Renewable Agriculture and Food Systems

cambridge.org/raf

Research Paper

Cite this article: Kerr J, De Laporte A, Weersink A, Vyn R, Van Eerd LL (2023). Effects of cover crop, N and residue management on the financial sustainability of processing tomatoes in Southwestern Ontario. *Renewable Agriculture and Food Systems* **38**, e40, 1–9. https://doi.org/10.1017/S1742170523000339

Received: 16 January 2023
Revised: 11 May 2023
Accepted: 15 July 2023

Keywords:
cover crop economics; cover crops; crop residue management; processing tomato management; sustainable tomato production; tomato economics

Corresponding author:
Aaron De Laporte;
Email: adela@uoguelph.ca

Effects of cover crop, N and residue management on the financial sustainability of processing tomatoes in Southwestern Ontario

Jamison Kerr[1], Aaron De Laporte[1], Alfons Weersink[1], Richard Vyn[1,3] and Laura L. Van Eerd[2]

[1]Department of Food, Agricultural and Resource Economics, University of Guelph, Guelph, Ontario, Canada;
[2]School of Environmental Sciences, University of Guelph Ridgetown Campus, Ridgetown, Ontario, Canada and
[3]Natural Sciences, Dordt University, Sioux Center, Iowa, USA

Abstract

Given the potential environmental and economic sustainability consequences of cover crop adoption, N fertilizer application, and residue management, this study focuses on the yield and financial effects of these on processing tomato production in Ontario, Canada. The study employs financial modeling using field data from a long-term cover crop experiment (oat, cereal rye, radish, and a radish-rye mixture) from 2010 to 2020. Averaged over six experimental years, compared to no cover (87 Mg ha^{-1}) radish (99.6 Mg ha^{-1}) and radish-rye mix (95.2 Mg ha^{-1}) cover crops produce statistically significantly higher tomato yields as isolated practices, increasing farm net returns by \$1120 ha^{-1} and \$604 ha^{-1}, respectively. When combined with N application, rye application additionally results in tomato yields statistically significantly higher than the base practice of no cover crop, zero N application and retained residue. Oat cover does not appear to have a statistically significant effect on tomato yields in this dataset. The application of N fertilizer results in statistically significantly higher tomato yield, increasing net returns by \$882 ha^{-1}, while residue management does not.

Introduction

Cover crops provide a myriad of environmental and agronomic benefits (Hillel, 2005), leading to more sustainable agricultural production. They can reduce soil erosion, add organic matter, reduce nutrient losses, reduce pest populations, reduce compaction, improve soil structure, aid in water management, and provide emergency forages for livestock consumption (Snapp et al., 2005; Blanco-Canqui et al., 2015). Cover crops can also provide broader ecosystem services such as enhancing biological diversity and water quality (Van Alfen, 2014; Van Eerd et al., 2023). Agronomic benefits from cover crops include increases in crop yield (Lenzi et al., 2009; Li et al., 2019; Sainju, Singh and Whitehead, 2001), weed suppression (Price et al., 2016), and lowered N input requirements (Frye, Smith and Williams, 1985). Thus, cover crops contribute to agroecosystem sustainability and food security.

Despite the environmental and agronomic benefits of cover crops, the economic and financial consequences are less clear. While researchers tend to find that cover crops influence the yield (and revenue) of the subsequent cash crops, the direction and magnitude of this yield effect changes with species of cover crop and timeframe (Muchanga, et al., 2020; Bourgeois et al., 2022). For example, short-term yield losses leading to long-term gains are possible, depending on soil characteristics (Creamer et al., 1996; Nunes et al., 2018). However, there is mixed evidence regarding whether the added costs of establishment and termination are greater or less than the additional returns expected from yield increases (Cai et al., 2019; Chahal et al., 2020; Yanni et al., 2021).

Previous financial and economic assessments of cover crops have been conducted on field crops (Frye, Smith and Williams, 1985; Gabriel, Garrido and Quemada, 2013), such as cotton (Boyer et al., 2018; Morton, Bergtold and Price, 2006), corn, soybean, and wheat (Champagne et al., 2021; Janovicek et al., 2021). Some research has employed cost–benefit analysis and financial accounting to assess cover crop viability (Bounaffaa, 2015; DeVincentis et al., 2020; Pratt et al., 2014; Snapp et al., 2005). The financial feasibility of cover crops within a vegetable crop farming system, particularly with field processing tomatoes, have been investigated in the United States (DiGiacomo et al., 2023; Price et al., 2016), and in Canada (Belfry et al., 2017; Chahal et al., 2020), but only for limited timeframes.

The production of processing tomatoes in Ontario, Canada is centered in Chatham-Kent and Essex counties in the extreme southwest of the province due to unique climate factors, including a long growing season, neutral (pH of 6.2–6.8), well-drained soil, and proximity to processing facilities. Total area of processing tomato production in Ontario since 2010 has averaged approximately 4900 ha. Yield per hectare has been increasing over time, while there have been fluctuations in gross farm value (Statistics Canada, 2021). Therefore, valuation of management practices that affect sustainability, like cover cropping, N application, and residue management, is critical for assessing the viability of tomato-based food production.

The purpose of this study is to investigate the effects of several cover crop options, along with nitrogen (N) application and winter wheat residue management, on processing tomato yield and profitability in Ontario's temperate humid climate, using farm-level financial analysis. The specific objectives of this research are to:

1) evaluate the effects of four different cover crop treatments, N application, and preceding crop residue management on the yield of processing tomatoes, over six growing seasons; and
2) determine the financial impact of the four cover crop treatments, N application, and residue management for processed tomatoes.

Better understanding of the financial implications of sustainable management practices (i.e., cover crops, fertilizer N and crop residue management) provides growers key information to assist in making management decisions that buttress sustainable adaptation efforts.

Methods and data

Experimental design and plot description

An ongoing research experiment was initiated in 2007 (Site A) and repeated a few meters adjacent in 2008 (Site B) at the Ontario Crops Research Centre, Ridgetown, ON, Canada (42.46 N, 81.89 W) using a split-split plot design with cover crop treatments arranged in a randomized complete block design with four replications (Belfry et al., 2017; Chahal and Van Eerd, 2021; Trueman et al., 2023). Soil texture was a sandy loam (Orthic Humic Gleysol), and the field was tile drained. This site had a temperate humid climate with a 30-year mean annual air temperature of 9.6°C and 30-year mean annual total precipitation of 900 mm. This experiment assessed the interaction of cover crop, fertilizer N, and crop residue management treatments applied in selected main crops within a nine-year vegetable and field crop rotation at both sites with Site B lagged one year from Site A. The rotation crop order was: (1) processing peas-CC, (2) sweet corn-CC, (3) spring (or winter) wheat-CC, (4) processing tomato-CC, (5), grain corn, (6) squash-CC, (7) soybeans, (8) winter wheat-CC, and (9) processing tomato-CC, where CC indicates that a cover crop was planted after main crop harvest. Depending on the main crop harvest date, cover crops were either planted in late July, August, or early September, accumulating at least 1 Mg ha^{-1} of dry biomass, and remained in place until the following spring (Belfry et al., 2017; Chahal et al., 2020).

This study isolated the processing tomato data obtained in years four and nine of the rotation. It measured the yield and financial consequences of cover crops planted after wheat the previous season, preplant fertilizer N application and preceding wheat residue management. We analyze the subset of data (Table 1) from 2010 to 2020 of six years with tomatoes (2010, 2015, and 2019 at Site A and 2011, 2016, and 2020 at Site B). The main plot factor (6 m by 16 m) was autumn cover crop treatment (i.e., planted after wheat and before tomatoes). The split plot factor (6 m by 8 m) implemented in the years preceding tomato production (2014 and 2018 at Site A; 2015 and 2019 at Site B) was wheat crop residue management (removal versus retention). In 2010, 2019 (Site A), 2011, and 2020 (Site B), there was also a split-split plot factor (6 m by 4 m) of N fertilizer applied to the tomato crop (140 kg N ha^{-1} versus zero).

Table 1. Site location (side-by-side in Ridgetown, ON), main plot, split plot and split-split plot factor for each year of tomato data considered in this study

Year	Site	Main plot (6 × 16 m)	Split plot (6 × 8 m)	Split-split plot (6 × 4 m)
2010	Site A	Cover crop	Cultivar[a]	N rate
2011	Site B	Cover crop	Cultivar[a]	N rate
2015	Site A	Cover crop	Residue management	
2016	Site B	Cover crop	Residue management	
2019	Site A	Cover crop	Residue management	N rate
2020	Site B	Cover crop	Residue management	N rate

[a]Results not presented in this study due to only being considered in the first two years.

Cropping practices

The cropping practices for this study were detailed in Belfry et al. (2017) for 2010 and 2011, in Chahal and Van Eerd (2018; 2021) for 2015 and 2016, and in Trueman et al. (2023) for 2019 and 2020. The year before tomato production, after wheat mechanical grain harvest, crop residue was either retained (evenly distributed with rake by hand) or removed (raked, collected, and removed by hand) to implement the residue management split-plot factor treatments. Cover crops were direct seeded after wheat harvest in late July or early August. There were five annual cover crop main-plot treatments: (1) no cover crop control; (2) oat (*Avena sativa* L.); (3) radish (*Raphanus sativus* L.); (4) winter cereal rye (rye; *Secale cereale* L.); and (5) a mixture of rye and radish (radish-rye) planted at 81, 16, 67, and 34 plus 9 kg ha^{-1}, respectively. No specific cultivars were used for cover crop species.

About 3 weeks after planting the four cover crops, glyphosate was applied at 540 g a.e. ha^{-1} to the no cover crop plots to control fall weeds (Chahal and Van Eerd, 2021). Radish (in mono- and bi-culture) and oat were frost terminated (typically in November), but rye (in mono- and bi-culture) overwintered. In the following spring (early May), the entire trial was sprayed with glyphosate at 810 g a.e. ha^{-1} to control rye and weeds.

Prior to tomato transplanting (late May), split-split-plot treatments of with or without N fertilizer were established by hand-broadcasting (or not in the zero-N control split plots) calcium ammonium nitrate 27:0:0 at 140 kg N ha^{-1} and the entire experimental area was disced and cultivated to incorporate cover crop residues and fertilizers. Some of the fertilizer (15 kg N ha^{-1}) was applied with water at transplanting (Belfry et al., 2017; Chahal and Van Eerd, 2021) in the first four tomato years but this was not done in 2019 and 2020 (Trueman et al., 2023). Tomato seedlings for all six years of the experiment were transplanted in late May when the major risk of frost was past. All other management practices (e.g., fertilizer, pest, and weed control) were in accordance with Ontario processing tomato production guide as part of a typical production program (OMAFRA, 2020), except a ripening agent was not applied prior to harvest to allow for assessments of maturity. Each subplot, 2 m from the center two rows, was hand harvested when visual observation of the experimental area estimated that 80% of fruit was red.

https://doi.org/10.1017/S1742170523000339 Published online by Cambridge University Press

Marketable fruit yield

Based on industry standards, tomato fruit was graded into five categories. The marketable categories consisted of red (exterior yellow color is <5%), green (external surface >50% yellow), and breakers (>90% blush of red, orange, or pink color). The unmarketable categories consisted of grass green (external surface being totally green or greenish-white and/or <50% yellow) and rots (OPVG, 2006). Using the marketable (red, green, and breakers) fruit weight and harvest area, marketable yield was calculated and expressed as fresh weight per hectare (Mg ha^{-1}). For the first four years, this measure was used directly (Belfry et al., 2017; Van Eerd, Loewen and Vyn, 2015) and for the 2019 and 2020 seasons, these values were corrected for anthracnose lesions as these assessments were available (Trueman et al., 2023).

Determining yield effects from cover cropping, N application, and crop residue management on tomatoes

Analysis of variance (ANOVA) (IBM SPSS Statistics) was used to determine if marketable yields of the treatments were statistically different, and Tukey's HSD at an alpha value of 0.05 was used to determine which specific treatment means were different from one another. In this study, fixed effects were cover crop (2010, 2011, 2015, 2016, 2019, 2020), N application rate (2010, 2011, 2019, 2020) and crop residue management (2015, 2016, 2019, 2020), and the random effects were year, replicate and replicate by cover crop to account for the split-plot factor. There was a total of 80 observations in each cover crop group. This analysis was done first by year and then considering the combined six-year dataset.

Financial effects of cover cropping, N application, and crop residue management on tomatoes

This study employed partial budgeting techniques for financial analysis (DiGiacomo et al., 2023). The potential partial benefits of the cover crop, N application and preceding residue management changes detailed above included increases in revenue from higher tomato yields, and the sale of crop residue (straw). Costs from the treatments included potential decreases in tomato yields and resulting revenues, along with expenses incurred from cover crop, fertilizer N application, and wheat residue harvest.

In this study, tomato revenue changed due to marketable yield only. Quality was not assumed to change with alternative management systems. The 2022 contract price for processing tomatoes was \$109.76 Mg^{-1} (OPVG, 2022). We employed a more conservative tomato price, fixed at \$105 Mg^{-1}, the estimated average price paid to producers between 2013 and 2022.

Cover crop costs included establishment, based on seeding rates and seed prices, and termination (Table 2). The costs of seeding, glyphosate burndown, and application were based on OMAFRA Publication 60 for switchgrass (Molenhuis, 2021) and custom rate surveys (OMAFRA, 2022). Since glyphosate was applied to the entire experimental area for ease of management (i.e., tractor and large sprayer as opposed to a back-pack sprayer) (see section 'Cropping practices'), rather than necessity, for the financial analysis, these costs were not included for oat and radish alone treatments because they were winterkilled.

The price for N fertilizer assumed in this study was \$1.10 kg^{-1} (Molenhuis, 2021). Custom N application was \$24.71 ha^{-1} (OMAFRA, 2022).

The crop residue management revenue and cost analyses were based on straw yield and N, P, and K removed from the field. Straw bale dimensions were assumed to be 0.91 m by 0.91 m by 2.44 m. This created a 375 kg bale (Steer Planet.com, 2020). This analysis assumed that the cost of producing a large square bale was \$4.72 m^{-1}, or \$11.52 bale^{-1} (OMAFRA, 2022). Straw yield was assumed to be 5955 kg ha^{-1} (Molenhuis, 2021) and consistent with 4-year sub-sampling estimates in this experiment. The amount of N removed with the straw residue was estimated to be 0.77% of bale weight, equivalent to 45.9 kg N ha^{-1} (Budynski, 2020). Given the price listed previously, N replacement costs were \$50.44 ha^{-1}. Replacement costs for P were \$9.39 ha^{-1} (at \$0.92 kg^{-1}) and for K were \$59.18 ha^{-1} (at \$0.82 kg^{-1}) (Molenhuis, 2021). Total residue removal costs were estimated at \$301.95 ha^{-1}. Straw prices were assumed to be \$0.0662 kg^{-1} (RealAgriculture.com, 2021). At 5955 kg ha^{-1}, the total revenue from the sale of wheat straw residue was \$394.23 ha^{-1}.

The breakeven yield for each treatment was determined through partial budgeting. This analysis determined the increase in tomato yield required to offset the costs of implementing the alternative management being considered. The breakeven equation for each treatment was calculated as the net cost of the treatment, independent of changes in tomato revenue, divided by the 10-year average tomato price.

Results

Yield effects

The difference in marketable yields between the treatments was first assessed by year (Table 3) and then the annual values were

Table 2. Direct expenses of cover crop establishment (adapted from Chahal et al., 2020)

Item	Oat	Rye	Radish	Radish/Rye
Seeding rate (kg ha^{-1})	81	67	16	9 + 34
Seed price (\$ kg^{-1})	1.31	1.11	6.42	6.42 + 1.11
CC seed cost (\$ ha^{-1})	106.11	74.37	102.72	95.52
Planting (\$ ha^{-1})[a]	54.36	54.36	54.36	54.36
Herbicide application (\$ ha^{-1})[a]		24.71		24.71
Herbicide treatment (\$ ha^{-1})[b]		31.51		31.51
Total establishment and termination costs (\$ ha^{-1})	160.47	184.95	157.08	206.10

[a]OMAFRA (2022) Table 8. Survey of Custom Farmwork Rates Charged in 2018.
[b]Calculated from Molenhuis (2021) using burndown line item for switchgrass.

https://doi.org/10.1017/S1742170523000339 Published online by Cambridge University Press

Table 3. Impact of cover crop, nitrogen, and crop residue management on marketable tomato yield (Mg ha^{-1}) in six years using ANOVA with Tukey HSD$_{0.05}$ with significance groups identified by letters

Treatment	2010	2011	2015	2016	2019	2020
Cover crop (CC)						
No CC	100.0	103.1 b	79.6	88.8 b	62.3 ab	87.8
Oat	95.7	113.4 ab	91.4	102.1 ab	61.1 b	96.4
Rye	91.2	111.7 ab	76.6	102.4 ab	73.2 ab	93.8
Radish	103.0	117.1 a	85.2	124.4 a	74.6 a	98.7
Radish/Rye	104.3	105.6 ab	89.9	104.4 ab	72.6 ab	96.3
S.E.	4.474	3.117	3.904	5.601	3.149	3.711
Nitrogen (N)						
Starter	96.8	101.3 b			67.4	86.6 b
Full N	100.9	119.0 a			70.0	102.6 a
S.E.	2.830	1.972			1.992	2.347
Crop residue (CR)						
Retained			85.0	100.9	67.2	93.7
Removed			84.1	108.0	70.3	95.6
S.E.			2.469	3.542	1.992	2.347
Effects	Pr > *F* value					
CC	0.224	**0.014**	**0.050**	**0.003**	**0.004**	0.294
N	0.312	**<0.001**			0.366	**<0.001**
CR			0.797	0.170	0.274	0.571
CC × N	0.817	**0.034**			0.899	0.746
CC × CR			0.935	0.798	0.920	0.973
CR × N					0.788	0.564
CC × N × CR					0.917	0.876

combined into a total dataset and analyzed over the relevant 4- to 6-year timeframes (Table 4). Tomato yields with radish cover crop were greater than without in two of the three years (i.e., in 2010 and 2016 but not 2019) when the cover crop effect was significant (Table 3; Fig. 1). However, yields under no cover crop were never significantly higher than with cover crops. Across the combined six-year dataset, the tomato yield with no cover crops was 87 Mg ha^{-1} (Table 4). This was statistically significantly lower than tomato yields after both radish (99.6 Mg ha^{-1}) and radish-rye mix (95.2 Mg ha^{-1}) cover crops based on significance groupings. Tomato yields with oat and rye only cover crops were not statistically significantly different than no cover crop nor the radish-rye mix.

Applying 140 kg N ha^{-1} increased tomato yield in all four applicable years but this increase was only statistically significant in 2011 and 2020 (Table 3). In the combined six-year dataset, the tomato yield significantly increased by 10.1 Mg ha^{-1} with fertilizer N application (Table 4).

Wheat crop residue removal before tomatoes had no statistically significant impact on tomato yield in any of the four years (Table 3) or in the combined dataset (Table 4).

The interaction effects between factors were generally insignificant. For example, harvesting crop residue did not influence tomato yield regardless of fertilizer N application in any year or overall. The only year where an interaction term was statistically significant was 2011, when tomato yield was influenced by the interaction of cover crop choice and N rate (Table 3). In the six-year dataset, cover crop was the only statistically significant effect (Table 4).

Crop management and uncontrolled growing season effects, captured in the 'year' variable, appeared to affect tomato yields statistically significantly (Table 4). In general, based on significance groupings, 2011 and 2016 were the highest yielding years, 2010 and 2020 were in the middle, followed by 2015, while 2019 was the lowest yielding year.

The changes in tomato yield due to each of the cover crops, N application, and crop residue management treatments for financial analysis were summarized in Table 5. The base cropping system assumed was no cover crops, with no N applied, and residue retained on the field. The remaining 19 cropping options were compared to this base to establish the results, which showed that any combination of cover crops, residue removal and N application resulted in positive total yield increases in the combined dataset. However, based on 95% confidence yield intervals, only rye, radish, and the rye-radish mix, with N application, independent of residue management, were significantly different from the base. The other results were not significantly different.

Financial analysis

Using the average price of tomatoes for the last 10 years of $105 Mg^{-1} multiplied by the change in yield due to the associated

https://doi.org/10.1017/S1742170523000339 Published online by Cambridge University Press

Table 4. Impact of cover crop, N application and residue removal on tomato yield (Mg ha^{-1}) in the total six-year dataset using ANOVA with Tukey HSD$_{0.05}$ with significance groups identified by letters

Treatment	Tomato yield (Mg ha^{-1})	Standard error	Number of observations
Cover crop (CC)			
No CC	87.5 c	1.613	80
Oat	92.7 bc	1.613	80
Cereal rye	91.9 bc	1.613	80
Radish	99.6 a	1.613	80
Radish/Rye	95.2 ab	1.613	80
Nitrogen (N)			
No nitrogen	88.0 a	1.141	160
Full nitrogen	98.1 b	1.141	160
Crop residue (CR)			
Retained	84.6	1.317	120
Removed	87.3	1.317	120
Year			
2010	98.8 bc	1.613	80
2011	110.2 a	1.613	80
2015	84.6 d	2.282	40
2016	104.4 ab	2.282	40
2019	68.8 e	1.613	80
2020	94.6 c	1.613	80
Effects	Pr > *F* value		
CC		**0.049**	
N		0.170	
CR		0.252	
CC*N		0.505	
CC*CR		0.481	
CR*N		0.261	
CC*N*CR		0.220	

treatment in Table 4 and subtracting the cost of cover crop management (Table 2), N application, and residue management, provided the average change in net returns from engaging in the practice (Table 6). The results presented assume a single period financial analysis and average overall changes in yield. The practices here were treated in isolation as independent decisions.

Examining the practices in isolation showed that all four cover crop options as well as N application and residue management resulted in positive net returns, but the oat and rye results were not significant (Table 6). Changes in yield from residue management were not significantly different from zero, but residue removal had a positive net return without any change in tomato yield ($92 ha^{-1}), based on a straw revenue of $394 ha^{-1} minus the cost of removal of $302 ha^{-1}.

The break-even yield analysis (Table 6) showed that increases in one to two Mg of tomatoes per hectare can cover the costs of all the management practices, with insignificantly small yield losses being covered by straw revenue in the case of residue removal. Similarly, the cover crops resulting in a statistically significant yield increase, radish, and radish-rye (Table 4), and N application, had lower break-even tomato prices.

The joint financial impacts of cover crop, N and crop residue management are shown in Table 7. This result was derived from Table 5, combined with changes in revenue and cost. This analysis showed that any cover crop had a net return that was higher than the base case (i.e., no cover crop control, with zero N application, and residue retention), regardless of N application and residue management. It also showed that N application increased net returns. However, depending on the cover crop and N rate, residue removal had an ambiguous effect on net returns compared to retention. Specifically, oat without N application, and radish-rye with N application, have lower net returns from crop residue removal. However, only the rye, radish, and radish-rye mix with N application, regardless of straw residue management, had changes in revenues, costs and net returns that were statistically significant from the base, based on yield intervals from Table 5.

Discussion and conclusions

Financial considerations are important determinants in the uptake of sustainable innovative technologies (Barnes et al., 2019; Gao and Arbuckle, 2021), including sustainable management practices like cover cropping (Lu et al., 2022; Van Eerd et al., 2023). Previous studies have found mixed evidence that cover crops increase farm financial performance, in perception (Morrison and Lawley, 2021), in the short run (Basche et al., 2016), and over longer periods (Chahal et al., 2020). For tomatoes, cover crops have been shown to increase farm returns in single years (Belfry et al., 2017; Trueman et al., 2023), but they have also been shown to result in negative financial outcomes (DiGiacomo et al., 2023). The results of this study indicate that financial gains can be realized from careful selection of cover crop types in various annual conditions, but there is potential for loss.

Much of the financial benefit stems from yield increases with cover crops, particularly radish and a radish-rye mixture, which may be crucial to sustainable food production systems (Kopittke et al., 2019; Schoolman and Arbuckle, 2022; Van Eerd et al., 2023). While all four cover crops increased average actual tomato yields in the trial years (Table 5), based on 95% confidence intervals, only tomato yields influenced by rye, radish and radish-rye with N application were significantly different from the base. However, radish and radish-rye also significantly increased tomato yields in isolation (Table 4). Possible mechanisms of this difference in yield effect could be related to greater disease suppression (Trueman et al., 2023) and greater available N (Chahal and Van Eerd, 2021). Coupled with reasonable costs that do not appear to exceed the benefits, carefully selected cover crops appear to increase the financial sustainability of crop production. This concept is reinforced by the break-even tomato price analysis (Table 6), where radish and radish-rye cover crops lower the tomato price required to make a profit from $105 to $93.76 and $98.66 Mg^{-1}, respectively.

In this study, cover crops were selected based on grower experience and regional seed availability when the experiment began in 2007. As horticultural crop yield and quality can be negatively influenced by excess N fertility (Chahal et al., 2021), legume cover crops, such as red clover, were not evaluated. More than ten years later, there are many additional available cover crops and cover crop mixtures in the area, and each could have different

https://doi.org/10.1017/S1742170523000339 Published online by Cambridge University Press

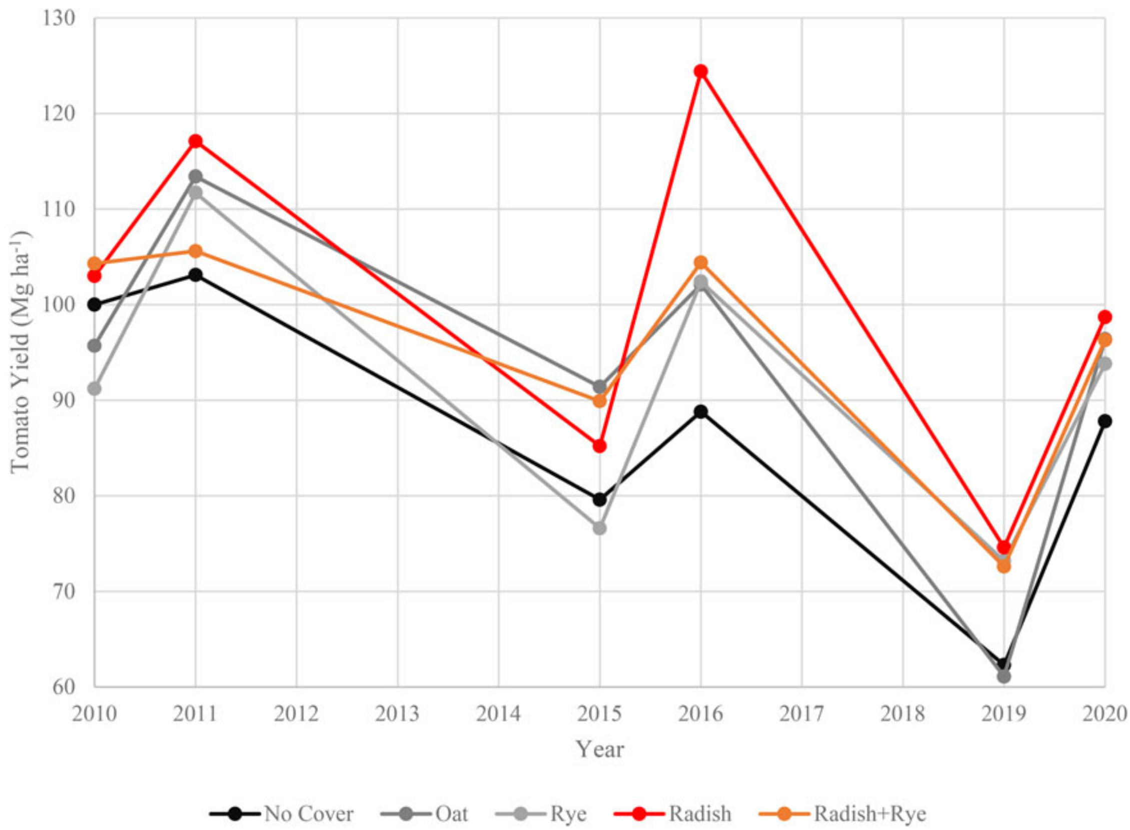

Figure 1. Processing tomato yields by cover crop treatment by year. Statistically significant groupings with Tukey HSD0.05 in 2011, 2016, and 2019. Standard errors by year: 2010—4.474; 2011—3.117; 2015—3.904; 2016—5.601; 2019—3.149; 2020—3.711).

effects, as inferred from the results of this study. This reinforces a need for additional research using different cover crops and mixtures and emphasizes careful selection of cover crop approaches.

Fertilizer N application at 140 kg ha^{-1} increased tomato yield by a statistically significant amount (Table 4). While N application is industry standard, the zero N rate treatment was included to examine the extent to which cover crops impact N availability to the following crop. Radish cover crop and N application as separate practices appear to have similar effects, overall (Table 6), with N application having a lower break-even yield, but higher break-even tomato price. This could make transitioning to organic production more attractive and lead to increases in cover crop adoption as suggested by Schoolman and Arbuckle (2022). Alternatively, this may limit the attractiveness of cover crop use as the standard N application practice has a similar effect. Furthermore, O'Reilly et al. (2012) suggested that many growers were unwilling to modify their N application behaviors due to the relatively high value of field processing vegetable crops and the lack of information surrounding cover crops on N availability for the subsequent crop. Regardless, the highest net return value in Table 7 was radish cover crop with N application. This implies that the recommended practice, with the highest net return, was radish and N application, followed by radish-rye with N application.

Removing crop residue from the winter wheat crop planted prior to tomatoes did not statistically significantly affect yields, in any year (Table 3), or in the combined six-year dataset (Table 4), compared to keeping residue in the field. Therefore, the result in Table 6 for residue removal, while showing a positive net return, has some uncertainty. There is some financial gain without a change in tomato yield (\$92 ha^{-1}) because the revenues from straw are generally higher than the costs of removal. However, there is one statistically significant scenario where residue removal is not advised (Table 7). Specifically, the rye-radish mixture with N application has higher net returns from straw retention. In this case, although there may be additional revenue from residue removal, the high value of the tomato crop means that any relative yield reduction can be detrimental. Care needs to be taken with residue removal, from a financial standpoint, and needs to be especially well considered from an environmental sustainability perspective.

Table 5. Tomato yield change by alternative cropping system compared to base [66 Mg ha^{-1}] (No cover crop, N= 0, and wheat residue retained)

	Change in tomato yield (Mg ha^{-1})				
Treatment[a]	No cover	Oat	Rye	Radish	Radish/ Rye
0 kg ha^{-1} N, Residue retained	Base	10.6	10.6	13.6	10.6
140 kg ha^{-1} N, Residue retained	14.5	15.4	**20.7**	**24.5**	**23.5**
0 kg ha^{-1} N, Residue removed	6.0	8.4	16.0	15.2	18.9
140 kg ha^{-1} N, Residue removed	15.4	16.5	**22.7**	**29.1**	**20.7**

[a]Bold indicates that 95% confidence yield intervals do not overlap with the base.

https://doi.org/10.1017/S1742170523000339 Published online by Cambridge University Press

Table 6. Independent net financial impact of cover crops, N application and residue removal treatments using partial budgets ($ ha^{-1}) along with the break-even yield required to offset treatment costs (Mg ha^{-1})

Treatment	Increased revenue ($ ha^{-1})	Increased costs ($ ha^{-1})	Net return ($ ha^{-1})	Break-even tomato price ($ ha^{-1})	Break-even yield (t ha^{-1})
No cover	Base	Base	Base	Base	Base
Oats	546.10	160.47	385.63	100.84	1.5
Rye	464.10	184.95	279.15	101.96	1.8
Radish[a]	**1277.22**	**157.08**	**1120.14**	**93.76**	**1.5**
Radish/Rye[a]	**809.86**	**206.10**	**603.76**	**98.66**	**2.0**
N (140 kg ha^{-1})[a]	**1060.50**	**178.71**	**881.79**	**96.02**	**1.7**
Residue removal	649.28	301.95	347.33	100.70	−0.9

[a]Bold indicates statistically significant yield differences in the six-year dataset.

The 'Year' variable, which implicitly captures, for example, differences in weather variables, including temperature and rainfall, and pest pressures (weeds, insects, diseases), along with minor differences in planting and harvest timing dictated mainly by weather and soil conditions, significantly impacted annual yields. All cash cropping operations are unique, in terms of inputs required, land or soil characteristics, and management type. When considering cover crops as part of an overall farm management strategy, it is important to understand that short-term changes in crop yield or soil health may not be noticeable and initial financial impacts may be negative. However, an extended outlook for yield increases and positive economic returns is necessary to successfully and fully integrate cover crops into an existing cash crop operation.

Stand-alone analysis showed that all cover crop, N application, and residue management treatments resulted in average actual positive tomato yields (Table 4) and net returns (Table 6), with increases due to N application, and radish and radish-rye mix cover crops being statistically significant. In combination, all 16 treatments provided positive processing tomato yields compared to the base (Table 5) and resulted in higher net returns (Table 7) that were significant for rye, radish, and radish-rye

Table 7. Change in net returns for alternative cover cropping systems ($ ha^{-1}) from no cover crop, N application, and residue retention

Cover crop[a]	N rate (kg N ha^{-1})	Crop residue	Change in revenue	Change in cost	Change in net return
None	0	Retained	Base	Base	Base
	0	Removed	1027	302	726
	140	Retained	1524	179	1346
	140	Removed	2015	481	1535
Oats	0	Retained	1108	160	948
	0	Removed	1279	462	816
	140	Retained	1622	339	1283
	140	Removed	2129	641	1487
Rye	0	Retained	1109	185	924
	0	Removed	2077	487	1591
	140	**Retained**	**2171**	**364**	**1807**
	140	**Removed**	**2779**	**666**	**2113**
Radish	0	Retained	1432	157	1275
	0	Removed	1990	459	1531
	140	**Retained**	**2569**	**336**	**2233**
	140	**Removed**	**3445**	**638**	**2807**
Radish/Rye	0	Retained	1117	206	911
	0	Removed	2383	508	1875
	140	**Retained**	**2469**	**385**	**2084**
	140	**Removed**	**2568**	**687**	**1881**

[a]Bold indicates that 95% confidence yield intervals do not overlap with the base.

https://doi.org/10.1017/S1742170523000339 Published online by Cambridge University Press

mix cover crops with fertilizer N applied, regardless of residue management. Therefore, rye, radish, and radish-rye cover crop adoption can be generally recommended as a beneficial management practice for tomato producers in Ontario. Building on previous literature analyzing cover crop influences on main cash crop yield and profitability, this research provides valuable information to tomato producers in southwestern Ontario, particularly that carefully selected cover crops may increase financial performance.

Competing interests. None.

References

Barnes, A.P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sanchez, B., Vangeyte, J., Fountas, S., van der Wal, T. and Gomez-Barbero, M. (2019) 'Exploring the adoption of precision agricultural technologies: a cross regional study of EU farmers', *Land Use Policy*, **80**, pp. 163–74. https://doi.org/10.1016/j.landusepol.2018.10.004

Basche, A., Archontoulis, S., Kaspar, T., Jaynes, D., Parkin, T. and Miguez, F. (2016) 'Simulating long-term impacts of cover crops and climate change on crop production and environmental outcomes in the Midwestern United States', *Agriculture, Ecosystems and Environment*, **218**, pp. 95–106. https://doi.org/10.1016/j.agee.2015.11.011

Belfry, K., Trueman, C., Vyn, R., Loewen, S. and Van Eerd, L. (2017) 'Winter cover crops on processing tomato yield, quality, pest pressure, nitrogen availability, and profit margins', *PLoS ONE*, **12**(7), p. e0180500. https://doi.org/10.1371/journal.pone.0180500

Blanco-Canqui, H., Shaver, T.M., Lindquist, J.L., Shapiro, C.A., Elmore, R.W., Francis, C.A. and Hergert, G.W. (2015) 'Cover crops and ecosystem services: insights from studies in temperate soils', *Agronomy Journal*, **107**, pp. 2449–74. https://doi.org/10.2134/agronj15.0086

Bounaffaa, M. (2015). *Benefits and costs of cover crops: a framework for data collection and analysis*. Open Access Thesis. Purdue University. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2161&context=open_access_theses

Bourgeois, B., Charles, A., Van Eerd, L.L., Tremblay, N., Lynch, D., Bourgeois, G., Bastien, M., Belanger, V., Landry, C. and Vanasse, A. (2022) 'Interactive effects between cover crop management and the environment modulate benefits to cash crop yields: a meta-analysis', *Canadian Journal of Plant Science*, **102**, pp. 656–78. dx.doi.org/10.1139/cjps-2021-0177

Boyer, C.N., Lambert, D.M., Larson, J.A. and Tyler, D.D. (2018) 'Investment analysis of cover crop and no-tillage systems on Tennessee cotton', *Agronomy Journal* **110**, pp. 331–38. https://doi.org/10.2134/agronj2017.08.0431

Budynski, S. (2020). Straw Manufacturing in Alberta. Alberta Agriculture and Forestry. ISBN: 978–1-4601-4685-9. Retrieved from: https://open.alberta.ca/dataset/690317b0-1d07-4f9e-ae71-6340e16f6493/resource/89789096-1c7a-47ab-beb2-94d55606c922/download/af-straw-manufacturing-in-alberta-2020-01.pdf

Cai, Z., Udawatta, R.P., Gantzer, C.J., Jose, S., Godsey, L. and Cartwright, L. (2019) 'Economic impacts of cover crops for a Missouri wheat–corn–soybean rotation', *Agriculture*, **9**(4), p. 83. https://doi.org/10.3390/agriculture9040083

Chahal, I. and Van Eerd, L.L. (2018) 'Evaluation of commercial soil health tests using a medium-term cover crop experiment in a humid, temperate climate', *Plant and Soil*, **427**(1–2), pp. 351–67. https://doi.org/10.1007/s11104-018-3653-2

Chahal, I. and Van Eerd, L.L. (2021) 'Cover crops increase tomato productivity and reduce nitrogen losses in a temperate humid climate', *Nutrient Cycling in Agroecosystems*, **119**(2), pp. 195–211. https://doi.org/10.1007/s10705-020-10105-6

Chahal, I., Vyn, R., Mayers, D. and Van Eerd, L.L. (2020) 'Cumulative impact of cover crops on soil carbon sequestration and profitability in a temperate humid climate', *Journal Nature*, **10**, p. 13381. https://doi.org/10.1038/s41598-020-70224-6

Chahal, I., Baral, K.R., Congreves, K.A., Van Eerd, L.L. and Wagner-Riddle, C. (2021) 'Opportunities to reduce nitrous oxide emissions from horticultural production systems in Canada', *Canadian Journal of Plant Science*, **101**, pp. 999–1013. https://doi.org/10.1139/cjps-2021-0107

Champagne, R.J., Wallace, J.M., Curran, W.S. and Baraibar, B. (2021) 'Agronomic and economic tradeoffs between alternative cover crop and organic soybean sequences', *Renewable Agriculture and Food Systems*, **36**, pp. 17–25. https://doi.org/10.1017/S1742170519000437

Creamer, N., Bennett, M., Stinner, B. and Cardina, J. (1996) 'A comparison of four processing tomato production systems differing in cover crop and chemical inputs', *Journal of the American Society for Horticultural Science*, **121**(3), pp. 559–68. https://doi.org/10.21273/JASHS.121.3.559

DeVincentis, A., Solis, S., Bruno, E., Leavitt, A., Gomes, A., Rice, S., and Zaccaria, D. (2020) 'Using cost-benefit analysis to understand adoption of winter cover cropping in California's specialty crop systems', *Journal of Environmental Management*, **261**, p. 110205. https://doi.org/10.1016/j.jenvman.2020.110205

DiGiacomo, G., Gieske, M., Grossman, J., Jacobsen, K., Peterson, H. and Rivard, C. (2023) 'Economic trade-offs: analysis of hairy vetch (*Vicia villosa*) cover crop use in organic tomato (*Solanum lycopersicum* L.) high tunnel systems across multiple regions', *Renewable Agriculture and Food Systems*, **38**(e10), pp. 1–11. https://doi.org/10.1017/S1742170523000029

Frye, W., Smith, W. and Williams, R. (1985) 'Economics of winter cover crops as a source of nitrogen for no-till corn', *Journal of Soil and Water Conservation*, **40**(2), pp. 246–9. Retrieved from: https://www.jswconline.org/content/40/2/246.short

Gabriel, J., Garrido, A. and Quemada, M. (2013) 'Cover crops effect on farm benefits and nitrate leaching: linking economic and environmental analysis', *Agricultural Systems*, **121**, pp. 23–32. https://doi.org/10.1016/j.agsy.2013.06.004

Gao, L. and Arbuckle, J. (2021) 'Examining farmers' adoption of nutrient management best management practices: a social cognitive framework', *Agriculture and Human Values*, **39**, pp. 535–53. https://doi.org/10.1007/s10460-021-10266-2

Hillel, D. (2005) Cover Crops. In Encyclopedia of Soils in the Environment. Elsevier. ISBN 978-0-12-348530-4. Retrieved from: https://www.sciencedirect.com/referencework/9780123485304/encyclopedia-of-soils-in-the-environment

Janovicek, K., Hooker, D., Weersink, A., Vyn, R. and Deen, B. (2021) 'Corn and soybean yields and returns are greater in rotations with wheat', *Agronomy Journal*, **113**, pp. 1691–711. https://doi.org/10.1002/agj2.20605

Kopittke, P.M., Menzies, N.W., Wang, P., McKenna, B.A. and Lombi, E. (2019) 'Soil and the intensification of agriculture for global food security', *Environment International*, **132**, p. 105078. https://doi.org/10.1016/j.envint.2019.105078

Lenzi, A., Antichi, D., Bigongiali, F., Mazzoncini, M., Migliorini, P. and Tesi, R. (2009) 'Effect of different cover crops on organic tomato production', *Renewable Agriculture and Food Systems*, **24**(2), pp. 92–101. https://doi:10.1017/S1742170508002445

Li, M., Peterson, C., Tautges, N., Scow, K. and Gaudin, A. (2019) 'Yields and resilience outcomes of organic, cover crop, and conventional practices in a Mediterranean climate', *Scientific Reports*, **9**, p. 12283. https://doi.org/10.1038/s41598-019-48747-4

Lu, J., Ranjan, P., Flores, K., Arbuckle, J.G., Church, S.P., Eanes, F.R., Gao, Y., Gramig, B.M., Singh, A.S. and Prokopy, L.S. (2022) 'A meta-analysis of agricultural conservation intentions, behaviors, and practices: insights from 35 years of quantitative literature in the United States', *Journal of Environmental Management*, **323**, p. 116240. https://doi.org/10.1016/j.jenvman.2022.116240

Molenhuis, J. (2021) Publication 60 Field Crop Budgets. 2021. Queen's Printer for Ontario. ISSN# 0838-5657X. Retrieved from: http://www.omafra.gov.on.ca/english/busdev/facts/pub60.pdf

Morrison, C. and Lawley, Y. (2021) 2020 Ontario Cover Crop Feedback Report. Department of Plant Science, University of Manitoba. https://gfo.ca/wp-content/uploads/2021/12/Ontario-Report-V12-Dec-1st-For-PDF-conversion-for-publishing.pdf

Morton, T., Bergtold, J. and Price, A. (2006) The Economics of Cover Crop Biomass for Corn and Cotton. In Proceedings of the Annual Southern Conservation Tillage Systems Conference. USDA-ARS. Retrieved from:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.562.7576&rep=rep1&type=pdf

Muchanga, R., Hirata, T., Uchida, Y., Hatano, R. and Araki, H. (2020) 'Soil carbon and nitrogen and tomato yield response to cover crop management', *Agronomy Journal*, **112**, pp. 1636–1648. https://doi.org/10.1002/agj2.20098

Nunes, M., Van Es, H., Schindelbeck, R., Ristow, A. and Ryan, M. (2018) 'No-till and cropping system diversification improve soil health and crop yield', *Geoderma*, **328**, pp. 30–43. https://doi.org/10.1016/j.geoderma.2018.04.031

Ontario Ministry of Agriculture, Food and Rural Affairs. (2020) OMAFRA Publication 838 at:

Ontario Ministry of Agriculture, Food and Rural Affairs. (2022) Table 8: Survey of Custom Farmwork Rates Charged in 2018 (Area 3). Retrieved from: http://www.omafra.gov.on.ca/english/busdev/2018customratesa3.htm

Ontario Processing Vegetable Growers Tomato (OPVG). (2006) Grading manual. p 15. Retrieved from: http://www.opvg.org/2006%20Tomato%20Grading%20Manual.pdf

Ontario Processing Vegetable Growers Tomato (OPVG). (2022) Tomatoes: Statistics. Retrieved from: https://www.opvg.org/ontario-processing-vegetables/tomatoes

O'Reilly, K., Lauzon, J., Vyn, R. and Van Eerd, L. (2012) 'Nitrogen cycling, profit margins and sweet corn yield under fall cover crop systems', *Canadian Journal of Soil Science*, **92**(2), pp. 353–365. https://doi.org/10.4141/cjss2011-065

Pratt, M., Tyner, W., Muth Jr, D. and Kladivko, E. (2014) 'Synergies between cover crops and corn stover removal', *Agricultural Systems*, **130**, pp. 67–76. https://doi.org/10.1016/j.agsy.2014.06.008

Price, A., Duzy, L., Balkcom, K., Kelton, J., Kornecki T. and Sarunaite L. (2016) Organic Weed Control and Cover Crop Residue Integration Impacts on Weed Control, Quality, Yield and Economics in Conservation Tillage Tomato-A Case Study, *Organic Farming—A Promising Way of Food Production*, Petr Konvalina, IntechOpen. https://doi:10.5772/61315

RealAgriculture.com. (2021) Wheat School: Doing the math on 2021 straw value. Interview with Peter Johnson. Retrieved from: https://www.realagriculture.com/2021/06/wheat-school-doing-the-math-on-2021-straw-value/

Sainju, U., Singh, B. and Whitehead, W. (2001) 'Comparison of the effects of cover crops and nitrogen fertilization on tomato yield, root growth, and soil properties', *Scientia Horticulturae*, **91**(3–4), pp. 201–14. https://doi.org/10.1016/S0304-4238(01)00264-3

Schoolman, E.D. and Arbuckle, J.G. (2022) 'Cover crops and specialty crop agriculture: exploring cover crop use among vegetable and fruit growers in Michigan and Ohio', *Journal of Soil and Water Conservation*, **77**(4), pp. 403–17. doi: 10.2489/jswc.2022.00006

Snapp, S., Swinton, S., Labarta, R., Mutch, D., Black, J.R., Leep, R., Nyiraneza, J. and O'Neil, K. (2005) 'Evaluating cover crops for benefits, costs and performance within cropping system niches', *Agronomy Journal*, **97**(1), pp. 322–32. https://doi.org/10.2134/agronj2005.0322a

Statistics Canada. (2021) Table 42-10-0365-01. Area, production and farm gate value of marketed vegetables. https://doi.org/10.25318/3210036501-eng

Steer Planet LLC. (2020) Round Bales vs. Square Bales Forum. Retrieved from: https://www.steerplanet.com/bb/the-big-show/round-bales-vs-large-square-bales/

Trueman, C.L., Awrey, J.C., Delaporte, A., Kerr, J., Weersink, A. and Van Eerd, L. L. (2023) Long-term cover cropping suppresses foliar and fruit disease in processing tomatoes. Plant Disease—In press Jan. 2023. https://doi.org/10.1094/PDIS-09-22-2095-RE

Van Alfen, N. (Ed.) (2014) Soil: Conservation Practices. In Encyclopedia of Agriculture and Food Systems. Elsevier. ISBN: 978-0-08-093139-5. Retrieved from: https://www.sciencedirect.com/referencework/9780080931395/encyclopedia-of-agriculture-and-food-systems

Van Eerd, L., Loewen, S. and Vyn, R. (2015) 'Winter wheat straw management on subsequent processing tomato yield, quality, economics and nitrogen dynamics', *Canadian Journal of Plant Science*, **95**, pp. 273–83. https://doi.org/10.4141/cjps-2014-321

Van Eerd, L.L., Chahal, I., Peng, Y. and Awrey, J.C. (2023) 'Influence of cover crops at the four spheres: a systematic review of ecosystem services, potential barriers, and future directions', *Journal: Science of the Total Environment*, **858**, p. 159990. https://doi.org/10.1016/j.scitotenv.2022.159990

Yanni, S.F., De Laporte, A., Rajsic, P., Wagner-Riddle, C. and Weersink, A. (2021) 'The environmental and economic efficacy of on-farm beneficial management practices for mitigating soil-related greenhouse gas emissions in Ontario, Canada', *Renewable Agriculture and Food Systems*, **36**, pp. 307–20. https://doi.org/10.1017/S1742170520000320