Effect of Cover Crops on Yield and Leaf Nutrient Concentrations in an Organic Honeycrisp Apple (*Malus domestica* ‘Honeycrisp’) Orchard in Nova Scotia, Canada

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Abstract. There is an increasing interest for use of cover crops in orchards; however, the species that are most likely to be successfully implemented and their impact on yield and soil productivity have not been fully explored under Maritimes climate. This study investigated the effect of various cover crops treatments on organic apple (*Malus domestica* Borkh cv. Honeycrisp) yield and leaf nutrient concentrations in Nova Scotia over 3 years. Various cover crop mixtures including legumes, cereals, and grasses were planted using a modified Swiss Sandwich System (SSS). The cover crops treatments did not affect apple yield. In 2012, the input of biomass to the soil was 89% and 144% greater for alfalfa (ALF) and other cover crop treatments than unseeded (CON) treatment, respectively. The pea, oats, vetch mixture (POVM) contributed 24% higher biomass N to soil compared with average of other cover crops in 2012. Soil available K concentration in the tilled strip was increased in the 3rd year of the study compared with the initial values across cover crop treatments. The red clover oats mixture (RCOM), POVM, and Triple Mix (TM) treatments appeared to add the greatest amount of available K to the soil among treatments. The CON, TM, and ALF treatments resulted in higher leaf Mn concentration in only 2012 and CON, sweet clover and oats mixture (SCOM), and ALF resulted in higher leaf P concentration in 2014, compared with other treatments. Cover crops did not compete with apple trees and their most beneficial and consistent contribution was to total C, total N, and K input to the soil.

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Groundcover options and management systems can affect organic orchards productivity and long-term sustainability. There are limited options available to organic apple growers for providing adequate amounts of nitrogen (N) at the appropriate time (Doran et al., 1996; Granatstein and Sanchez, 2009). The N requirement in organic apple orchards is usually supplied through leguminous cover crops biological N fixation (BNF) and/or the use of organic amendments such as composted animal manure and mulches (Granatstein and Sanchez, 2009). The amendments that organic farmers rely on to provide nutrients especially N are becoming increasingly expensive (Granatstein and Mullinix, 2008). Reducing the need for

these amendments through the use of cover crops has the potential to reduce production costs for organic farms. Furthermore, cover crops have several other benefits including increasing soil organic matter and stimulating soil microbial activity (Nielsen et al., 2009; Yao et al., 2005). However, cover crops can also compete with fruit bearing trees for resources, negatively affecting yield, and fruit quality (Granatstein and Sanchez, 2009). For that reason there is a need to identify cover crops and residue management systems that will minimize competition with trees, while at the same time contributing to soil productivity.

Legume cover crops can provide N and have the potential to reduce or replace off-farm sources of N fertilizers (Smukler et al., 2012). Cover crops contribute to soil inorganic N and soil labile N pools. The N content of a legume cover crop can be as high as 240 kg N/ha, most of which is released in the first year after incorporation (Stark and Porter, 2005). Insufficient N supply results in poor plant growth, lower yields, and small fruit size (Nielsen and Nielsen, 2003), whereas excess N or late supply of N can negatively impact fruit quality by delaying maturity, or reducing firmness, and poor coloration (Kays, 1999; Marsh et al., 1996). Excess application of N will also increase the risk of N losses to the environment, especially in the humid temperate climate of eastern Canada. Provincial guides to cover crops for organic production in eastern Canada (OMAFRA, 2011a, 2011b) suggest, in addition to perennials like red clover (*Trifolium pratense*) and alfalfa (*Medicago sativa* L.), cover crops such as hairy vetch (*Vicia villosa*), sweet clover (*Melilotus* sp.), field peas (*Pisum sativum* L.), or their mixtures. Green manure options for organic producers are not limited to perennial leguminous crops (Munoz et al., 2005), and variability in tree N uptake response to a legume cover crop may also be attributed to the productivity of a cover crop, and timing of its incorporation into the soil (Messiga et al., 2016).

Determining cover crops that contribute to tree growth and fruit yield is important, especially in organic apple orchards. Cover crops have the potential to compete with trees for water and N, and thus affect tree growth and fruit production (Kuhn and Pedersen, 2009). Sánchez et al. (2007) reported in a steady decline in organic apple leaf N for all their cover crops (alfalfa/fescue, strawberry clover, and vetch) and control treatments in Argentina when no supplemental source of nutrients was added. There are evidences to suggest that the long-term decline of soil health due to poor floor management may be more detrimental to productivity than cover crop competition during the initial orchard establishment (Atucha et al., 2011; Oliveira and Merwin, 2001; Yao et al., 2005). It has also been shown that the reduced yields during orchard establishment with cover crops are not sustained in the long-term and that trees eventually adapted and became more yield efficient than trees in herbicide

treated weed-free system (Atucha et al., 2011). This is especially important for organic apple orchards aiming to increase their long-term sustainability.

There is also little information on the effects of different cover crops on organic apple yields. We hypothesized that cover crops will improve soil properties and will have no effect or positive effect on the organic orchard yield under the condition of the experiment. This study examined the impacts of different cover crops, or mixtures, using a modified SSS on apple yields, tree growth, and leaf nutrient concentrations in an organic apple orchard in Nova Scotia, Canada.

Materials and Methods

The study was conducted at Boates Farms Limited, a 10 ha certified organic apple farm in Woodville, Nova Scotia, Canada. The area is characterized by sandy and silt loam soil and a humid temperate climate with mean temperature of 12.4 °C and precipitation of about 724 mm during the growing season. The orchard was established in 2005, and a section with 'Honeycrisp' variety on 'EMLA 7' root system was chosen for this study. 'EMLA 7' rootstock is well suited in the Maritime region. Mature tree on this rootstock are semidwarfed reaching 3.7–4.6 m in height. This rootstock is desirable because it is winter hardy, fire-bright tolerant, provides good anchorage, and does well in most soils. As trees were crafted on 'EMLA 7' rootstock, which provides good anchorage, they are freestanding reaching about 4 m tall. These semidwarf trees are spaced 2.4 m within a tree row and the alley width is 5.5 m between two tree rows.

Cover crops were planted using a modified SSS. The SSS is an apple orchard floor management system, which leaves a strip of vegetation to grow naturally in the tree row with two narrow strips maintained weed free by tillage on each side mostly used in Organic production (Schmid and Weibel, 2000; Stefanelli et al., 2009). The grassy strip acts as groundcover, which adds organic matter and nutrients through regular mowing. However, it can result in less suitable growing conditions for trees due to competition for water and nutrients. We proposed a modified SSS in this study. A narrow band, 0.5 m, of goose grass (*Galium aparine* L.) in the tree line was left undisturbed. This goose grass strip was mowed twice each season using a grass trimmer when the grasses were over 0.5 m tall and touched the tree branches. Cover crops treatments were grown in a 3.5 m width in the alley with a 0.5 m wide unseeded tilled strip at both sides of goose grass strip. Tilling was done using a Trump tiller at 500 rpm to the depth of 5–7 cm. Cover crops in the alley were mowed, raked to tilled strip, and incorporated into the bare strip, thus the grassy strip in the tree row and cover crops in the alley area both adds organic matter and nutrients. Cover crop treatments and their seeding rates were as follows:

- 1) CON (control)
- 2) RCOM, at 6 + 80 kg·ha⁻¹
- 3) POVM, at 100 + 80 + 20 kg·ha⁻¹
- 4) SCOM, at 5 + 80 kg·ha⁻¹
- 5) TM: red clover, alsike clover and timothy grass, at 2.25 + 2.25 + 10.5 kg·ha⁻¹
- 6) ALF at 25 kg·ha⁻¹

The CON treatment was included to be able to monitor the soil N dynamics with and without cover crops. Each year, the seed germination rates were tested and the seeding rate adjusted for germination rate. Alleyways were shallowly cultivated with rotor tiller in early May to remove the previous vegetation. The cover crops were seeded twice in 2012, May 17 and June 13, and on 1 May 2014. The first cover crop seeding in 2012 was not successfully established, likely due to below 30-year average precipitation. Cover crop treatments were not reseeded in 2013 due to labor and funding constraints. This was not a concern for perennial cover crops treatments (i.e., RCOM, SCOM, TM, and ALF); however, the annual cover crop treatment (POVM) was also able to reseed itself in 2013 due to the late mowing in 2012. Cover crop seeding rates were according to the recommendation of New Brunswick Department of Agriculture, Aquaculture and Fisheries (Government of New Brunswick, 2009).

Each plot consisted of a row of five trees: three study trees with a guard tree on each side in a randomized complete block design (similar cover crops on both sides of the tree line) with four replications. Seeding was done carefully so minimum cross-contamination of cover crops seeds between adjoining plots were occurred. Yield and trunk cross-sectional area (TCA) data were collected for each individual tree (12 experimental units for each treatment), whereas all other measurements were collected by plot.

All treatments received 2000 kg·ha⁻¹·year⁻¹ (half of the recommended rate) Nutri-Wave™ (NW), certified organic dehydrated pelletized poultry manure (4-1-2 analysis), in the unseeded tilled strips at the both side of goose grass strip as starter fertilizer in May. Cover crops were mowed (at about 6 cm height from the ground) twice in the season and the clippings were pushed to unseeded tilled strip by a tractor mounted rake and incorporated to top 5 cm of the tilled strips using a rototiller. The mowing dates for 2012 were 21 Aug. and 6 October; for 2013, were June 19 and July 20; and for 2014, were June 20 and July 19. Grass strip was mowed twice using a hand held mower when the grasses were over 0.5 m tall and touching the tree branches. Before each mowing date only in 2012, three quadrats (0.25 m²) of cover crop sample were collected randomly from each plot. The samples were oven dried at 65 °C for 48 h, dry weights were recorded. Plant tissue samples were ground and analyzed for total N concentration by the Dumas method using a LECO CNS-1000 analyzer (LECO Corporation, St. Joseph, MI). Cover crops N uptake was calculated by multiplying the biomass by N concentration. Cover crops

biomass were not sampled in 2013 and 2014 due to labor and funding constraints.

Relative chlorophyll content was recorded using a SPAD-502 m (Spectrum Technologies Inc., Plainfield, IL) on four fully expanded leaves from four sides of each test tree at 1.3 m height in late July in 2012 and 2014. The SPAD readings were not recorded in 2013. Mature midshoot leaves (7–8 from each test tree, i.e., 21 to 24 from each plot) were collected on July 25th 2012 and 7 Aug. 2014 and analyzed for N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, and B after oven drying for 48 h at 65 °C and grinding. Total leaf tissue N was analyzed by Dumas method using a LECO CNS-1000 analyzer. Other macro and micronutrients were extracted by the dry ash method (Westerman, 1990) and analyzed using a Varian 725-ES Radial ICP-OES inductively coupled plasma mass spectrometer (ICP).

Standard organic practices were used for weed, insect, and disease control (OMAFRA, 2016). The fruits were harvested in the last week of September each year. While harvesting, number and weights of total and marketable fruits from each of the test trees were recorded. A fruit was considered marketable based on acceptable fruit color, size, blemishes, and pest attack (insect and disease). The TCA was calculated from trunk circumference measured at 25 cm above graft union of each test tree as a measurement of growth of the previous year in April of each year. In 2012, before the start of the experiment, four composite soil samples consisting of eight cores from each of the four blocks were collected from the tilled strip area at 15 cm depth and initial soil properties were analyzed (Table 1). Micro and macronutrients except N were measured using a Varian 725-ES Radial ICP-OES after extraction with Mehlich-3 solution. In Apr. 2012, four soil core samples (one from each block) were also collected for bulk density calculation (Blake and Hartge, 1986). In 2013 (August) and 2014 (April and October), composite soil samples (eight cores from each plot) were taken from the tilled strip, and analyzed for soil pH and available P and K.

Table 1. Mean values (n = 4) for soil characteristics at the start of experiment (Spring 2012).

Soil parameter	Value
pH	5.75 (0.06) ²
Bulk density (g/cm ³)	1.37 (0.32)
Organic matter (%)	3.30 (0.22)
CEC (meq/100 g)	9.28 (0.46)
P (kg·ha ⁻¹)	285 (84.89)
K (kg·ha ⁻¹)	175 (20.05)
Ca (kg·ha ⁻¹)	2,016 (123.66)
Mg (kg·ha ⁻¹)	288 (6.99)
S (kg·ha ⁻¹)	33 (1.73)
Al (ppm)	1,378 (41.41)
Fe (ppm)	168 (13.60)
Mn (ppm)	37 (5.92)
Cu (ppm)	24 (6.01)
Zn (ppm)	1.30 (0.22)
B (ppm)	<0.5 (0.00)

CEC = cation exchange capacity.

²Values in brackets are SD.

Each year, data were analyzed using MIXED procedure of SAS version 9.3 with replicates as random effects and cover crops as fixed effects except for soil properties that soil sampling dates were considered as a repeated effect. Tree location in the orchard and TCA were used as covariates for analyzing total apple numbers and apple yield. These covariates helped to account for soil variability and tree size. Differences among least square means for all treatment pairs were tested at a significance level of $P < 0.10$. The $P < 0.10$ was chosen over $P < 0.05$ due to high variability of tested parameters and higher chance of capturing the differences. Yield efficiency was calculated using the total weight of apples produced divided by TCA of previous year. The yield data for each tree was analyzed individually for each study year due to different environmental conditions.

Results

Seasonal air temperature and precipitation.

The 30-year average growing season rainfall for the area is 724 mm. The first year of the study had rainfall only 86% of the 30-year average, which resulted in a delay in the sowing of cover crops. The warmest months were July and August in all years, reaching temperatures of 20.9 and 21.7; 21.5 and 19.1; 22.2 and 18.9 °C, respectively, whereas the 30-year average was 19.6 and 19.1 °C for July and August, respectively.

Soil properties. Initial soil test results showed that soil pH was 5.7, and recommended lime application at 6 Mg·ha⁻¹ to increase the pH to the desired 6.5 level (Table 1). Organic matter content of the soil was 3.3%. Soil bulk density up to 30 cm depth was 1.37 g·cm⁻³. Cation exchange capacity of the soil was 9.28 meq 100 g/soil.

Soil properties were measured in three sampling dates during the experiment (Aug. 2013, Apr. 2014, and Oct. 2014) in addition to initial soil sampling (Apr. 2012). Soil properties were unaffected by the treatments during the experiment except for available K. There was a significant difference between soil available K content among sampling dates, as well as among treatments across sampling dates (Fig. 1). The treatment by sampling date interaction was not significant. The Aug. 2013 sampling date had the highest soil K content. Both sample dates in 2014 showed higher soil K content when compared with the initial concentrations in 2012. The RCOM, POVM, and TM treatments appeared to increase soil available K (Fig. 1). The available K levels in TM were intermediate and not significantly different from RCOM, POVM, SCOM, or ALF, but higher than CON. The SCOM and ALF resulted in lower soil available K compared with POVM and SCOM and not different from CON.

Cover crops. Cover crop biomass and N content was only measured in 2012. Cover crop establishment was delayed, in 2012, due to a dry period with minimal precipitation during May. At first mowing date, dry

matter (DM) yield ranged between 120 and 164 g·m⁻², and N content ranged between 2.77% and 3.88% (Table 2). However, these values did not statistically differ among cover crop treatments including the unseeded

treatment. The *Amaranth* sp. and *Chenopodium album* L. weed species dominated the unseeded treatment. However, after first mowing, *Amaranth* sp. and *C. album* did not grow further and at second mowing date (first week

Fig. 1. (A) Mean soil available K concentrations by sampling dates. (B) Mean soil available K concentrations by treatment, bars with the same letter are not significantly different, $\alpha = 0.1$. CON = unseeded; RCOM = red clover and oat mix; POVM = pea, oat, hairy vetch mix; SCOM = sweet clover and oat mix; TM = triple mix; ALF = alfalfa.

Table 2. Cover crop dry matter yield and N contents in 2012.

Cover crop ²	First mowing		Second mowing		Total dry matter ³ (Mg·ha ⁻¹)	Plant N uptake (kg·ha ⁻¹)
	DW (g·m ⁻²)	N (%)	DW (g·m ⁻²)	N (%)		
CON	131	3.88	0	0	0.84 c	32 c
RCOM	151	2.77	159 b*	4.53 ab	1.98 a	72 b
POVM	129	3.17	219 a	4.72 a	2.23 a	88 a
SCOM	164	2.95	175 ab	4.09 c	2.17 a	76 b
TM	141	3.80	145 b	4.17 bc	1.82 ab	73 b
ALF	120	3.33	129 b	4.47 abc	1.59 b	62 b
Analysis of variance	NS	$P = 0.072$	***	***	***	***
CV (%)	16	17	23	7.0	14	8.7

²CON = unseeded; RCOM = red clover and oat mix; POVM = pea, oat, hairy vetch mix; SCOM = sweet clover and oat mix; TM = triple Mix; ALF = alfalfa.

³64% of the alley way were used for calculation of cover crop dry matter.

*Values in each column with the same letter are not significantly different at 0.05 P level using least square differences.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. Probability levels between 0.05 and 0.1 have been reported.

of October), there were no weeds in the unseeded treatment at mowing height and other cover crop treatments were mostly weed free. At the second mowing date, significant differences were observed in DM production and N contents among cover crop treatments (Table 2). The highest DM yield in the second cut was recorded for POVM (219 g·m⁻²), which was comparable with SCOM (175 g·m⁻²). The RCOM, TM, and ALF had similar DM yields and were comparable with SCOM. The POVM had the highest N concentration (4.7%) and it was comparable with RCOM (4.5%). The SCOM had the lowest N concentration (4.1%), which was comparable with TM and ALF. Highest values for total cover crops DM production were measured at POVM, SCOM, and RCOM followed by TM and ALF. Highest values for total cover crops N uptake were measured in POVM and total N uptake was not different among other cover crops treatments. The CON treatment had the lowest total DM and total N uptake. Taking into account that cover crops were grown in 64% of the alley area, 1.59 to 2.23 Mg·ha⁻¹ DM

and 62–88 kg·ha⁻¹ N were made available to the orchard soil during 2012 growing season. The unseeded treatment received about 0.84 Mg·ha⁻¹ DM and 32 kg·ha⁻¹ N through weeds biomass.

Leaf nutrient contents and SPAD measurements. Leaf tissue samples were only analyzed in 2012 and 2014. Leaf nutrient analysis showed that there was a significant difference among cover crops treatments for only Mn ($P = 0.083$) in 2012 and only P ($P = 0.008$) in 2014. In 2012, the CON treatment had the highest concentration of Mn followed by TM and ALF, whereas the RCOM had the lowest (Fig. 2). The POVM and SCOM resulted in intermediate concentration of Mn in leaves. Sufficient levels of Mn are 25–200 ppm, which all of the treatments were within this range (OMAFRA, 2016). In 2014, the CON, SCOM, and ALF resulted in significantly higher leaf P concentration compared with RCOM (Fig. 2). The tissue P concentrations in POVM and TM were intermediate and not significantly different from RCOM or ALF. Sufficient levels of leaf tissue P for fruit trees range from 0.15% to 0.26% (OMAFRA,

2016), only the RCOM treatment was below the recommended range. SPAD measurements (only taken in 2012 and 2014) ranged from 45.0 to 46.8 in 2012 and from 39.2 to 42.5 in 2014, and were not significantly affected by cover crop treatments (Table 3).

Marketable and unmarketable yield. Fruit yield (total or marketable) and yield efficiency were not significantly affected by cover crop treatments including CON (Table 3). Number of fruits per tree ranged from 53 to 86 across treatments in 2012, 71–132 in 2013, and 46–160 in 2014. The percentage of marketable yield to total yield on weight basis was 58% in 2012, 65% in 2013, and 82% in 2014. Yield efficiency ranged from 0.76 to 1.07 kg·cm⁻² TCA in 2012, 0.49 to 0.90 kg·cm⁻² TCA in 2013, and 0.14 to 0.61 kg·cm⁻² TCA in 2014. The highest mean yield efficiency was in 2012, followed by 2013, with 2014 having the lowest.

Discussion

Soil properties. Some of the impacts of cover crops on soil properties particularly nutrients might have been masked by addition of NW amendment in this study. The only significant difference between years or treatments on soil properties was soil available K content. Potassium affects fruit quality and yield for apples (Ernani et al., 2002). It is also an important nutrient for legumes, as low soil K availability can reduce N fixation (Duke et al., 1980). This was unlikely an issue in this study as an organic amendment (NW, 4-1-2) was applied. The two cover crops that produced the largest amount of total biomass (RCOM and POVM) in 2012 were also the treatments that had the highest soil K concentrations. Aug. 2013 soil samples had the highest soil K concentrations, although the K concentrations decreased for both sampling dates in 2014, which can likely be attributed to uptake of available K by cover crops. The spike in 2013 was likely due to the midseason sampling date, when the cover crops were cut and incorporated in the tilled strips. The increase in soil available K concentrations was seen in 2014 when compared with 2012. This increase could be due to the current and residual effect of NW application and residual effect of cover crop incorporation from the

Fig. 2. Leaf tissue concentrations of Mn in 2012 and P concentrations in 2014 for all treatments. Bars with the same letter (capital letters used for P) are not significantly different within that year at $\alpha = 0.1$. CON = unseeded; RCOM = red clover and oat mix; POVM = pea, oat, hairy vetch mix; SCOM = sweet clover and oat mix; TM = triple mix; ALF = alfalfa.

Table 3. Analysis of variance and least square means for total apples, apple yield, yield efficiency and SPAD in 2012, 2013, and 2014.

Treatment ^a	Total apples/tree			Unmarketable apples/tree			Marketable wt (kg)			Unmarketable wt (kg)			Yield efficiency (kg·cm ⁻²)			SPAD	
	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2014
CON	75	107	92	30	37	18	23	30	31	14	15	5	1.07	0.78	0.40	45.9	39.2
RCOM	64	102	114	27	36	23	18	34	38	13	15	7	0.90	0.85	0.61	46.8	42.5
POVM	53	132	46	22	59	21	16	32	9	11	25	2	0.80	0.85	0.14	45.6	39.5
SCOM	56	99	53	23	34	10	13	33	20	11	13	4	0.76	0.90	0.36	46.0	40.1
TM	86	71	160	40	29	40	20	20	36	17	10	8	1.03	0.49	0.55	45.8	42.4
ALF	55	100	100	22	36	28	18	32	35	10	15	9	0.79	1.01	0.57	45.0	41.7
Mean	65	102	94	27	39	23	18	30	28	13	16	6	0.89	0.81	0.44	46	41
SE	12	14	33	5	9	9	3	5	10	2	4	2	0.15	0.13	0.22	0.60	0.92
P value	0.341	0.125	0.171	0.119	0.267	0.263	0.301	0.318	0.301	0.225	0.143	0.29	0.625	0.142	0.649	0.610	0.162

^aCON = unseeded; RCOM = red clover and oat mix; POVM = pea, oat, hairy vetch mix; SCOM = sweet clover and oat mix; TM = triple mix; ALF = alfalfa. SPAD data for 2013 were not collected.

previous years. It is difficult to determine the K contribution of the cover crops as cover crops DM and their tissues K concentration were not determined in this study.

Cover crops. Cover crop establishment and consequently their DM and N contribution were limited by lower than normal precipitation in 2012. Cover crop data were not collected in subsequent years due to labor and budget constraints. Overall, in 2012, although POVM, SCOM, and RCOM performed comparatively better than other cover crops in terms of DM yield, POVM outperformed the other two in terms of total N uptake probably due to high protein contents in peas and vetch (Porter et al., 1999). The low ALF DM can be attributed to slow growth of alfalfa in the establishment year. At an apple orchard in New Zealand, it was estimated that 58 kg-ha⁻¹ N was removed in the fruit and through leaching losses (Goh et al., 1995), whereas a clover cover crop provided nearly that much N in its biomass. This illustrates the potential for organic orchards to obtain a significant portion of their N needs through legume-based cover crops incorporation (Hoagland et al., 2008). Growing cover crops in the alley area may allow a large area for biomass production and symbiotic N fixation by legumes.

The amount and rate of N mineralized from cover crop residues has been shown to be dependent on the C:N ratio of the residue, as well as environmental conditions such as moisture and temperature (Kuo and Sainju, 1998). Cover crop residues with lower C:N ratios (C:N <20) will decompose more rapidly than those with higher ratios (C:N >20) (Kuo and Sainju, 1998). The C:N ratios for different cover crops can range from 12:1 for sweet clover to 80:1 for timothy grass (Havlin et al., 2005). One study determined that POVM had an average C:N of 10.4:1 in Nova Scotia, Canada (M. Sharifi et al., unpublished data). Legumes have a low C:N ratio and as a result rapidly decompose, given appropriate soil moisture and temperature (Abdul-Baki et al., 1997; Strivers and Shennan, 1991). This allows the N contained in these residues to become more quickly available to crops.

As a result of differing C:N ratios in cover crops, it is important to synchronize the N release from cover crops with high orchard N demand to maximize N use efficiency and minimize losses through leaching and emissions. Cover crop residues would need to be incorporated in early July to allow adequate time for mineralization in humid temperate climate of Ontario, Canada. Soil moisture/precipitation at this time will be a key factor influencing mineralization rate (Dessureault-Romp et al., 2011). In the future, looking at the timing of incorporation could influence decisions on when to cut and incorporate cover crops. Although this would also have to take into account seeding as well as nutrient uptake and competition with orchard trees. The effect on the nutrient availability can be attributed to differences in BNF, root structure and depth, and affinity of the nutrient among cover crops species.

Leaf nutrient contents. Although there was a significant difference among some cover crops treatments for leaf Mn concentration in 2012, all leaf Mn concentration values were within the sufficiency range. Therefore, these differences are unlikely to have affected yield production or quality. Only the leaf P concentration in RCOM treatment fell below the recommended sufficiency levels for P; however, all of the treatments were in the lower end of the range. The RCOM treatment was the lowest for both Mn and P leaf concentrations.

Marketable and unmarketable yield. Yield efficiency may have been lowest in 2014 due to more unproductive trees than previous years (data not shown). There does not appear to be any recognizable trend between treatments and yield. Comparisons among years, for this short study, are also hampered by the Honeycrisp cultivars propensity for overcropping which results in strong biennial bearing (Crassweller et al., 2005; Embree and Nichols, 2005; Robinson and Watkins, 2003).

Yield efficiencies as high as 1.62 kg-cm⁻² TCA and as low as 0.74 kg-cm⁻² TCA have been demonstrated with Honeycrisp in one study in Nova Scotia (Wright et al., 2006). Another study, also in Nova Scotia, documented yield efficiencies ranging from 0.74 to 1.24 kg-cm⁻² TCA (Braun et al., 2010). While the yield efficiencies in the current study were in the low end of these ranges, it is important to note that, unlike the current study, the previous examples are from conventional apple orchards and organic yields are generally lower.

There is other evidence to suggest that while different orchard floor management strategies might not affect fruit yield or quality in the short term, they have potential to improve soil properties and reduce erosion and nutrients losses to the environment (Nielsen et al., 2014; Oliveira and Merwin, 2001; Yao et al., 2005). Previous studies have reported that, in the long-term (>9 years), apple trees will adapt to compensate for groundcover competition, and can even end up outperforming trees grown without groundcover (Atucha et al., 2011). It has also been previously postulated that maintaining groundcover free plots might result in the long-term deterioration of soil physical and biological conditions (Oliveira and Merwin, 2001; Yao et al., 2005), despite the short-term release of nutrients.

Conclusions

The different cover crops treatments did not affect apple yields in this study. Differences in tree growth and yield among the treatments may not have been large enough to be reflected in short-term. The spring application of poultry manure may also mask the effect of treatments. The use of cover crops in organic apple orchards contributes to soil organic matter and soil N, and would not negatively affect yields under low input organic management. Based on establishment

costs and biomass amount, perennial cover crops that include a mixture of legumes and grasses were found to be more suitable compared with annual cover crops for orchards in this region. Other than possible N contribution of legume-based cover crops, our findings showed that the cover crops can affect nutrient availability in soil. Future studies are needed to screen a wide range of cover crops species and their management for the effects on soil health, and orchard yield and yield quality in Atlantic Canada.

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