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Review

The Current State and Future Directions of Organic No-Till Farming with Cover Crops in Canada, with Case Study Support

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Abstract: Eliminating regular tillage practices in agriculture has numerous ecological benefits that correspond to the intentions of organic agriculture; yet, more tillage is conducted in organic agriculture than in conventional agriculture. Organic systems face more management challenges to avoid tillage. This paper identifies factors to consider when implementing no-till practices particularly in organic agronomic and vegetable crop agriculture and describes techniques to address these factors. In some cases, future research is recommended to effectively address the current limitations. The format includes a literature review of organic no-till (OrgNT) research and two case studies of Ontario organic farmers that highlight no-till challenges and practices to overcome these challenges. Cover crops require significant consideration because they are the alternative to herbicides and fertilizers to manage weeds and provide nutrients in the OrgNT system. Equipment requirements have also proven to be unique in OrgNT systems. In the future, it is recommended that researchers involve organic farmers closely in studies on no-till implementation, so that the farmers' concerns are effectively addressed, and research is guided by possibilities recognized by the practitioners.

Keywords: cover crop; mulch; no-till; organic agriculture; roller-crimper; rye; tillage; vetch

1. Introduction

Standardized organic agriculture is one of the major alternatives implemented in an attempt to decrease the negative impacts of conventional agriculture. Organic agriculture in Canada is becoming increasingly prevalent; between 2001 and 2011, the number of organic operations increased by 66%, and organic acreage has increased steadily for the past decade [1,2].

The Canadian Organic Standards (COS) outlines the methods of organic agriculture in Canada. The COS provides the framework for an alternative agricultural system by requiring operations to practice techniques that are sustainable in their use of resources that are added to or removed from the agroecosystem [3]. In eliminating a variety of inputs that entered agriculture in the last century, including genetically engineered organisms and synthetic crop-production aids such as fertilizers and pesticides, organic farming turns primarily to biological activities and crop residues to maintain soil fertility, and mechanical methods and crop rotations to control pests and disease [3]. The COS states that a goal of organic farm systems is to promote and maintain the health of ecological processes and systems, so that natural resources and services are indefinitely available to future generations [3]. From the perspective of organic farmers, they are more prepared for the depletion of external resources than the conventional agriculture system is [4].

Organic agriculture has a caveat: the strong dependence on systemic soil disturbance by tillage and other cultivation practices needed to control weeds without the option of synthetic chemical inputs [4,5]. This caveat has gone mostly unaddressed in the community of organic producers, while in conventional agriculture no-till has increased markedly; in the Canadian Prairies, no-till increased 40% to 45% from 1991 to 2006 and in Ontario from 31.2% in 2006 to 33.1% in 2011 [6,7]. Among organic farmers, tillage is the foremost weed control method [4]. With tillage alternatives unaddressed, organic agriculture faces criticism as to whether it is as sustainable as it is made out to be [8,9] (p. 1).

In light of the environmental and ecological benefits associated with reducing tillage in the agroecosystem, the COS would more strongly uphold its principles under the wide application of no-till. Currently, "minimal tillage" is only mentioned in the introduction of COS rather than being a regulated practice detailed in the standards [3].

To become common practice in organic systems, the challenges of no-till need to be addressed in a manner applicable to organic producers. The methods supported by recent research rely heavily on cover crops to a greater extent than is already practiced in organic agriculture [10]. Since the majority of organic herbicides is ineffective at controlling weeds, mechanically terminated cover crops are placed on the soil surface as weed-suppressive mulch for the following cash crop, a crop considered by this paper to be any crop intended to be marketed [11–13]. There are a number of mechanical termination methods, but the roller-crimper is credited with making no-till more available to organic farmers in Canada and is most strongly supported by research [14].

This paper reviews the state of no-till practices of agronomic and vegetable cropping systems in North America, including a review of issues and options for OrgNT farmers to consider during implementation. This paper presents two case studies (field crop farm and vegetable farm) of Southern Ontario organic farmers' no-till experiments and knowledge to complement the academic research. The discussion compares results from the academic literature and the farmer observations. By comparing the academic analysis and the farmer observations, the discussion will highlight the value of the producer's experience in driving future areas of investigation. The review will also emphasize the importance of on-farm experimentation, observation, and critical thinking among organic producers who aim to enhance their organic farming practices.

2. Literature Review: Current State of Organic No-till Agriculture

2.1. Benefits of Reducing Soil Disturbance in the Agroecosystem

Soil erosion is a visible sign of the unsustainability of conventional tillage practices. The loosening of aggregates by tillage makes them more mobile under water and wind pressure [15]. Erosion assessment technology on corn (*Zea mays*) reveals that over 20 years, sediment loss can be reduced by 99%, and over 100 years by 90%, with no-till practices [15].

Other signs of the negative impact of tillage relate to nutrients, soil microbial activity, and greenhouse gas emissions. West and Post perform a global analysis of long-term (6–100 years) experiments measuring changes in carbon sequestration rates (CSR) in converting from conventional or reduced tillage to no-till practices in managing rotations involving dominantly corn, soybean (*Glycine max*) and wheat (*Triticum aestivum*) [16]. Including continuous and up to 4-year-long rotations and excluding wheat-fallow rotations, West and Post find that CSR increased significantly by 57 g m-2 y-1 in taking up no-till practices.[16]. Soil organic carbon and nitrogen levels tend to be higher in no-till systems near the soil surface, which is where the majority of crop roots are located [17–19]. No-till farming increases the microbial biomass carbon, bacterial abundance, Arbuscular Mycorrhizal Fungi spore diversity, and earthworm diversity, suggesting an enhanced ability of no-till to sustain nutrient cycling in soils [20–22]. As well, no-till practices in crops such as barley (*Hordeum vulgare*), wheat and corn can consume as little as 12% of the fuel used by tilled systems throughout the season, reducing CO_2 emissions significantly [23].

2.2. How Little Tillage is "No-Till"?

Both "reduced tillage" and "no-till" are believed to affect soil health positively with regards to increased soil organic carbon and aggregate stability, among other soil physical and chemical properties [24]. However, the differing extents of their influence is debatable [24]. No-till can be defined as a complete elimination of tillage in agricultural systems [6]. It is difficult to define reduced tillage because reduction can occur along a spectrum and mean different practices over time and in different regions. Reduced tillage often refers to shallower tillage depths and fewer cultivation passes relative to traditional tillage practices in the region [6]. "Rotational tillage" is limited tillage at particular points in an otherwise tillage-free rotation [9]. In the book *Organic No-Till Farming*, author Jeff Moyer defines the OrgNT farming system as one with reduced and rotational tillage, in which shallow, non-inversion incorporations of organic amendments, and control of perennial weeds occur at key points in a rotation [9] (p. 7).

Technically, it can be difficult to differentiate no-till from rotational tillage in research; no-till may be established for three or four years on a historically tilled plot, but this is also replicating the conditions of a three or four-year rotationally tilled plot. Sources do not state a minimum number of years of "no-till", to be considered rotational no-till farming. Hou et al.'s study considers tillage as regularly as every other year to be rotational [25]. Hill states that the length of time of maintained no-till or the tillage depth do not define rotational tillage, in opposition to Moyer [26]. He defines it as any crop rotation that involves any alternating pattern of no-till and tillage [26]. For the purpose of this paper, "organic no-till" is discussed in the context of rotational no-till farming according to Moyer, as his definition more strongly emphasizes continuous minimal disturbance practices even during tillage events.

2.3. Cover Crops as a Central Feature for Weed Management

Cover crops are an important feature of organic systems, contributing to the fertility of the soil upon incorporation and decomposition in the soil [9] (p. 5). In OrgNT systems, their physical presence *above* the soil surface is paramount [9] (p. 5).

Conventional no-till farmers largely depend on the use of herbicides. Conventional growers tend to increase their herbicide application rates from 10 to 25% when adopting no-till [27]. Too much residue in the field is cited as a concern in conventional no-till agriculture, with recommendations to bale up the excess residue that cannot be incorporated under no-till [6]. The approach toward the use of cover crops in OrgNT is much different.

Both cover crop growth and cover crop mulches have roles in organic weed suppression methods. Planted in the fall, well-managed cover crops outcompete weeds for resources during the winter and early spring, prior to the planting of a spring-seeded cash crop [28]. The allelopathic effects of some cover crops, cereal rye (*Secale cereale*) being a common example, also aid in controlling weeds in living mulch form [9,29] (p. 25). After termination, cover crop residues provide weed control throughout the growing season. Bernstein et al. observe that weed density in rye cover-cropped OrgNT system peaks later in the season than its tilled counterpart [30]. Tilled plots have the highest weed incidence in mid-June to early July (44 plants m^{-2} versus 0.2 plants m^{-2} in no-till), while no-till have the highest in late August (reaching 1.8 plants m^{-2}) [30]. The total weed biomass by late season is 73–92% lower in no-till plots [30]. The suppression of early weed emergence can minimize weed biomass and the negative impact of weeds on the cash crop.

The extent to which the cover crop covers the soil defines its success in weed suppression. A greater biomass at termination leads to lower weed incidence. Teasdale et al. report that 97% mulch ground cover in the OrgNT system is required for a 75% reduction in weed biomass [31]. To achieve this level of mulch coverage, 8 to 9 tonnes of dry matter per hectare is required [13,32]. The relationship between biomass and weed control is not linear; at 7000 kg/ha of cover crop mulch, the ground area infested by weeds in OrgNT soybeans is 90%, while at 9000 kg/ha weed cover, it is reduced to less than 15% [13]. A similar relationship is described by Zinati et al. who find that a 50% reduction in rye cover-crop biomass leads to a three times greater weed infestation in OrgNT soybean fields [33]. Others cite 6000 kg/ha as the lower threshold of cover crop biomass to sufficiently suppress weeds [34]. The small margin between suppression and infestation calls for an intensive management of cover crops to meet biomass requirements.

Cover-crop-based no-till farming is currently less common in vegetable than agronomic production across both conventional and organic agriculture, as it is considered a more difficult application [35]. High rates of weed suppression by crimped cover crops are documented in organic vegetable production, including spaghetti squash (*Cucurbita pepo*), pumpkin (*Cucurbita pepo*), bulb onion (*Allium cepa*), and spinach (*Spinacia oleracea*) [34,36,37]. In growing spinach, forage radish (*Raphanus sativus* var. *longipinnatus*) mixed with oats (*Avena sativa)* and monoculture forage radish and oats as cover crops in OrgNT reduce weed infestation to the levels of rototilled bare fields of spinach [37]. In the case of bulb onions, foxtail millet (*Setaria italica*) mulch suppresses more weeds with more biomass than cowpea (*Vigna unguiculata*) mulch, but the latter results in higher yields [36].

2.4. Impact of Cover Crop Establishment in Organic No-Till Systems

Farmers must dedicate more knowledge and physical resources to their cover crops in OrgNT systems because cash crop success is strongly dependent on that of the cover crops. A high seeding rate and fertilization are both recommended to reach the desired 8–9 tonnes/ha for weed suppression. Silva et al. recommend fertilization to reach 90–110 kg of available nitrogen per hectare [11]. Meanwhile, a high seeding rate of 134 kg/ha of the common cover crop cereal rye is recommended by Wallace et al. to reach 8 tonnes/ha [38]. Halde et al. cite recommendations for rye seeding rates ranging from 110 kg/ha to 150 kg/ha [34]. For leguminous hairy vetch (*Vicia villosa*), the total biomass of monocultures is about half that of cereal cover crops like rye, making it difficult to achieve suppressive biomass levels [39,40]. Rye is shown to have more consistent weed suppression capabilities, reaching 95–98% suppression, than vetch, reaching 71–91% [41]. In organic agriculture, leguminous cover crops are needed to fix nitrogen for the following heavy-feeding cash crop, like corn [38]. When combining rye and vetch for a cover crop, Hayden et al. state that at least half the biomass should be contributed by rye in order to effectively suppress winter annual weeds [41].

The timing of cover crop seeding in the fall is another important consideration to achieve a high cover crop biomass. Mirsky et al. found that planting the fall rye and rye–vetch cover crops on August 25 versus October 15 resulted in a 65% increase in cover crop biomass [42]. With each 10 day delay, the potential biomass loss increases; the reduction in the resulting biomass between just October 5 and 15 planting dates was 24% [42].

2.5. Impact of Cover Crop Termination in Organic No-Till Systems

In addition to the biomass, farmer's practices regarding the timing of termination and method of termination of the cover crop can affect the cover crop's mulch ground cover. Termination should occur late in the spring, when the cover crop reaches maximum height [9] (p. 93). With warming temperatures, the growth rate also increases, making each extra day of cereal and legume cover crop growth an increasingly larger contribution to the final biomass [9,38] (p. 19). Mirsky et al. find that the biomass at termination increases from 7599 kg/ha on May 20 to 10,066 kg/ha on May 30, a greater change than that observed for the earlier 10 day increments [42].

Boydston et al. find that rye has a higher mortality than vetch under the roller-crimper at the recommended termination times [35]. Attempting to crimp too early in the season results in the survival of the cover crop and thus it requires further passes with equipment to attempt total termination [34]. Cover crop bounceback reduces its role as a mulch ground cover not only because it is less prostrate, but also because the living cover crop may become a weed itself as it competes with the cash crop for resources [43].

Termination should occur at the anthesis stage for rye, and when bloom is no less than 75% for hairy vetch [9] (p. 3). Despite their different positive contributions, cereal–legume cover crops mixtures are difficult to manage because of the variability in ideal termination time within the cover crop stand [9] (p. 91).

Choosing early maturing cultivars is beneficial in allowing earlier termination and cash crop seeding in the spring [12]. Cultivar examples that are acceptable in certified organic systems include Québec-bred CETAB-HÂTIF, a fall rye variety that tends to bloom 7–10 days earlier than common fall rye, and North-Eastern USA-bred Purple Bounty and Purple Prosperity, hairy vetch varieties that bloom in late May as opposed to early June [9,34] (p. 88). Reberg-Horton et al. compare rye varieties and find that an early maturing rye can have 25% more biomass than late maturing varieties even when the early maturing type is terminated in late April rather than in early May as for the late maturing variety [12].

The most common method of termination is by way of the roller-crimper, a cylinder with angled blades running along the outside in a pressure-maximizing chevron curve that achieves 90–100% termination in one pass [9] (p. 43–50). This method was designed collaboratively at Rodale Institute to achieve a number of goals, unavailable through other termination methods like those employing mowers [9] (pp. 35–50). The roller-crimper lays down a cover crop neatly and evenly and crushes the mature stems without severing them [9] (p. 44). This means that the residues remain in place when the tractor passes during planting and in extreme weather. Gaps can appear in cut mulches, exposing the soil and promoting weed growth [9]. Crimping the cover crop perpendicularly to the cover crop rows further prevents within-row gaps in the mulch [44].

Mowers used in recent studies include the sickle-bar mower and the flail mower [13,30]. According to Bernstein et al., the sickle-bar mower is a viable termination option because it is half the cost of the roller-crimper and leaves residues more intact and evenly placed than other mowers [30]. Smith et al. find that the decomposition of rye is similar between crimped and flail-mowed termination, but mowed legume cover crops decompose more rapidly relative to their crimped counterparts, making crimping preferable at least for legumes [13]. Meanwhile, Moyer states that the roller-crimper was designed to avoid a faster decomposition of all cover crops as a result of a lower surface area compared to mowing [9] (pp. 38–39).

Economic advantages do exist when using the roller-crimper over the mowers because the former functions at higher speeds to reduce time and energy expenditure in the field [13]. This is an important consideration in an OrgNT system because it reduces human and non-renewable energy demands, improving the production efficiency.

2.6. Organic No-Till Options Beyond Cover Crops to Suppress Weeds

Inadequate weed suppression is a possibility in OrgNT, requiring additional management that can be applied curatively to make a profit at season's end. The use of a high-residue cultivator has been applied in a variety of studies in OrgNT practices [13,33,38,45]. High-residue cultivation involves a coulter slicing through the residue to allow for a horizontal sweep to be inserted into the soil and cut weed roots with minimal soil and mulch disturbance [38]. This cultivation method is unique because it targets weeds that are more developed than those severed, often pre-emergence, by traditional cultivators that pass over the fields regularly [38]. The application of high-residue cultivation in OrgNT soybean and corn can reduce weed biomass by over 50%, leading to a yield gain of 23–61%, according to Mirsky et al. [45]. The high-residue cultivation of soybean at its intermediate development stage increases yields more (22% versus 18%) than the cultivation of soybean at an earlier development stage [33]. This makes high-residue cultivation an appropriate "Plan B" option for organic farmers who want to adhere to the cover crop-based no-till methods despite a potential instance of poor weed suppression.

2.7. Cash Crop Considerations

In organic systems, corn often depends on leguminous cover crops to fix nitrogen, but in OrgNT, vetch often produces too little biomass to also provide sufficient weed suppression as a cover crop mulch [11]. In a study of corn planted into a crimped hairy vetch mulch, corn yield increases as the cover crop termination and cash crop planting date are delayed from late May to late June, despite nitrogen levels in the vetch being highest in early June [9] (pp. 19–20). An increased biomass for weed suppression appears to have a more positive effect on corn yield than the higher nitrogen tissue levels earlier in the season.

In onions and spinach production, it appears that other effects of cover crops have a greater impact on the marketable yield than the cover crop biomass. In onions, a millet cover crop has a higher biomass and weed suppression efficacy than cowpea, but millet causes night frost injuries by reducing heat absorption during the day, making the majority of the bulbs unmarketable [36]. The emergence is reduced and blooming delayed for snap beans under a crimped rye cover crop, despite the lower weed biomass with rye than under vetch [35]. Spinach shows a greater success in a low-mulch-covered field after winterkilled forage radish, at just under two times the yield of rototilled methods [37]. Research suggests that favorable climate conditions override the biomass maximization when growing marketable OrgNT vegetables.

High cash-crop seeding rates can increase yield and profitability [44]. Organic growers do not use genetically engineered seeds, whose cost has traditionally encouraged conventional growers to reduce the seeding rates [44]. OMAFRA recommends a planting rate of 395,000 seeds/ha for a 76 cm row width [46]. In Liebert et al.'s study, a planting rate of 646,000–728,000 food-grade soybean seeds/ha into rye and triticale mulch in 76 cm wide rows maximizes profit [44]. Also, a narrower row arrangement of the cash crop hastens canopy closure, outcompeting weeds for light [44,47]. Bernstein et al. find that soybean at a narrower row spacing of 19 cm into crimped rye yield 21% more than in 76 cm rows [47]. This result suggests that intraspecific competition by being close has less negative effects than the positive effects of canopy closure speed and increased seeding density [47].

Both no-till drills and planters designed for conventional agriculture applications require modifications to plant through the heavy mulch of the OrgNT systems. Added weight, row cleaners, and sharpened coulters help to cleanly cut through the mulch [9,35] (pp. 53–57). Trade-offs identified by Liebert and Ryan are that drills can achieve a beneficial narrower spacing, while planters seed more uniformly [44]. Another important consideration for organic farmers is that a spacing narrower than 76 cm eliminates the possibility to perform high-row cultivation as a secondary management measure [38].

2.8. Nutrient Challenges

Cover-crop mulch composition, whether a monoculture or mixture, should have a C:N ratio over 20 to properly control weeds throughout the season [9] (p. 3). Consequently, deficiencies in nitrogen [11,47], sulfur [11], and copper [47] have been reported in soybeans planted into a high-carbon rye mulch throughout the growing season, in spite of their nitrogen-fixing abilities. Bernstein et al. observe a 72% lower nitrogen content in OrgNT soybeans with a rye cover-crop than under tillage [47]. Current common cover-crop species that provide readily available nutrients for temperate organic fields, like Austrian winter pea (*Pisum sativum* var. *arvense*) or crimson clover (*Trifolium incarnatum*), are more susceptible to winterkill than rye [9,39] (pp. 20–21).

2.9. Economic Challenges

With research revealing that both OrgNT corn and soybean can reach lower, higher, or comparable yields than their tilled equivalents in organic systems, economic stability remains a concern [28,30,34,38]. Bernstein et al. conclude that, with a 46% and 42% reduction in labour and fuel, respectively, in OrgNT, profitability remains 27% lower because of the reduced soybean yields [47]. Even with management cost savings of OrgNT, the yields must still be high enough to maintain or improve profits and thus ensure implementation.

3. Case Studies of Two Ontario Organic Farmers

The primary author conducted two interviews on 9 October and 10 October 2017 with two farmers on their Southwestern Ontario farms. Each conversation lasted about 90 min and was audio-recorded.

It is currently challenging to find organic farmers in Ontario performing no-till. These two farmers are renowned in the regional farm community for their OrgNT experimentation for which they receive no research assistance. Two separate interviews with an agronomic and a vegetable crop farmer identified differing priorities and a variety of options and challenges for organic farmers in this region.

3.1. Morris Van De Walle (MV), Organic Cash Crop Farmer

In 2008, MV became a certified organic grower on his farm near St. Marys, Ontario, because he saw that fellow farmers were producing high yields through organic practices. He was also unhappy with sacrificing farm profit by paying so much money to large seed and chemical companies. MV began a no-till rotation in his organic system in 2015.

MV plants cover crops in the fall and mechanically terminates them in the spring. He says this provides nutrients to the spring-planted cash crop and suppresses weeds by canopy coverage and allelopathy. In 2016, he planted soybean into 80 acres of crimped cereal rye, and the soybean yield averaged 50 bu/ac. The 2016 season was particularly dry, and he attributes the success of his no-till soybean crop to the moisture retention that the cover crop provided. He theorizes that another advantage of OrgNT would be a lower cash crop seeding rate and seed cost because there is no physical disturbance in no-till that would take out young plants. He observes that disturbance is an issue in post-emergence cultivation.

In 2017, he grew 10 acres of corn into crimped hairy vetch. This season was particularly cool; as a result, the hairy vetch cover crop was late to mature and thus late to terminate. Tilled corn yielded 150 bu/ac, while yields from no-till were variable because of the poor termination of the vetch and of the competition with both weeds and the cover crop. In areas of adequate termination, no-till corn yields were 100 bu/ac.

MV planted black beans (*Phaseolus vulgaris*) into rye in 2017 to address the issue of late-maturing cover crops delaying cash-crop establishment, because black beans are a shorter season crop than soybean. Still, the no-till black beans yielded up to 1500 lb/ac, whereas the tilled black beans averaged 2000 lbs/ac. MV attributes this to poor weed control by the rye mulch because of the late rye establishment the previous fall.

MV has since sought out a hairy vetch cultivar, Purple Bounty, that matures earlier in the spring, so corn can be planted earlier with more time to grow. He planted Purple Bounty in August 2017 and will observe its survival and persistence in spring 2018. MV's fallback method to manage weeds if the cover crop mulch has low biomass is to perform high-clearance mowing over the canopy by clipping the heads off tall weeds to avoid flowering and seed dispersal.

MV developed an ideal 6 year rotation that includes three years of alfalfa (*Medicago sativa*), followed by one year each of winter wheat, no-till corn into vetch, and no-till soybean into rye. He believes this rotation addresses issues of nutrients and perennial weeds. The management of this rotation includes occasional tillage after the alfalfa, soybean, and wheat portions of the rotation. This is still a big reduction in tillage compared to his traditional practices. The main reason for tillage is to incorporate residues rather than suppress weeds, and he notes that such tillage can be timed to have less impact, when the soil is relatively dry.

MV values neighboring organic farmers, especially in his regional group called SLOP (Slow-Learning Organic Producers), where they share their experiences. "If organic agriculture had as many research dollars thrown at it [as conventional], we'd be further ahead, too". He would like to see research in breeding for cover crops that survive winter and mature early in the spring.

3.2. Ken Laing (KL), CSA Model Vegetable Farmer

KL, his wife, Martha, and his daughter, Ellen, farm over 90 acres south of St. Thomas, Ontario. KL transitioned to organic production in 1989. He works the fields with Suffolk punch horses and grows hay and pasture for them on the farm.

"Tillage is so engrained in organic farmers because they use it to terminate crops and they use it for weed control, so most of them don't even know where to start". KL's recent experimentation with no-till was spurred by his involvement in a committee to develop a provincial soil health policy—and a challenge from his conventional no-till farming nephew. In 2017, he practiced no-till on 4 acres of land. He has applied no-till to both vegetables and field crops.

He fall-seeded daikon radish (*Raphanus sativus*) as a cover crop to hold soil until the spring planting of an oat–barley (*Hordeum vulgare*)–pea (*Pisum sativum*) mixture. The radish winterkills and breaks down quickly in the spring. Early cover crop breakdown allows for early cash crop seeding and supplies nutrients for the spring cereals. Fall 2016-planted sorghum–Sudan grass (*Sorghum x drummondii*) was also winterkilled. While the sorghum–Sudan grass was very thick, KL was able to plant spring oats and barley into the mulch. The mulch biomass coverage persisted on the field into the fall of 2017.

KL wants to introduce faba bean (*Vicia faba*) as a cover crop for its cold hardiness relative to other legumes. Previously, he grew faba bean in the spring prior to brassicas, but deemed it a failure. Alternatively, he seeded faba bean in the fall of 2017 and attributed its impressive growth to a more favorable cool, wet climate. KL believes faba bean would be a good fall-seeded legume cover crop before early spring cereals and vegetables. He experimented with cover-crop mixtures of rye and vetch, but found them difficult to terminate because of their variable maturation.

The establishment of cover crops was a major challenge in the 2017 season because of the dry season. KL's buckwheat (*Fagopyrum esculentum*) cover crop, seeded in late summer and intended to be crimped, was one-third the size he expected it to be. He mowed a portion of buckwheat prior to seeding spelt (*Triticum spelta*) and rye and crimped the portion that was seeded into wheat as it finally reached acceptable height. When the cover crop biomass is low for vegetable crops, he may supplement the crimped mulch with cut mulch from another field. However, he does not believe this is a worthwhile method for cereal crops.

When KL transplanted squash into crimped rye, the squash had slow growth. He will try again, but add fertility both when seeding the rye cover crop and later when transplanting the squash to ensure that both the cover crop and the cash crop get sufficient nutrients.

KL believes in investing knowledge and resources in cover crop management. He saves on compost and weeding when he chooses the best cover crop and it is successful. In KL's opinion, organic farmers can cause nutrient imbalances by relying on compost for nitrogen and, unintentionally, overapplying phosphorus or potassium. Prioritizing legume cover crops as a nitrogen source avoids this imbalance, according to KL. He says organic farmers must rely on high seeding rates and biomass to control weeds; he seeded 250 lb/ac of rye for the squash mulch.

KL notes that "some conventional no-till farmers, such as Gabe Brown, have been able to practically quit using pesticides, quit using fertilizer inputs, and have very productive, profitable farms." (See Gabe Brown video at [48]).

KL says, "other farmers think OrgNT is impossible, and so did I. After seeing Gabe Browns' videos, I now realize that I can make it work." He aspires to do continuous no-till because he believes it contributes more to lasting soil health properties, like the establishment of mycorrhizal and saprophytic fungi, than rotational tillage. "I'm rotating back and forth [between no-till and tillage], so all the gains I make with no-till I'm probably destroying with tillage."

4. Discussion

4.1. Comparison and Contrasts of Organic No-Till Methods in Researchers' and Farmers' Fields

i. The role of cover crops

The role of successful cover crop growth, achieved through good management and favorable, but uncontrollable, environmental factors, is central to a viable cash crop output according to MV and KL. They attribute varying successful and disappointing cash crop yields to the capability of the cover crop stand to retain water, suppress weeds, and contribute nutrients and organic matter.

MV credited the moisture conservation capabilities of the rye mulch to retain enough water for the soybean crop in the dry 2016 season for the achievement of a good yield. In support of this association between water retention and cover crop mulch, Bernstein et al. determine that the volumetric soil moisture content in the top 6 cm of the soil under the mulch is significantly higher than that of the exposed soil throughout the growing season [47].

Both MV and KL rely on the weed suppression of the cover crops as mulches. MV uses rye and vetch, whereas KL also experiments with alternative cover crops, such as sorghum–Sudan grass as mulch for its persistence. Sorghum shoots have a C:N ratio of 77:1 [49], compared to rye with a C:N ratio of 40:1 [9] (p. 3), providing an effective season-long cover. The resulting carbon contribution to the soil per year by sorghum can be up to 78% greater than that of rye, according to Frasier et al. [49].

MV and KL highlight ways in which cover crops suppress weeds other than as mulch. In MV's ideal long-term no-till rotation, he incorporates three years of alfalfa to outcompete perennial weeds. In line with this goal, farmers in Frey and Entz's survey mention alfalfa rotations as a means to control weeds in their general organic practices [4]. In his experimentation, KL finds daikon radish to be an effective weed suppressor in the fall, while supplying nutrients early in the new season. KL's planting of buckwheat in the fall acts dually as a canopy coverage during the winter months to suppress weeds and as a nutrient supply by decomposing before the next season's cash crop requires nutrients [9] (p. 88).

KL's trials exemplify the multifunctional roles of cover crops in OrgNT, beyond providing persistent biomass for weed suppression. These crops include buckwheat, daikon radish, and faba bean. In Ruhlmann et al.'s study on legume cover crops as weed suppressors, they recommend field pea (*Pisum sativum*) for extreme conditions including drought and severe weed problems [50]. Meanwhile, faba bean, vetch, and narrowleaf lupin (*Lupinus angustifolius*) perform better in wet seasons and under less weed pressure [50].

Both MV and the literature highlight the difficulties vetch can provide if not terminated properly. Vetch bounceback and competition with the cash crop caused the no-till corn yield to be unsatisfactory for MV in 2017. Delate et al. also cite vetch competing with corn and reducing corn yield [43].

It is perhaps counterintuitive, or considered a waste of purchased nutrients, to fertilize a crop that is not harvested for sales. This practice represents a barrier to OrgNT production by increasing costs and labour at the cover-crop stage in a rotation. Fertilization recommendations by KL and Silva et al. emphasize the importance of cover crop success to the success of the following cash crop in OrgNT systems [11].

ii. Alternative methods

MV and KL's experiences emphasize that "Plan B" is essential to OrgNT farming. Adding mulch in KL's case and clipping tall weeds in MV's case show that alternative weed management methods help to reduce risks in the OrgNT system. MV considers high-residue cultivation, commonly used in research, but is concerned about the added equipment costs.

KL's method of adding mulch is in line with a concept from Wiens et al. [51]. This concept involves strip-planting alfalfa with the cash crop, mowing the alfalfa ,and distributing it as mulch over the wheat strips [51]. Wiens et al. find that this method benefited the growth of the wheat through a combination of increased weed suppression, moisture retention, and available nitrogen [51]. While complex, this innovation is a potential "Plan C" in OrgNT cropping systems. If there is a poor cover crop establishment and growth, strip-planted alfalfa could provide extra mulch as required. Otherwise, alfalfa can be managed traditionally, mowed, and used for livestock feed. Currently, MV is not inclined to grow his corn or soybean in strips with alfalfa, in part because of the required precise dimensions of the strips. He notes that, in the future, when autonomous equipment is more common, it would likely be smaller and could be manoeuvred accurately on strips to distribute alfalfa evenly.

iii. Cash crops and equipment

In contrast to Liebert and Ryan's encouragement for a higher soybean planting rate to suppress weeds through interspecific competition for light, MV sees the potential to reduce cash crop seeding rates because of fewer losses to mechanical disturbance [44]. Producers should assess the cover crop biomass to weigh the costs of more seeds against the risk of weeds on a case-by-case basis.

In agreement with sources cited by Liebert and Ryan, MV finds the planter more effective at seeding uniformly than the drill [44]. Aside from equipment modifications made to work with his horses, KL bulks up his planter with stronger pieces and metal plates, despite its original design as a no-till planter. Adding weight to the equipment and row cleaners to the planters is recommended by Boydston et al. [35]. These changes improve no-till planters designed for a conventional no-till system that does not involve as heavy a layer of residues [6]. In the area of termination equipment, MV and KL primarily use the roller-crimper, but KL does mow as a less desirable alternative to crimping when the cover crop is too small for crimping termination.

iv. Yields

MV and KL are hesitant to state how they perceived the success of their no-till yields compared to tilled yields. Neither has applied no-till to a field long enough to consider it under accurate no-till conditions. This would be an acceptable stance to have if it indeed takes over 20 years for a converted no-till system to reach its maximum soil health potential, as Radford and Thornton report [52]. Averaged over multiple years, it is possible that MV's ideal 6 year no-till crop rotation will achieve yields that are more profitable, even with the variability of OrgNT. With decades of time as a factor in reaching peak soil health and perhaps, consequently, peak yields in no-till systems, it may be necessary to extend the lengths of OrgNT studies to determine the long-term viability of no-till for organic farmers.

v. The rotational tillage debate

An interesting contrast between MV and KL is their position concerning acceptable tillage practices under a no-till system to achieve soil health benefits. MV envisions himself performing rotational tillage in his no-till system, while KL's goal is the complete elimination of tillage. In line with MV is Moyer, who describes a "need for tillage" at "strategic times" for residue incorporation and compaction reduction [9] (p. 7). Moyer promotes the less invasive non-inversion tillage over the inversion tillage for its production advantages. Pierce et al. find that the bulk density decreases and the porosity and nitrogen mineralization increase within a 20 cm depth with tillage after 6–7 years of no-till practices and last for one year after tillage is performed [53]. In a sense, the rotational tillage in organic agriculture provides a "quick fix" relative to no-till that can otherwise not be easily achieved without synthetic chemicals. However, soil carbon decreases with tillage and takes five years to reach baseline levels [53]. Also detrimental is the reduction in the beneficial fungal and bacterial populations in tilled soils [53]. As such, this organic quick fix, occasional tillage, provides temporary benefits, but simultaneously may be detrimental to the overall natural processes observed in sustainable agroecosystems.

4.2. Advancing Organic No-Till Research

Arguably, the most pertinent information obtained through the interviews addresses a long-standing call for more knowledge resources relevant to organic farmers. From 1984, Kramer's survey of Canadian organic farmers reveals their desire for relevant organic farming resources from agricultural representatives and research stations; in 2014, Frey and Entz's survey of the same demographic reveals their desire for resources from extension and agronomist services [4,5]. The commitment and power of observation of KL and MV are not unique to them—or to OrgNT farmers. Frey and Entz associate these characteristics with the community of organic farmers [4]. Organic farmers must make "make their own mistakes" to find answers to farming challenges that conventional growers find easily in published papers [5]. MV and KL would like to see more government support at the provincial level. Organic agriculture makes up 2% of Ontario farmland, yet receives only 0.4% of agricultural funding from the province to improve their practices [54]. It is frustrating for organic growers that they must pay check-off fees to agricultural organizations that do not prioritize their concerns [54].

A century ago, agricultural resources provided information that was "de facto organic", as chemical-based agriculture was not yet mainstream, according to Granatstein [55]. It is not only difficult to access this information outside of academia (in libraries or stored in membership-access databases), but it is scientifically outdated. No-till factors that are particular to organic stakeholders remain elusive and in need of further research to address OrgNT farming challenges. Three main areas of further research summarized from Halde et al. and Wallace et al. are (1) cover crop management to maximize weed suppression, (2) balancing mulch coverage with the need to supply nutrients and light to the cash crop, and (3) development of machinery suitable to work with thick mulches [34,38]. By finding viable solutions to address OrgNT challenges, conventional no-till will be at an advantage as well. For example, the roller crimper is increasingly being used by proponents of conventional farming, including Howard Buffet, showing its potential across both farming systems [56] (pp. 308–316). Dedicated research to address the needs of organic agriculture, such as organically bred cover crops that address winter survival and biomass production on one hand and nutrient supply to cash crops on the other hand, could reduce variability and make OrgNT an economically safe system for organic growers.

Participatory research is effective for organic farmers, who are often neglected by major research programs and for whom area-specific results are all the more valuable [57]. North American examples include the University of Manitoba, offering organic farmers plant-breeding research collaborations, and Practical Farmers of Iowa and the Ecological Farmers Association of Ontario, offering broad-topic platforms for ecologically minded organic and conventional farmers to share their on-farm trials [57–59]. Research collaboration can address the balance between regionally specific recommendations for organic farmers and farm-specific techniques. By addressing the issues facing organic agriculture specifically, the resulting practices are applicable to all agriculture that aims to improve long-term sustainability.

5. Conclusions

The dependence on tillage is a strike against organic agriculture because the literature has identified the importance of reducing soil disturbance to the agroecosystem and farmers' expenses.

This paper's literature review and case studies highlight the importance of cover crops in the successful implementation of OrgNT practices for both agronomic and vegetable crops. The biomass levels are a function of many management strategies that include planting and termination date, seeding rate, fertilization, and species choice. In combination with variable environmental conditions, balancing these strategies for consistency is a challenge. Winterkilled radish species and cereal–legume mixtures are both options to manage weeds and nutrients. The agronomic crop success depends strongly on the cover crop ability to suppress weeds. Vegetable crop growth is perhaps more susceptible to the effects of cover crop mulches, including the mulch's impact on soil temperature and nutrient availability.

Uncovering a weed control strategy that does not involve chemical applications in case of low mulch coverage is important for organic agriculture. High-residue cultivation, supplementing mulch, and clipping mature weeds above the canopy are methods applied in OrgNT trials by researchers and Ontario farmers to address the weed issue without resorting to tillage.

Participatory research projects are ideal, with active collaboration between researchers and commercial farmers on productive farmland. In this way, scientists can support farmers and compile organic farmers' unique experiences to make it widely relevant. Local no-till research initiatives are important in ensuring that recommendations are geographically relevant in order to meet the particular biological and weather conditions of the areas where individual organic farms are located.

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