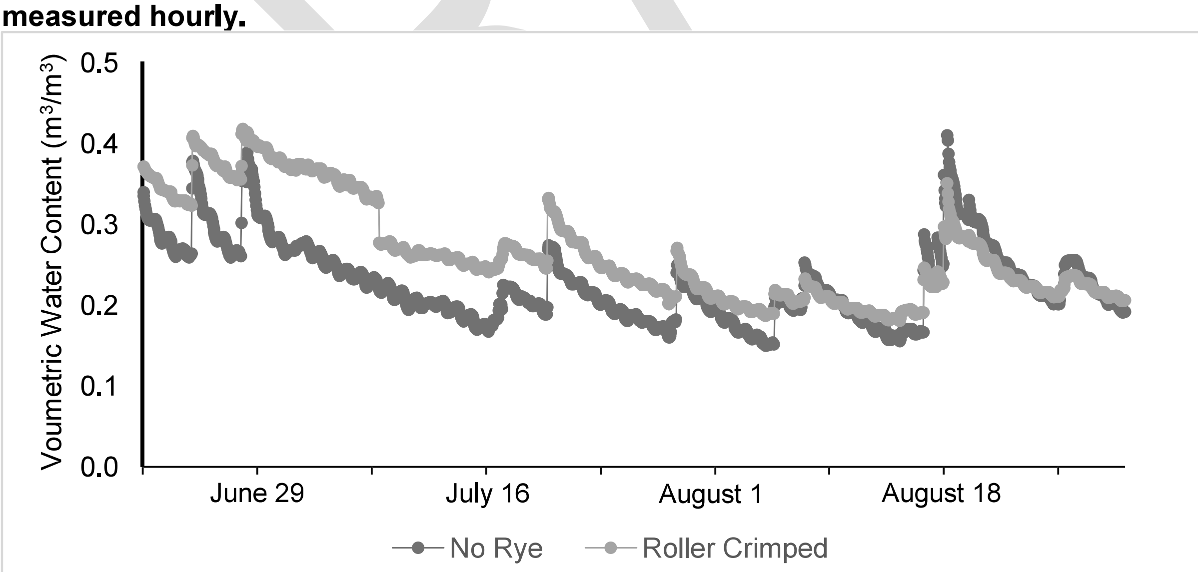
At the Bornholm site in 2020, the opposite effect was observed (Figure 17). Soil under rye was consistently drier from the period of May 23 until planting on June 9th. Even following over 1-inch of rainfall on June 10th, soil moisture was lower in the rye treatment throughout the month of June. This highlights the risk of soil moisture depletion from cereal rye in a drier-than-normal spring.

Figure 17. Average soil moisture at the Bornholm site in 2020. Moisture at 2-inch depth in no-rye control treatment (blue) and roller crimped treatment (grey) from May 23 to June 23, measured hourly.

Summer

In 2019 at Elora, soil moisture levels remained higher under the roller crimped treatment after planting (Figure 18). The rye mulch on the soil surface helped to reduce evaporation and maintain higher soil water content following rainfall events. This was important from June 29th through to July 17th, during which time there was no rainfall. As the season progressed and the soybeans canopied, the difference between treatments was reduced.

Figure 18. Average soil moisture at the Elora-2019 site. Moisture at 2-inch depth in no-rye control treatment (blue) and roller crimped treatment (grey) from June 21 to August 31, measured hourly.

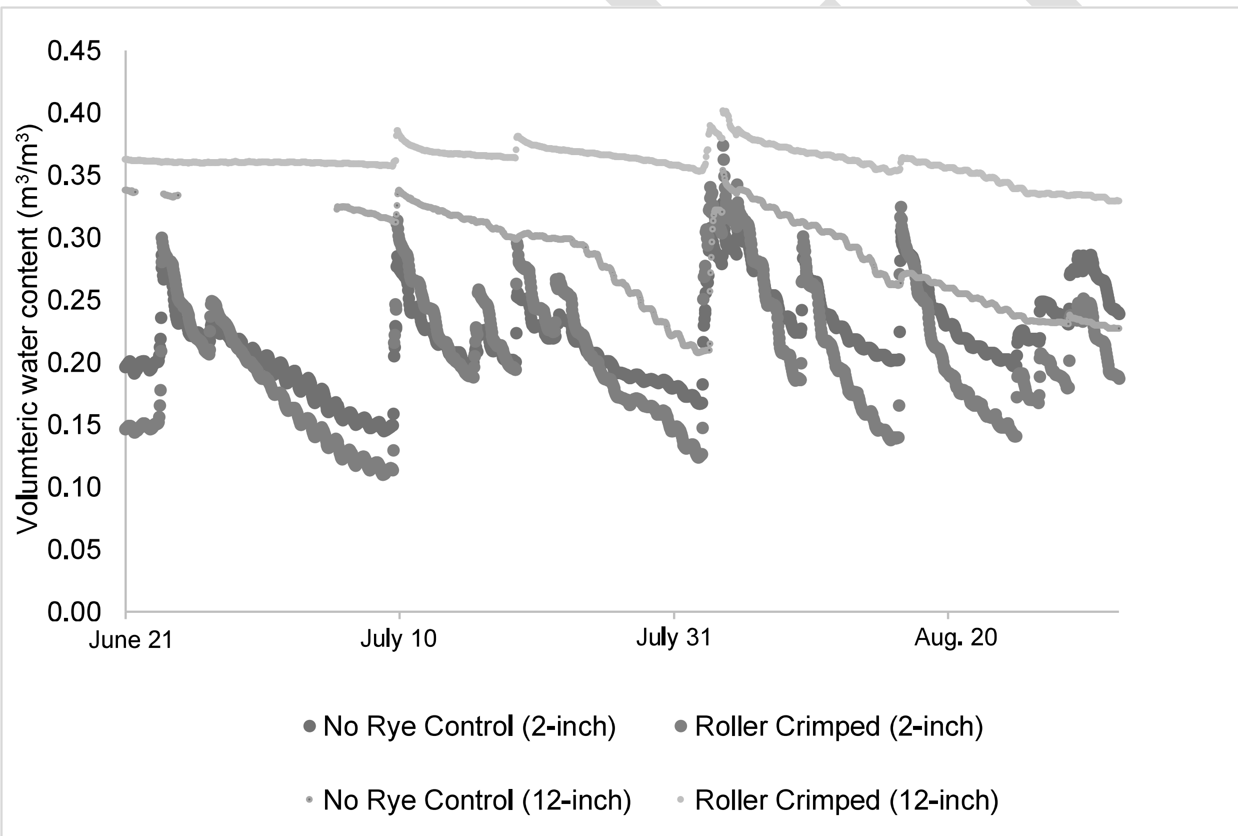


At the Bornholm site in 2020, once again the opposite trend was observed (Figure 19). The roller crimped treatment had persistently lower soil moisture at 2-inch depth throughout the summer. This was likely due in part to depleted moisture levels from the rye, which was not terminated until June 13. Also, the rye mulch was not very thick, which may have limited its ability to conserve moisture near the soil surface.

Sensors at 12-inch depth showed the reverse: the roller crimped treatment had consistently higher soil moisture than the no rye control. It's hypothesized that this is because the soybeans in the control treatment grew much more rapidly and developed a deeper root system that was able to access moisture in the subsoil.

Increased access to moisture in the subsoil may be a further explanation as to the slower draw-down of soil moisture at 2 inches in the control treatment. With limited root systems, soybeans in the roller crimped treatment were almost entirely dependent on soil moisture in the upper portion of the soil profile. Soybeans in the no rye control appeared to have access to moisture in both the topsoil and subsoil.

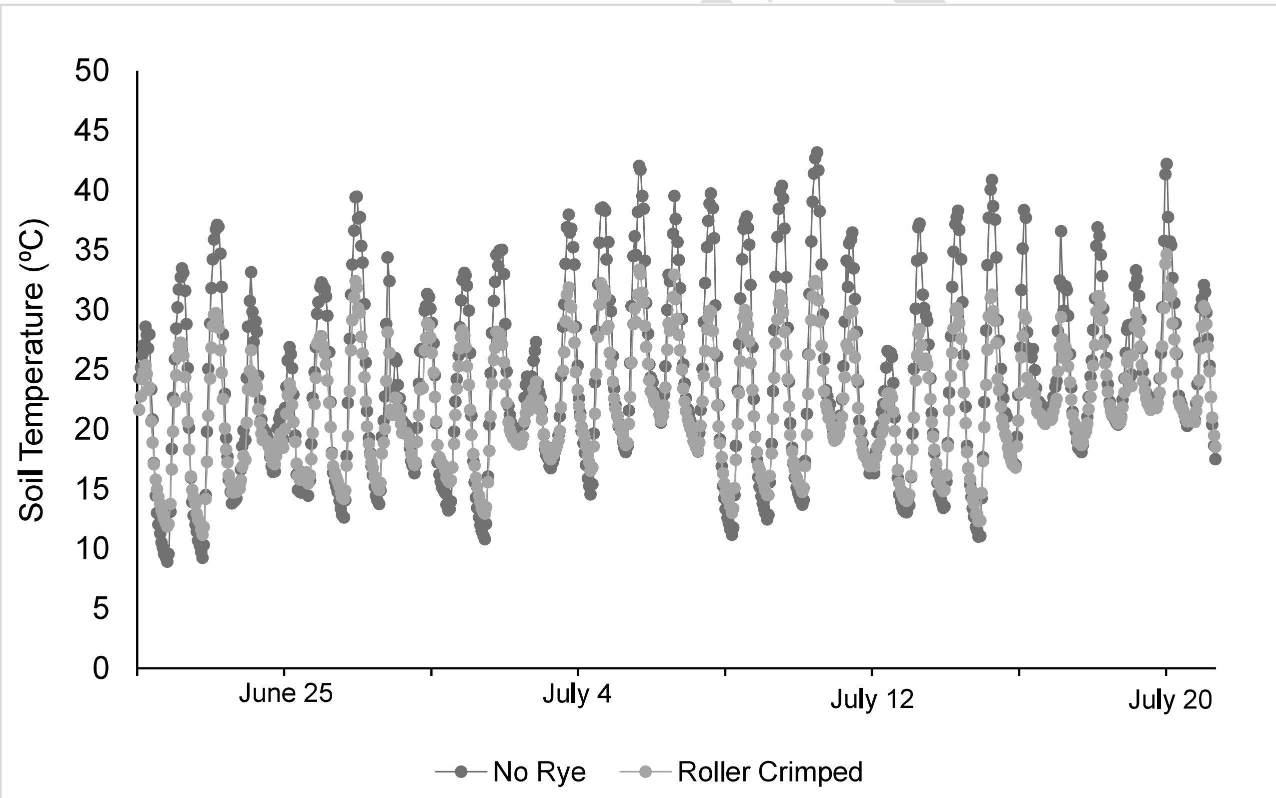
Figure 19. Average soil moisture at the Bornholm site in 2020. Moisture in the no-rye control treatment (dark blue: 2-inch, light blue: 12-inch) and roller crimped treatment (dark grey: 2-inch, light grey: 12-inch) from June 21 to August 31, measured hourly.



Soil temperature

In the spring, rye slowed the soil from warming compared to the no-rye control at Elora-2019 – daily maximum temperatures under rye were 5-7ºC lower in late May and early June. Throughout the summer, the rye mulch had a moderating effect on soil temperature. Soil in the roller crimped treatment had lower daily maximum temperatures and higher daily minimum temperatures than the no-rye control treatment (Figure 20). The soil temperature surpassed 40ºC five times under the no-rye control but remained below 35ºC throughout the hottest part of the season in the roller crimped rye treatment.

Figure 20. Average soil temperature (ºC) at 2-inch depth in no rye (control) treatment (blue) and roller crimped treatment (grey) from June 21 to July 21, 2019, measured hourly.



Yield results

Strip trial sites

The average soybean yield across nine strip trial sites in 2019, 2020 and 2021 in the roller crimped system was 32.4 bushels/acre, which was 21.1 bu/ac less than the no-rye control yield of 53.5 bu/ac (Table 5). The difference in yield was greater in 2020 (25.8 bu/ac) than in 2019 (11.5 bu/ac) or 2021 (18.5 bu/ac). It should be noted that Elora (2019, 2020, 2021), Bornholm (2020, 2021) and Woodstock (2020) strip trials had no-rye control treatments that were managed with conventional production practices (fungicide and insecticide seed treatment, 15-inch row spacing and herbicide applications).

While insufficient mulch and weed pressure, as well as soybean stand damage from crimping, were factors in the low yields at a couple of sites, they did not fully explain the yield reduction. The Drayton and Seaforth sites in 2020, for example, had acceptable weed suppression, but both yielded below 25 bu/ac. It's believed that dry soil conditions in May and June were exacerbated by the cover crop-based organic no-till system. This, in turn, severely stunted vegetative growth, root development and limited yield potential, as seen in Figure 21. Soybeans in roller crimped treatments at sites in 2020 had a 30% lower pod count of those in the no rye treatment. Slightly smaller seed size likely further contributed to reduced yields.

Figure 21. Soybeans in a roller crimped strip at the Drayton-2020 site on August 12th. Given a May 24th planting date and narrow spacing, these beans should have canopied well before this date.

Despite ample in-season rainfall and full weed suppression at strip-trial sites, soybean yields in crimped rye still lagged behind the no-rye control in 2021 (Table 5). Dry conditions under rye mulch delayed soybean emergence for an estimated 1-2 weeks following planting at Bornholm (Figure 22), which hampered yield potential. At Elora, however, a 10.7 bu/acre yield reduction was observed under crimped rye although herbicides were used to supplement rye weed suppression and ample soil moisture was present throughout the growing season.

Yield reductions in organic no-till soybean production reported here are similar to those found under dry spring conditions in trials at Cornell University in New York state. Aside from soil moisture depletion, other studies have suggested that reduced soybean nodulation and nitrogen immobilization under crimped rye may be another contributor to delayed growth and development. Slow early-season growth may be a stronger yield limitation in a shorter growing season region like Ontario.

Figure 22. Significantly drier soil under rye relative to no-rye strip at Bornholm site on day of crimping and planting in 2021 (June 7; left). Soybean was seeded into dry soil under rye.

Observational sites

Cover-based organic no-till soybeans yields at observational sites averaged 38.7 bu/ac (35 bu/ac including Blyth 2019 site) across three seasons, ranging from a crop failure to 55 bu/acre (Table 6). The higher yield for these sites was due, in part, to grower experience with the organic no-till system, as well as more timely planting. Observational sites were also concentrated near St. Marys, in a growing region with a longer season and higher crop heat units than some of the strip-trial sites. Higher relative maturity soybeans were also grown there.

Sharp openers, increased down-pressure and a higher soybean seeding rate may have helped to overcome some of the issues experienced at the unharvestable Blyth site in 2019. At the St. Marys M site in 2019 and all St. Marys sites in 2020, narrow row spacing at a high soybean seeding rate enabled the grower to achieve reasonable weed suppression despite low rye biomass. At St. Marys M-2021, a light rye mulch allowed for substantial weed competition, which reduced soybean yield. Earlier seeding in fall 2020 would have helped to address this yield limitation. As with the strip trial sites, it's believed that low soil moisture conditions made worse by rye contributed to the lowest yields for observational sites in 2020.

Table 6. Summarized yield results from all sites. All values corrected to 13% moisture. Statistically significant differences are shown by different letters.

Site	Yield (bu/acre)	
	No Rye (Control)	Roller Crimped
2019		

Blyth (O)	-	0*
Drayton-2019 (ST)	45.4 A	36.8** B
Elora-2019 (ST)	48.8 A	34.5 B
New Hamburg (O)	-	-
St. Marys J (O)	-	38
St. Marys M (O)	-	47
2019 Average **(strip-trial sites only)**	**47.1**	**35.6**
2020		
Bornholm-2020 (ST)	60.7 A	33.2 B
Drayton-2020 (ST)	46.9 A	22.9 B
Elora-2020 (ST)	66.2 A	19.3 B
Seaforth (ST)	35.3*** A	24.9 B
St. Marys D-2020 (O)	-	30
St. Marys H-2020 (O)	-	32
St. Marys J-2020 (O)	-	28
St. Marys M-2020 (O)	-	35
Woodstock Demo (O)	-	-
Woodstock (ST)	53.0 A	32.7 B
2020 Average **(strip-trial sites only)**	**52.4**	**26.6**
2021		
Bornholm-2021 (ST)	74.3 A	48.0 B
Drayton-2020 (O)	-	55
Elora-2020 (ST)	49.9 A	39.2 B
St. Marys H-2021 (O)	-	43
St. Marys M-2021 (O)	-	35
St. Marys R-2021 (O)	-	44
2021 Average **(strip-trial sites only)**	**62.1**	**43.6**
Overall Average **(strip-trial sites only)**	**53.5**	**32.4**
Overall Average	**-**	**35.7**

(strip-trial and observational sites)		

* Soybeans at the Blyth site were unharvestable due to insufficient weed suppression, poor soybean growth and red clover re-growth. Not included in averages.
** approx. 18% of this yield value is estimated to come from rye seed
*** inadequate soybean stand
- no data

Effect of soybean planting date and seeding rate: Bornholm-2020

The site at Bornholm a total of six treatments – an addition of four beyond what is reported in Table 5. The two no-rye control strips yielded the highest – 75.4 and 60.7 bu/ac, respectively, for the May 23 and June 9 seeding dates (Table 7). The comparison also highlighted the importance of timely soybean seeding. The June 9-planted soybeans planted into terminated rye residue yielded 57.5 bu/ac, which was not statistically different from the no-rye treatment.

Soybeans seeded into rye at the boot stage and crimped three weeks later yielded 37.6 bu/ac, which was not statistically different than the soybeans planted on June 9th at 300,000 seeds/acre (33.2 bu/ac). It was a higher yield than the later seeded soybeans planted at a lower population, which yielded only 30.5 bu/ac. Although the early-seeded soybeans into standing rye performed relatively well, they struggled under the rye canopy due to slug feeding and lack of light.

This is the first known replicated trial in Ontario evaluating the practice of interseeding into standing rye 3-4 weeks before crimping. Wisconsin research showed lower yields in one out of two trial years using interseeded planting vs. planting soybeans at crimping. More research is required to establish greater confidence in this practice.

Table 7. Soybean yields from five different treatments at the Bornholm site in 2020. All values corrected to 13% moisture. Statistically significant differences are shown by different letters.

Rye	**Planting date**	**Seeding rate (seeds/acre)**	**Yield (bu/ac)**
No rye (control)	May 23	300,000	75.4 A
Roller crimped rye	May 23	300,000	37.6 C
No rye (control)	June 9	300,000	60.7 B
Early terminated rye (sprayed April 27)	June 9	300,000	57.5 B
Roller crimped rye	June 9	300,000	33.2 CD
Roller crimped rye	June 9	225,000	30.5 D

Effect of added fertility and soybean seeding rate: Bornholm and Elora 2021

Phosphorus and potassium fertility treatments were compared at the strip-trial sites in 2021, in addition to three different seeding rates. Each successively higher seeding rate resulted in a statistical greater soybean yield at Bornholm (Table 8). At Elora, the 300,000 and 250,000 seeds/acre rates resulted in higher yield than 175,000 seeds/acre.

Added P, P and K or N, P and K did not affect yield at Elora. At Bornholm, however, addition of nitrogen to rye in April resulted in a 7.1 bu/ac yield reduction relative to the P only treatment. The added nitrogen resulted in greater rye biomass and reduced soybean stands at both Bornholm and Elora. The lower stand at Bornholm was likely in part responsible for reduced yield in the treatment with added nitrogen.

Table 8. Soybean yields from different treatments at the Bornholm and Elora sites in 2021. All values corrected to 13% moisture. Statistically significant differences amongst treatments at the same site are shown by different letters.

Rye	Applied fertility	Seeding rate (seeds/acre)	Yield (bu/ac) – Bornholm	Yield (bu/ac) – Elora
No rye (control)	None	300,000	74.3 A	49.9 A
Roller crimped rye	None	175,000	40.9 E	32.0 C
Roller crimped rye	None	250,000	49.9 CD	38.3 B
Roller crimped rye	None	300,000	54.2 B	42.8 B
Roller crimped rye	60 lbs P_2O_5/acre	300,000	52.1 BC	39.5 B
Roller crimped rye	60 lbs P_2O_5/acre and 60 lbs K_2O/acre	300,000	-	40.1 B
Roller crimped rye	60 lbs P_2O_5/acre, 60 lbs K_2O/acre and 70 lbs N/acre	300,000	45.0 DE	42.0 B

- no data

Summary:

Cover crop-based organic no-till soybean production was evaluated at 22 different sites across southwestern Ontario over three seasons. Across all sites, the average yield was close to 36 bushels per acre, with significant variability from year-to-year. The organic no-till system shows some promise but represents too much risk to recommend on a large scale. It is possible to grow a cover crop that can do a good job suppressing weeds, though this was not universally achieved. Early-planting and good base soil fertility to support tillering and aggressive rye growth are key. Use of appropriate soybean seeding equipment is also critical.

Below-average precipitation in the spring and early summer of 2020 and 2021 exposed a key vulnerability of the system, resulting in disappointing yields, even in cases where everything else was done properly. Adaptive management is a key to success with cover crop-based no-till soybean production. It is critical to have a plan B and adjust based on cover crop stand in spring and weather conditions.

Based on observations from the past three seasons, the following lessons were learned:

1. Select fields with low perennial weed pressure and at least moderate background fertility (e.g. >15 ppm P, >100 ppm K)
2. Seed rye early (by mid-September) and thick to achieve sufficient rye biomass
3. Use appropriate seeding equipment to ensure good cutting of the rye mulch, placement of soybeans, and closing of the seed trench
4. Seed soybeans at a high rate (minimum of 250,000 up to 300,000 seeds/acre)
5. If rye stand is poor or precipitation is below normal in May, strongly consider an alternative to crimping and seeding soybeans no-till, e.g. tilling rye under or cutting rye for feed and planting tillage-based soybeans

> **"Success starts with planting your rye in the fall and carries through to the soybean crop. Good base fertility and planting the rye thick are key."**
>
> **"Don't go in with the assumption that it's going to work the same way every year – be ready to alter your plans if needed."**
> - Morris Van De Walle, farmer cooperator

Cover crop-based organic no-till demands a high level of management. It requires adjustments in crop rotation and ample pre-planning. Despite observed yield reductions, when done successfully, it can provide excellent weed suppression and respectable organic soybean yields while freeing up significant time in-season, lowering fuel usage and providing soil health and erosion reduction benefits.

Next Steps:

Future areas of research on cover crop-based organic no-till soybean production include:
- Evaluation of cereal rye varieties that reach anthesis earlier, e.g. Aroostook and ND Gardner
- Best crops to precede cereal rye cover crop
- Best crops to seed following organic no-till soybeans

Acknowledgements:
This project was supported by OSCIA Tier 2 project funding. It funded in part by the Ontario Ministry of Agriculture, Food and Rural Affairs through the Canadian Agricultural Partnership, a five-year federal-provincial-territorial initiative. Donations of cereal rye seed were generously made by Cribit Seeds and The Andersons (formerly Thompsons Ltd.). Ecological Farmers Association of Ontario (EFAO) assisted with statistical analysis and financial support through their Farmer-Led Research Program. Soils at Guelph supported the Woodstock strip-trial site in 2020. Thank you to Horst Bohner and Mike Cowbrough for key project support (OMAFRA). Finally, thank you to the farmer cooperators who made the project possible.

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Location of Project Final Report: This document is the final report.