Survey of interseeded red clover management and perceived challenges by Ontario wheat growers

Authors: Ogilvie, Cameron M., Loucks, Cora, Beach, Heather, Johnson, Peter, and Martin, Ralph C.

Source: Canadian Journal of Plant Science, 100(5) : 560-567

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/cjps-2020-0039

NRC Research Press

ARTICLE

Survey of interseeded red clover management and perceived challenges by Ontario wheat growers

Cameron M. Ogilvie, Cora Loucks, Heather Beach, Peter Johnson, and Ralph C. Martin

Updated online 28 July 2020: The license for this article has been changed to the CC BY 4.0 license. The PDF and HTML versions of the article have been modified accordingly.

Abstract: Interseeding red clover (RC; *Trifolium pratense* L.) to winter wheat (WW; *Triticum aestivum* L.) is a recommended management practice for wheat growers in Ontario, as it is known to provide a host of services including a significant nitrogen credit for the subsequent crop. However, fewer Ontario wheat acres are being interseeded with RC because of challenges with nonuniform stands. A survey was developed to explore why growers use the winter wheat – red clover (WWrc) system and to evaluate the management practices being used. We received 179 responses, 142 which were from growers currently practicing WWrc and the rest were from growers who had used WWrc in the past. Of those who were currently practicing WWrc, increasing degrees of tillage, wider WW row spacing, and higher RC seeding rates showed some indication of improved RC stand uniformity, and qualitative feedback from growers in the survey supports this. It is recommended that these management practices receive formal evaluation to increase the success of the WWrc system in Ontario.

Key words: clover (red), wheat (winter), management, survey, Ontario.

Résumé : On recommande la culture intercalaire de trèfle rouge (RC — « red clover »; *Trifolium pratense* L.) et de blé d'hiver (WW — « winter wheat »; *Triticum aestivum* L.) aux producteurs ontariens, car cette pratique présente maints avantages, y compris un apport appréciable d'azote pour l'assolement subséquent. Malheureusement, le manque d'uniformité des peuplements a pour effet qu'on ensemence moins de blé qu'on le pourrait avec du RC en Ontario. Les auteurs ont élaboré un sondage pour essayer de comprendre pourquoi les cultivateurs recourent ou pas au système blé d'hiver – trèfle rouge (WWrc) et évaluer les pratiques culturales en usage. Cent soixante-dix-neuf personnes ont répondu au questionnaire, dont 142 utilisant l'assolement à l'étude, le reste l'ayant fait dans le passé. Parmi ceux qui ont adopté cette pratique, accroître le travail du sol, écarter les rangs de WW davantage et augmenter le taux d'ensemencement du RC sont des moyens qui contribuent à rendre les peuplements de trèfle plus homogènes, ce que confirment les commentaires qualitatifs des agriculteurs qui ont répondu au sondage. On recommande d'évaluer de façon formelle ces pratiques de gestion en vue d'augmenter la popularité du système WWrc en Ontario. [Traduit par la Rédaction]

Mots-clés : trèfle (rouge), blé (d'hiver), agronomie, sondage, Ontario.

Introduction

Winter wheat (WW; *Triticum aestivum* L.) acreage in Ontario has increased 38.5% from 1941 to 2017; there were just over 370 000 ha of WW grown in 2017 (Hunt 1980; Kulasekera 2014; Mailvaganam 2018). At the same time, there has been a notable decline in wheat acreage being interseeded with red clover (RC; *Trifolium pratense* L.) in Ontario (Queen et al. 2009; Gaudin et al. 2013; Loucks et al. 2018). Growers struggle to establish consistent RC stands following WW, and an increasing number are opting instead for other cover crops such as oat (*Avena sativa* L.). It is likely that as little as 25% of WW acres in Ontario are being interseeded with RC (Johnson 2005).

Received 13 February 2020. Accepted 24 March 2020.

C.M. Ogilvie, C. Loucks, H. Beach, and R.C. Martin. Department of Plant Agriculture, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1, Canada.

P. Johnson. RealAgriculture, Ontario AgriCentre, Suite 109, 100 Stone Road West, Guelph, ON N1G 5L3, Canada.

Corresponding author: Ralph C. Martin (email: rcmartin@uoguelph.ca).

RC is a short-lived perennial, growing for 1–2 yr in southern Ontario. It is shade tolerant, grows well in cool, moist conditions, and flowers approximately 9–10 wk after establishment. RC fits well as a relay cover crop alongside small-cereal crops when it is frost-seeded into the standing crop just before the spring thaw (Verhallen et al. 2003; Gaudin et al. 2013). This practice is generally understood to not affect the yield of the cereal crop (Gaudin et al. 2013).

Interseeding winter wheat with red clover (WWrc) provides a number of ecosystem services by increasing cropping system diversity and reducing risks of crop failure due to drought stress (Gaudin et al. 2015). This may be because RC can improve organic matter and aggregate stability (Carter and Kunelius 1993), as well as increase moisture retention and suppress weeds (Gaudin et al. 2013; Koehler-Cole et al. 2017), all of which can contribute to better water management. Being a nitrogen (N) fixing legume, RC increases organic soil-N pools (Schipanski and Drinkwater 2011). In studies of corn following RC, it was shown that RC can provide an N credit to the following corn crop and increase corn yields (Vyn et al. 1999, 2000; Gaudin et al. 2014). RC interseeded to WW as a best management practice has also been shown to contribute to better fertilizer N-use efficiency, reduced nitrate leaching in the non-growing season, and reduced N_2O emissions, thus requiring less fertilizer N than management that does not implement a RC cover crop (Jayasundara et al. 2007).

RC interseeded to WW tends to establish evenly, but subsequent plant desiccation and uneven recovery or death leads to nonuniformity that cannot be recovered after wheat harvest (Gaudin et al. 2013; Loucks et al. 2018). Light competition between the wheat canopy and RC can reduce clover biomass (Blaser et al. 2011), but this effect is thought to be less critical than moisture depletion by the wheat crop, which leads to plant desiccation and death and then nonuniformity (Cherr et al. 2006; Queen et al. 2009). Some have attempted to alter WW management — seeding rate, row spacing — to increase RC survival and biomass production, but with little success (Teich et al. 1993; Blaser et al. 2007).

When RC stands are not uniform, farmers no longer depend on RC to reduce the N requirements of the following corn crop or to control weeds and thus are forced to apply additional fertilizers and herbicides. Applying a full rate of fertilizer N on nonuniform RC stands is likely to result in excess N and therefore losses to the environment. Furthermore, increased input costs and low yields may negate the economic benefit of interseeding and may even result in a financial loss when using RC (Stute 2016).

Farmer adoption of the WWrc system and the agroecological benefits that the WWrc system offers are likely to increase if research into WWrc management leads to robust management solutions that can be extended to farmers; however research that is not informed by farmer knowledge and experience can lead to a disconnect and distrust of the scientific community by farmers (Wick et al. 2019). To address this, a survey was distributed in the summer of 2017 to a network of Ontario wheat growers. The objectives of the survey were to learn about the perceived advantages and disadvantages of WWrc, along with the RC and WW management practices of this group of farmers.

Materials and Methods

An online questionnaire was drafted with 41 questions exploring objective and subjective aspects of farmer experiences with the WWrc system (see Supplementary data[1]). Qualtrics® software (Qualtrics XM, https://www.qualtrics.com/) was used to format the questionnaire, and the questionnaire received approval from Research and Ethics at the University of Guelph (Guelph, ON, Canada) before being distributed. A link to the online questionnaire was distributed through personal communication with growers, through grower association newsletters, and over social media.

All 199 survey responses were received between 20 June and 12 Sept. 2017. Of this group, when asked "What county is your home farm located in?", 1 respondent identified that they farmed in Hungary, 2 farmed in Quebec, and 12 farmed in Ontario but did not name the county. Additionally, five respondents reported that they did not have prior experience with WWrc. These 20 respondents were not considered in the analysis to avoid skewed results, leaving a sample size of 179 respondents who previously or currently practiced WWrc. Descriptive statistics were analyzed in Microsoft Excel version 2016. Quotations are used to support themes and are preceded by an identification (ID) number that was assigned at the time of survey submission.

Results

Of the 179 respondents, 142 identified as currently practicing WWrc: 9 from central Ontario, 5 from eastern Ontario, 12 from Golden Horseshoe, 1 from northeastern Ontario, and 115 from southwestern Ontario — in total, 28 out of 49 Ontario counties were represented (Table 1). Next to the Temiskaming district, which only had one respondent, the Golden Horseshoe region had the lowest proportion of respondents (50%) identifying nonuniform stands as an issue for WWrc; central, eastern, and southwestern Ontario all had similar proportions of 78%, 80%, and 75%, respectively.

Of those currently practicing WWrc, the top three perceived advantages of the system were improved soil

[1]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjps-2020-0039.

Table 1. Survey responses according to region and reported prevalence of nonuniform red clover stands.

Census division	Secondary region	Currently practice WWrc	Nonuniform stands identified as an issue (%)
Dufferin County	Central	2	2
Northumberland County	Central	1	0
Peterborough County	Central	2	1
Prince Edward County	Central	1	1
Simcoe County	Central	3	3
Total		9	7 (78)
Lanark County	Eastern	1	1
Lennox and Addington County	Eastern	2	1
City of Ottawa	Eastern	1	1
United Counties of Prescott and Russell	Eastern	1	1
Total		5	4 (80)
Regional Municipality of Durham	Golden Horseshoe	5	4
Regional Municipality of Halton	Golden Horseshoe	1	1
City of Hamilton	Golden Horseshoe	1	0
Regional Municipality of Niagara	Golden Horseshoe	4	1
Regional Municipality of York	Golden Horseshoe	1	0
Total		12	6 (50)
Timiskaming District	Northeastern	1	0 (0)
Brant County	Southwestern	1	1
Bruce County	Southwestern	2	1
Chatham-Kent	Southwestern	16	11
Elgin County	Southwestern	5	5
Essex County	Southwestern	4	2
Grey County	Southwestern	2	1
Haldimand-Norfolk	Southwestern	14	7
Huron County	Southwestern	15	12
Lambton County	Southwestern	15	11
Middlesex County	Southwestern	19	17
Oxford County	Southwestern	10	6
Perth County	Southwestern	7	7
Wellington County	Southwestern	5	5
Total		115	86 (75)
Total of all census divisions		142	103

Note: WWrc, interseeding winter wheat – red clover.

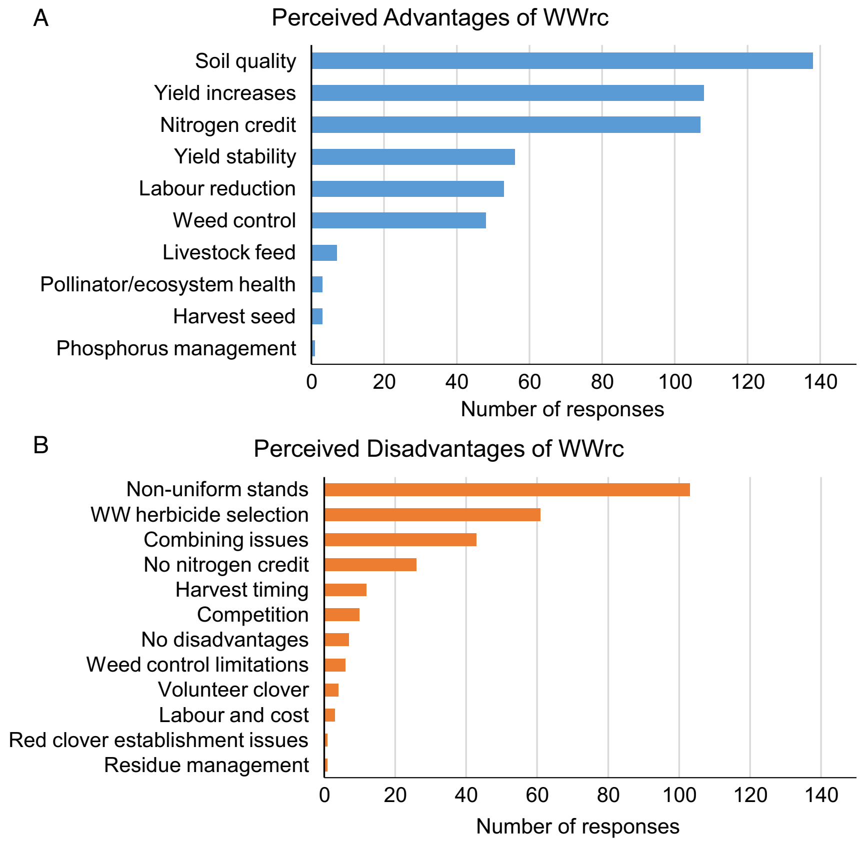
quality (97%, $N = 138$), yield increases for subsequent crops (76%, $N = 108$), and an N credit (75%, $N = 107$) (Fig. 1A). The top three perceived disadvantages were nonuniform stands (73%, $N = 103$), limitations to WW herbicide selection (43%, $N = 61$), and possible difficulties in combining WW when there is excessive RC growth (30%, $N = 43$) (Fig. 1B). The other 37 respondents were not currently practicing WWrc but had in the past, and for this group as well, the most commonly perceived disadvantage was nonuniform RC stands (70%, $N = 26$).

RC management

There were some dominant practices for RC management among respondents; the majority of growers used double-cut (68%), common seed (74%), seeded at a rate between 7 and 9 kg ha^{-1} (70%), broadcasted (97%), and frost-seeded sometime in March or April (87%; Table 2). Fifty individuals, or 35% of the sample population practicing WWrc, used all these same practices; 40 of these (80%) identified nonuniform stands as an issue with WWrc.

The proportion of growers who identified nonuniformity as a challenge in WWrc did not change from common seed to certified seed (70%–68%; Table 2). A greater proportion of people planting a mix of single-cut and double-cut identified uniformity as a challenge, compared with those planting only single-cut or double-cut (91% compared with 72% and 71%, respectively). There were no discernable trends in how seeding time or seeding method affected perceived challenges with uniformity; however, as RC seeding rate increased, the proportion of people identifying nonuniformity as a challenge decreased from 86% at 7 kg ha^{-1} to 25% at >11 kg ha^{-1}. Aggregating the growers' seeding at a rate of 10 kg ha^{-1} or greater, 53% reported challenges with nonuniform stands compared with 78% who seeded less than this.

Fig. 1. Perceived advantages (A) and disadvantages (B) of interseeding red clover to winter wheat (WWrc) identified by growers currently practicing WWrc. [Colour online.]



WW management

There were also dominant practices in WW management; the majority of growers grew soft red wheat (79%) and direct seeded (i.e., no tillage, 74%) at 19 cm row spacing (75%; Table 3). The most popular seeding rates were either 157–168 kg ha^{-1} ($N = 25$) or 0.57–0.65 million seeds ha^{-1} ($N = 49$). The two most popular WW varieties were 'Pioneer 25R40' ($N = 28$) and 'Dow Branson' ($N = 21$).

As tillage increased, the proportion of people identifying nonuniform stands as an issue decreased from 77% under no tillage to 33% under conventional tillage (Table 3). Similarly, as row spacing increased from <15 to >20 cm, the proportion of people identifying nonuniformity as an issue decreased from 100% to 0%. There were conflicting trends in how WW seeding rate impacted nonuniformity between those reporting in kg ha^{-1} and millions of seeds ha^{-1}.

Fertility

Of those practicing WWrc, 123 respondents applied synthetic fertilizer N and 83 of these applied starter N. Of those who applied starter N, 69 (83%) had it placed and 14 (17%) had it broadcasted. Respondents were asked to report their fertilizer N application rates, but high variability in rates, forms, and units made these difficult to compare and so they were left out of the analysis.

Herbicides

The most popular spring herbicide application in WW was the bromoxynil–MCPA combination (Buctril M; $N = 79$), with 23 respondents applying other herbicides or some combination, and 40 non-responses. Of the bromoxynil–MCPA users, 75% ($N = 59$) reported challenges with nonuniformity compared with 74% of other herbicide users ($N = 17$). When asked if they thought their choice of herbicide affected RC uniformity, 23 responded "Yes", 86 responded "No", 11 said they did not apply an herbicide while RC was growing, and there were 22 non-responses. Of those who said "Yes" to the herbicide affecting RC uniformity, 61% used bromoxynil–MCPA.

Respondent feedback

Respondents were given the opportunity to list any management strategies or issues that they felt contributed to the success or lack of success of their RC stand; quotes related to these topics are categorized by ID numbers and themes and are listed in Table 4. A number of growers commented that a no-tillage system contributed to poor establishment (see quotes in Table 4, ID numbers 25, 78, 149, 154, 186, 189, 192). Explanations for this varied. Several respondents remarked that the amount of crop residue left on the surface affected RC seed–soil contact and thus stand uniformity (ID numbers 32, 117, 132, 154, 192).

Table 2. Red clover management for those currently interseeding winter wheat with red clover and interactions with perceived uniformity issues.

Variables	*N* (%)	Nonuniform stands identified as an issue (%)
Red clover seed		
Common	105 (74)	73 (70)
Certified	22 (16)	15 (68)
Other	3 (2)	3 (100)
Unknown	11 (8)	11 (100)
NR	1 (1)	1
Total	142 (100)	103
Red clover growth type		
Single-cut	29 (20)	21 (72)
Double-cut	97 (68)	69 (71)
Mix	11 (8)	10 (91)
Other	5 (4)	3
NR	0 (0)	0
Total	142 (100)	103
Seeding time		
Fall	2 (1)	1 (50)
Frost seed, before March	2 (1)	0 (0)
Frost seed, March–April	124 (87)	93 (75)
Spring seed, not frost seeding	9 (6)	5 (56)
Spring seed, May–June	4 (3)	4 (100)
Other	1 (1)	0
NR	0 (0)	0
Total	142 (100)	103
Seeding method		
Broadcast	137 (97)	101 (74)
Drill	1 (1)	0 (0)
Other	4 (3)	2 (50)
Total	142 (100)	103
Seeding rate (kg ha^{-1})		
<7	7 (5)	4 (57)
7	29 (20)	25 (86)
8	35 (25)	27 (77)
9	35 (25)	27 (77)
10	12 (9)	9 (75)
11	16 (11)	7 (44)
>11	4 (3)	1 (25)
NR	4 (3)	3
Total	142 (100)	103

Note: NR, no response.

Table 3. Wheat management for those currently interseeding winter wheat with red clover and interaction with perceived uniformity issues.

Variables	*N* (%)	Nonuniform stands identified as an issue (%)
Tillage		
No tillage	105 (74)	81 (77)
Minimum tillage	23 (16)	16 (67)
Conventional tillage	9 (6)	3 (33)
Other	3 (2)	2 (67)
NR	2 (1)	1
Total	142 (100)	103
Row spacing (cm)		
<15	2 (1)	2 (100)
18	27 (19)	22 (82)
19	107 (75)	78 (73)
20	1 (1)	0 (0)
>20	3 (2)	0 (0)
NR	2 (2)	1
Total	142 (100)	103
Seeding rate (kg ha^{-1})		
<135	0 (0)	0 (0)
135–146	11 (16)	6 (55)
146–157	13 (19)	7 (54)
157–168	25 (37)	17 (68)
168–179	8 (12)	5 (63)
>179	11 (16)	9 (82)
Total	68 (100)	44
Seeding rate (million seeds ha^{-1})		
<0.49	1 (1)	1 (100)
0.49	0 (0)	0 (0)
0.57	21 (30)	18 (86)
0.65	28 (39)	24 (86)
0.73	17 (24)	13 (76)
>0.73	4 (6)	1 (25)
Total	71 (100)	57
Total seeding rate	139	101
NR	3	2
Total	142 (100)	103

Note: NR, no response.

Some identified that forms of light tillage such as tine weeding (ID number 14) helped to incorporate seeds; others felt that it was necessary to plow down corn stalks (ID numbers 32, 117, 186). In some cases, this was accomplished because previous crops in the rotation required tillage, e.g., edible beans (ID numbers 100, 186, 189); however, other respondents attributed the nonuniform stands in no tillage to earthworm activity (ID numbers 25, 78). Several respondents identified competition between WW and RC as an issue (ID numbers 18, 58, 92, 98, 136, 155, 190). Limited moisture was thus identified as the source of competition between the two crops. Other respondents commented similarly on the necessity of adequate and timely rainfall for RC success (ID numbers 92, 162, 190). Some growers recommended wheat management strategies to make room for RC (ID numbers 76, 110, 173). Other growers seem resigned to RC success being entirely dependent on the weather (ID number 10).

Discussion

While the survey had an adequate response rate, its insights are limited by the uneven distribution of respondents in their regions and management decisions. There did not appear to be a regional association with RC stand uniformity, but 115 of the 142 growers currently

Table 4. Respondent's short answers regarding issues and strategies contributing to red clover success in the winter wheat – red clover system.

ID	Quotes	Themes
10	"I do not think there are any management changes we can do. It is mostly weather (soil moisture) related."	Water limitations
14	"Tine weed to bury seed for uniform stand."	Tillage
18	"Thick heavy wheat stands reduce red clover stands. Rain throughout the spring really helps."	Competition, water limitations
25	"I have been no-till since 2000 and starting to wonder if [dew] worms are eating all my seed as I am having more of a problem these last few years getting a good stand of red clover. I have lots of worms."	No tillage, earthworms
32	"The field is tilled the previous year to mulch stubble and residue to get good seed to soil contact with clover seed. Too much residue will greatly reduce stand."	Tillage, residue
58	"It seems to me it's difficult to grow great wheat and clover together. As I don't grow great wheat with no intention of spending the money for great wheat yields clover is easier to grow."	Competition
76	"Get a better clover stand in soft red wheat than hard, Harvard has too much top growth seems to choke out the clover a lot more than R34."	Competition, wheat management
78	"Long term no till is-hard to get red clover to catch. Blame the earth worms pulling seeds too deep into middens."	No tillage, earthworms
92	"High water demand in the wheat crop, coupled with dry weather, increases the risk for failure on red clover."	Water limitations, competition
98	"If I have a poor stand of wheat in the spring I plant red clover and it will grow in the thinner stands of wheat but a good thick wheat crop won't let the clover become established."	Competition
100	"Better stands of clover after edible beans."	Residue, rotation
110	"Adding sulfur to wheat crop also benefits red clover. Ever since we started adding sulfur to wheat we get more uniform red clover stands."	Wheat management
117	"We find, sometimes, that plowing corn stalks down creates a better chance of getting a good catch, as there is less corn stalk residue remaining on top of the soil, preventing good seed–soil contact when spreading clover. However, we think rain is probably the most influential factor in keeping clover alive: if we ever have a wet spring there is usually no problem."	Tillage, residue
132	"Less corn stalks equals better red clover stand."	Residue
136	"It seems you either have a real good wheat stand and poor clover or thin wheat and better clover. I had a poor field of wheat a couple of times and the clover was thick enough to leave for beef feed next year."	Competition
149	"I feel no till contributes to poorer establishment."	No tillage
154	"In no-till there seems to be more trash still on the surface in the spring and I believe that this leads to poorer clover seed germination when frost seeding."	No tillage, residue
155	"The last few winter wheat crops have been so thick and good that the red clover really hasn't had a chance to grow, either due to lack of moisture or just too thick of wheat."	Competition, water limitations
162	"I feel biggest challenge is soil moisture to keep crop thriving during the growing season. This year the clover has done very well on my farm. Last year was disappointing."	Water limitations
173	"10″ (25.4 cm) row width reduces competition and shading of the clover by the wheat, allowing for excellent and consistent clover catch."	Wheat management
186	"Clover stands are generally more consistent in wheat following edible beans than after soybeans. We think that is because of tillage practice — soybeans are no-tilled into corn stalks while edibles are conventional tillage. We think the reduced residue and the shorter interval between seeding clover and the last tillage pass may help with establishment."	Tillage, residue, rotation, no tillage
189	"I feel we have limited success growing red clover because of our no-till system. I feel other growers in the area have more success if they include tillage somewhere in their rotation."	No tillage, tillage, rotation
190	"It usually depends on what rainfall and the temperatures after broadcast. We had 3 good years in a row with clover. This year I had variable results and depends mostly how thick the wheat is."	Water limitations, competition
192	"All my winter wheat follows a strict rotation of corn and no-till soy. There was always so much residue especially in low ground. I had difficulty getting clover seed to soil contact in these areas and therefore very uneven emergence."	Residue, no tillage

practicing WWrc were from southwestern Ontario (Table 1) — though this does correspond with the dominant WW growing regions. As RC seeding rate increased, the proportion of people identifying nonuniformity as an issue decreased, but only 32 growers used a seeding rate ≥10 kg ha^{-1} compared with 106 who used a seeding rate less than this (Table 2). Similarly, as tillage increased, the proportion of people identifying nonuniformity as an issue decreased, but only 35 growers used some form of tillage compared with 105 growers who did not till (Table 3). Growers planting wheat at 20 cm spacing or greater did not report any challenges with uniformity, but only four were represented by this management decision.

Nevertheless, these trends find further support from growers' qualitative responses. Respondents believed there was an association between no tillage, crop residue left on the surface, and nonuniform stands (Table 4). As 97% of those currently practicing WWrc broadcast their RC seed, it is not difficult to imagine that crop residue could interfere with seed–soil contact resulting in reduced and uneven stands. Indeed, there is evidence to suggest that cover crops establish better when they are drilled as opposed to broadcast (Fisher et al. 2011). A few growers also commented on the increased earthworm activity in no tillage (Table 4), and this is supported by the literature (House and Parmelee 1985; Reeleder et al. 2006), as is the potential for earthworms to bury seeds (Bertrand et al. 2015). Additionally, in winter canola, the crown tends to be raised in no tillage compared with conventional tillage (Assefa et al. 2014). While this does not appear to affect canola winter survival, the ability of RC to survive summer moisture deficits could depend on conserving crown water content (Loucks et al. 2018), which might be compromised if the crown is raised. Whether RC grows large enough in a WW stand to consider crown placement an issue is unclear. Unfortunately, only one grower direct seeded their RC seed, and though this grower did not report challenges with nonuniform stands, this represents an insufficient sample size.

Growers also noted competition between the WW crop and the RC crop as a factor in RC stand uniformity (Table 4), and quantitative responses suggested that higher RC seeding and wider WW row spacing reduced the likelihood of nonuniform stands (Tables 2 and 3), possibly due to less competition. Other studies, however, have not found that adjusting WW row spacing effectively increases RC survival (Teich et al. 1993; Blaser et al. 2007). In the study by Blaser et al. (2007), the field was tilled with a tandem disc and a cultipacker before seeding WW; Teich et al. (1993) did not consider no tillage as it was still relatively uncommon at that time. If tillage is one of the main management factors influencing RC stand uniformity, this may override other management efforts. It has been noted before that the rise of nonuniform RC stands seems to correspond with the arrival of direct seeding technology (Gaudin et al. 2013), but a study by Blaser et al. (2012) did not find any difference in RC biomass between tilled and no-tillage treatments. More research on the effect of tillage is warranted.

A few final qualifications are necessary. First, weather in any given year will interact with a management practice to influence RC stand uniformity, but this year-to-year interaction could not be captured through the survey. Secondly, the conflicting impacts of WW seeding rates on RC stand uniformity may be due to the WW seeding date, which has a dramatic impact on the optimal seeding rate. Thirdly, the analysis assumed that the management practice under question is truly associated with RC stand uniformity; however, it may be that several management practices (or none) contribute to RC stand uniformity and the relationship is merely coincidental. Indeed, it may be that stand uniformity has less to do with management and more to do with weather (Westra 2015), as suggested by some of the respondents (Table 4). Nevertheless, survey responses showed some indication that using tillage, wider WW row spacing, and higher RC seeding rates may improve RC stand uniformity. Due to limited sample sizes with these management practices, more research is needed to formally evaluate them.

Acknowledgements

We are grateful to all the farmers who completed the survey and acknowledge Loblaw Co. Ltd. for operating funds donated to Ralph C. Martin.

References

Assefa, Y., Roozeboom, K., and Stamm, M. 2014. Winter canola yield and survival as a function of environment, genetics, and management. Crop Sci. **54**: 2303–2313. doi:10.2135/cropsci2013.10.0678.

Bertrand, M., Barot, S., Blouin, M., Whalen, J., de Oliveira, T., and Roger-Estrade, J. 2015. Earthworm services for cropping systems. A review. Agron. Sustain. Dev. **35**: 553–567. doi:10.1007/s13593-014-0269-7.

Blaser, B.C., Singer, J.W., and Gibson, L.R. 2007. Winter cereal, seeding rate, and intercrop seeding rate effect on red clover yield and quality. Agron. J. **99**: 723–729. doi:10.2134/agronj2006.0247.

Blaser, B.C., Singer, J.W., and Gibson, L.R. 2011. Winter cereal canopy effect on cereal and interseeded legume productivity. Agron. J. **103**: 1180–1185. doi:10.2134/agronj2010.0506.

Blaser, B.C., Singer, J.W., and Gibson, L.R. 2012. Winter wheat and red clover intercrop response to tillage and compost amendment. Crop Sci. **52**: 320–326. doi:10.2135/cropsci2011.05.0268.

Carter, M.R., and Kunelius, H.T. 1993. Effect of undersowing barley with annual ryegrasses or red clover on soil structure in a barley-soybean rotation. Agric. Ecosyst. Environ. **43**: 245–254. doi:10.1016/0167-8809(93)90089-8.

Cherr, C.M., Scholberg, J.M.S., and McSorley, R. 2006. Green manure approaches to crop production: a synthesis. Agron. J. **98**: 302–319. doi:10.2134/agronj2005.0035.

Fisher, K.A., Momen, B., and Kratochvil, R.J. 2011. Is broadcasting seed an effective winter cover crop planting method? Agron. J. **103**: 472–478. doi:10.2134/agronj2010.0318.

Gaudin, A.C.M., Westra, S., Loucks, C.E.S., Janovicek, K., Martin, R.C., and Deen, W. 2013. Improving resilience of northern field crop systems using inter-seeded red clover: a review. Agronomy, **3**: 148–180. doi:10.3390/agronomy3010148.

Gaudin, A.C.M., Janovicek, K., Martin, R.C., and Deen, W. 2014. Approaches to optimizing nitrogen fertilization in a winter wheat–red clover (*Trifolium pratense* L.) relay cropping system. Field Crops Res. **155**: 192–201. doi:10.1016/j.fcr.2013.09.005.

Gaudin, A.C.M, Tolhurst, T.N., Ker, A.P., Janovicek, K., Tortora, C., Martin, R.C., and Deen, W. 2015. Increasing crop diversity mitigates weather variations and improves yield stability. PLoS ONE, **10**: e0113261. doi:10.1371/journal.pone.0113261.

House, G.J., and Parmelee, R.W. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Tillage Res. **5**: 351–360. doi:10.1016/S0167-1987(85)80003-9.

Hunt, L. 1980. Winter wheat in Ontario. [Online]. WAP publications, McGill University, Ste-Anne-de-Bellevue, QC, Canada. Available from https://eap.mcgill.ca/CPW_10.htm [3 Feb. 2020].

Jayasundara, S., Wagner-Riddle, C., Parkin, G., von Bertoldi, P., Warland, J., Kay, B., and Voroney, P. 2007. Minimizing nitrogen losses from a corn–soybean–winter wheat rotation with best management practices. Nutr. Cycling Agroecosyst. **79**: 141–159. doi:10.1007/s10705-007-9103-9.

Johnson, P. 2005. An evaluation of red clover establishment. OMAFRA Field Crop Project Reports. [Online]. Available from http://www.ontariosoilcrop.org/wp-content/uploads/2015/07/V2Cer4.pdf [3 Feb. 2020].

Koehler-Cole, K., Brandle, J.R., Francis, C.A., Shapiro, C.A., Blankenship, E.E., and Baenziger, P.S. 2017. Clover green manure productivity and weed suppression in an organic grain rotation. Renew. Agric. Food Syst. **32**: 474–483. doi:10.1017/S1742170516000430.

Kulasekera, K. 2014. Historical provincial estimates by crop, 1981–2014. [Online]. Ontario Ministry of Agriculture, Food and Rural Affairs, ON, Canada. Available from http://www.omafra.gov.on.ca/english/stats/crops/estimate_hist_metric.htm [3 Feb. 2020].

Loucks, C.E.S., Deen, W., Gaudin, A.C.M., Earl, H.J., Bowley, S.R., and Martin, R.C. 2018. Genotypic differences in red clover (*Trifolium pratense* L.) response under severe water deficit. Plant Soil, **425**: 401–414. doi:10.1007/s11104-018-3594-9.

Mailvaganam, S. 2018. Area, yield, production and farm value of specified field crops, Ontario, 2012–2017. [Online]. Ontario Ministry of Agriculture, Food and Rural Affairs, ON, Canada. Available from http://www.omafra.gov.on.ca/english/stats/crops/estimate_new.htm [3 Feb. 2020].

Queen, A., Earl, H., and Deen, W. 2009. Light and moisture competition effects on biomass of red clover underseeded to winter wheat. Agron. J. **101**: 1511–1521. doi:10.2134/agronj2008.0163.

Reeleder, R.D., Miller, J.J., Ball Coelho, B.R., and Roy, R.C. 2006. Impacts of tillage, cover crop, and nitrogen on populations of earthworms, microarthropods, and soil fungi in a cultivated fragile soil. Appl. Soil Ecol. **33**: 243–257. doi:10.1016/j.apsoil.2005.10.006.

Schipanski, M.E., and Drinkwater, L.E. 2011. Nitrogen fixation of red clover interseeded with winter cereals across a management-induced fertility gradient. Nutr. Cycling Agroecosyst. **90**: 105–119. doi:10.1007/s10705-010-9415-z.

Stute, J. 2016. Economic analysis of cover crops: impact of interseeding red clover in wheat on corn production economics. [Online]. Michael Fields Agricultural Institute, East Troy, WI, USA. Available from http://michaelfields.org/wp-content/uploads/2018/01/Economic-Analysis-of-Cover-Crops-January-2018.pdf [3 Feb. 2020].

Teich, A.H., Welacky, T., Hamill, A., and Smid, A. 1993. Row-spacing and seed-rate effects on winter wheat in Ontario. Can. J. Plant Sci. **73**: 31–35. doi:10.4141/cjps93-005.

Verhallen, A., Hayes, A., and Taylor, T. 2003. Cover crops: red clover. [Online]. Ontario Ministry of Agriculture, Food and Rural Affairs, ON, Canada. Available from http://www.omafra.gov.on.ca/english/crops/facts/cover_crops01/redclover.htm [3 Feb. 2020].

Vyn, T.J., Janovicek, K.J., Miller, M.H., and Beauchamp, E.G. 1999. Soil nitrate accumulation and corn response to preceding small-grain fertilization and cover crops. Agron. J. **91**: 17–24. doi:10.2134/agronj1999.00021962009100010004x.

Vyn, T.J., Faber, J.G., Janovicek, K.J., and Beauchamp, E.G. 2000. Cover crop effects on nitrogen availability to corn following wheat. Agron. J. **92**: 915–924. doi:10.2134/agronj2000.925915x.

Westra, S.V. 2015. Non-uniform stands of red clover (*Trifolium pratense* L.) underseeded to winter wheat (*Tritcum aestivum* L.): a survey study to identify causes. M.Sc. thesis, University of Guelph, Guelph, ON, Canada. 128 pp.

Wick, A.F., Haley, J., Gasch, C., Wehlander, T., Briese, L., and Samson-Liebig, S. 2019. Network-based approaches for soil health research and extension programming in North Dakota, USA. Soil Use Manage. **35**: 177–184. doi:10.1111/sum.12444.