Effects of Within-row Intercropping with Snow Peas on Yield and Quality of Cherry Tomatoes in an Organic High Tunnel Production System

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Abstract. Intercropping can increase land use efficiency in high tunnel crop production, but it may also lead to decreases in yield and quality of main crops due to the potential competition for resources. This study evaluated the agronomic viability of intercropping snow pea (*Pisum sativum* L., ‘Ho Lan Dou’) with cherry tomato (*Solanum lycopersicum* L. var. *cerasiforme* ‘Sarina hybrid’) without additional inputs of water and fertilizers on peas in an organic high tunnel production system under Southern Ontario climate conditions in Guelph, Ontario, Canada (lat. 43.5°N, long. 80.2°W) during 2015 and 2016. In each 80-cm-wide bed, the tomato crops were planted alternately in double rows spaced 30 cm apart, with in-row spacing of 110 cm, which resulted in a planting density of ≈24,000 plants/ha. The snow pea seeds were sown between the tomato plants (i.e., within the same beds as tomatoes) in holes (two seeds per hole), with four rows in each bed and in-row holes spaced 10 cm and at least 25 cm away from the tomato plants, which resulted in a seeding rate of ≈650,000 seeds/ha. The same amount of water or fertilizer was applied to the intercropping and nonintercropping plots based on the needs of the cherry tomato plants. Plant growth, fruit yield, and quality were compared between tomato plants with and without intercropping. Intercropping with snow peas did not affect total marketable fruit yield, unmarketable fruit percentage, fruit quality traits (e.g., individual fruit weight, soluble solids content, dry matter content, and postharvest water loss), or early-stage plant growth of the cherry tomato. Therefore, it is at least an agronomical possibility to intercrop snow peas with cherry tomatoes on the same beds without additional inputs of water and fertilizer on snow peas in an organic high tunnel system. The additional yield of pea shoots or pods in the intercropping treatment also increased economic gross returns in the high tunnels, although the economic net return might vary with the costs of seeds and labor involved in snow pea growing.

In recent years, adoption of high tunnel production systems for vegetable production has rapidly increased in North America

(Carey et al., 2009). High tunnels can increase yields, improve product quality, and extend the growing season compared with open field production (Carey et al., 2009; Kong et al., 2017). However, the additional costs of high tunnel structures and operations cannot be neglected, especially for small farmers (Belasco et al., 2013). Tomato has become one of the most important high-value vegetable commodities grown using high tunnel production in North America (Carey et al., 2009; Jett et al., 2005). Recently, organic cherry tomato has been grown successfully inside high tunnels in Southern Ontario, Canada, producing substantially higher yields than the open field (Kong et al., 2020). However, organic production normally has a lower crop yield than conventional production (Röös et al., 2018). Also, with tomato areas increasing in recent years, production of this crop has become less profitable for high tunnel growers. Because the limited space in the high tunnel is valuable “real estate,” multi-crop systems (e.g., intercropping) may improve economic returns, especially for small farmers whose markets typically demand a

wide variety of commodities but not particularly in large quantities (Chase and Naeve, 2012).

Intercropping, the practice of growing more than one crop concurrently in the same area, is an approach commonly used in organic production systems (Theunissen, 1997). Intercropping can potentially increase economic returns by adding the yield of another crop species while also potentially reducing weed, pest, and disease infestations (Horwith, 1985; Theunissen, 1997). However, intercropping can also lead to a competition for light, nutrition, and water between the main crops and intercropped plants, which could result in yield reduction of one or both crops (Horwith, 1985; Theunissen, 1997). Consequently, when using an intercropping system for high tunnel tomato production without additional inputs of water and fertilizer, it is critical to choose an intercropped crop that has the least competition with tomato for resources, thereby resulting in the least negative effect on tomato yield. In previous studies, the intercropping effects on tomato yield varied with different intercropped crops. In a field production trial performed in Kenya, intercropping tomato with onion and kale did not reduce marketable tomato yields compared with monocropping tomato; however, intercropping tomato with maize reduced the tomato yields, possibly due to the taller canopy of maize than other intercrops (Ramkat et al., 2008). In a tomato/garlic intercropping system using organic medium under plastic tunnels in China, intercropping reduced the total spring tomato yield than did monoculture of tomato, possibly due to its competition with garlic for nutrients and water (Liu et al., 2014). In Brazil, the productivity of greenhouse-grown tomato was not reduced by intercropping with lettuce at 0 to 42 d after the tomatoes were transplanted, possibly due to the short growth period of lettuce (Cecilio Filho et al., 2011). It appears that if reducing resource competition without additional inputs is the goal, then the selected crop species suitable for intercropping with tomatoes should have at least a small canopy, short overlapped growth period, and low demand for nutrients and water (Cecilio Filho et al., 2011).

Snow pea is a specialty vegetable that can be consumed either as tender shoots (i.e., pea shoots) or as immature pods (i.e., pea pods) (Kong et al., 2018; Kong and Zheng, 2019; Miles and Sonde, 2003). Also, the snow pea crop has a much smaller canopy size, shorter growth period, and lower water and fertilizer requirements than tomato (Jett et al., 2004; Miles and Sonde, 2003). Furthermore, snow pea, as a legume intercrop, can provide additional nitrogen (N) to the system via N₂ fixation (Corre-Hellou and Crozat, 2005). This may positively affect the yield of tomato crops intercropped with legume in organic cropping systems, where nutrient (especially N) availability is most important for limiting tomato yields (Clark et al., 1999). Possibly, snow pea is a good candidate crop for within-row intercropping with cherry tomato

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Table 1. Key time points for the production of high tunnel cherry tomatoes and intercropped snow peas in 2015 and 2016.

Crop species	Planting date	Flower initiation date	Harvest period	Crop completion date
2015				
Cherry tomato	7 May	14 May	15 July–13 Oct.	16 Oct.
Snow pea	12 May	—	12–25 June (shoots) 7–27 July (pods)	18 Aug.
2016				
Cherry tomato	2 May	12 May	7 July–20 Oct.	26 Oct.
Snow pea	27 Apr.	—	1–14 June (shoots)	14 June

Fig. 1. Spatial planting arrangements of cherry tomato and snow pea intercropped in a growing bed. ● Cherry tomato. ▽ Snow pea. The two parallel solid lines indicate the sides of the growing bed. The dashed line across the middle of the growing bed indicates the location of the drip irrigation line.

without additional water and nutrient inputs for peas in an organic high tunnel system.

No published studies have investigated the effects of intercropping snow peas on the yield of tomatoes in organic high tunnel production if the input levels of water and nutrients in the intercropping system are the same as those in the monocropping system. It has been reported that legume mulches or cover crops, particularly hairy vetch (*Vicia villosa* Roth.), increased the marketable tomato yield by more than 28% compared with a conventional production system (i.e., tilled soil) despite no additional input of water and nutrients on tomatoes associated with the legume crops (Campiglia et al., 2010; Sainju et al., 2001). In this case, the legume crops were planted at least 7 months earlier than the tomatoes, and they were mowed immediately before tomato transplanting; then, the residuals were incorporated in or mulched on the soil for growing the tomatoes. Therefore, the legume crops not only had little competition with the tomato plants for water and nutrients but also increased soil nutrients (especially N) for the succeeding tomato production. However, in open field tomato production, intercropping with snap bean (*Phaseolus vulgaris*) without additional inputs of water and fertilizer reduced the yield and growth of tomato compared with monocropping tomato (Teasdale and Deahl, 1987). Obviously, the snap peas competed with the tomatoes for resources during their overlapped growth period; however, snap pea, as a legume crop, could potentially add N to soil via N_2 fixation. Different from snap pea, snow pea is a shorter-stature plant with less vigorous growth; therefore, it may have less competition with tomato for resources (e.g., water and nutrients). Intercropping short-stature legume crops with long-term fruiting vegetables like tomato may not be successful for the legume because of limited residual light available for legume crops under the canopy of adult fruit and vegetable crops (Tittatelli

et al., 2016). However, it has been suggested that snow pea could be grown as a fast maturing crop that could be ready for harvesting before the canopy of the tomato crop is fully formed. This approach to intercropping is the most common system in Asian countries (Blair et al., 2016). It appears that if crop spacing and timing are suitable, then it may be possible to intercrop snow peas with cherry tomatoes in organic high tunnel production without additional inputs of water and fertilizers.

Although evaluations of the feasibility of intercropping systems for organic production in open fields have been performed in many previous studies, little information is available regarding the effects of intercropping (particularly with snow peas) on cherry tomato production in organic high tunnel systems. The objective of this study was to determine the agronomic viability of intercropping snow peas for cherry tomato production in an organic high tunnel system without additional inputs of water and fertilizer for snow peas under Southern Ontario climate conditions by evaluating the intercropping effects on crop growth, fruit yield, and quality of cherry tomato and the gross returns of this production system.

Materials and Methods

Experimental site and design. The trial was conducted at the Guelph Center for Urban Organic Farming, Guelph, Ontario, Canada (lat. 43°33'N, long. 80°15'W) during the 2015 and 2016 growing seasons. This farm has been certified organic by Ecocert Canada since 2009. The soil is categorized as a Harriston loam (USDA textural classification) with 4.6% of organic matter (Walkley-Black method), 18.4 meq/100 g of cation exchange capacity, and 7.4 of pH (based on saturated soil paste from a 1:2 ratio of soil:water). The soil contains the following nutrients ($mg \cdot L^{-1}$): 16 P, 56 K, 2877 Ca, 318 Mg, 4.2 Cu, 0.81 B, 25.0 Mn, 3.0 Zn, and 54.3 Fe, and the soil N level was estimated according to the organic matter content. Generally, for each 1% organic matter content of soil, it can be assumed that there are 9 kg of residual N per acre (Jett et al., 2004). Cover crops of buckwheat (*Fagopyrum esculentum*) and sorghum (*Sorghum bicolor*) lightly underseeded with red clover (*Trifolium pratense*) were used to maintain soil stability and structure and reduce weed incidence in the years before this trial. There has been no recent history of *Solanaceae* production at this site.

The three free-standing, NE–SW-oriented, quonset-style high tunnels (10.8-m long $\times$ 7.2-m wide $\times$ 3.8-m high; DeCloet Greenhouse Mfg. Ltd., Delhi, Ontario, Canada) used for this trial were constructed on-site in Fall 2014. The side vents and door openings of the tunnels were covered with anti-insect screens (Econet T; Gintec Shade Technologies Inc., Windham Center, Ontario, Canada). The tunnels were covered with a single layer of 0.15-mm polyethylene film with 90% initial light transmission (Suncover Clear CA; Ginegar Plastic Products Ltd., Kibbutz Ginegar, Israel). The side walls were manually rolled up or down to adjust the interior air temperature based on weather conditions and crop requirements. The soil in all the high tunnels was cultivated using a rototiller before transplanting, and then four raised beds (0.8-m wide $\times$ 10.3-m long $\times$ 0.25-m high) that were spaced 0.4 m apart were prepared for the 2-year trial in the middle zone of each high tunnel. One drip irrigation line (Garden Drip Tape, GO151000; Dubois Agrinovation Inc., St. Rémi, Québec, Canada) was installed in the middle of each raised bed.

A split-plot design was used for the two-factor factorial experiment with three replicates (i.e., blocks). Trial year and intercropping treatments were allocated to main plots and subplots, respectively. Two adjacent rectangular plots (i.e., main plots, 24.8 m² each) inside each high tunnel were randomly arranged for use in 2015 or 2016. In each trial year, within each main plot in each tunnel, two adjacent rectangular plots (i.e., subplots, 12.4 m² each) were randomly assigned to either the intercrop or no intercrop treatments.

Plant materials and crop management. Indeterminate-type cherry tomato, 'Sarina hybrid' (William Dam Seeds Co., Dundas, Ontario, Canada) seedlings were propagated using a peat-perlite mix (Pro-Mix MP Mycorrhizae Organik; Premier Tech Horticulture Ltd., Rivière-du-Loup, Quebec, Canada). Snow peas, 'Ho Lan Dou' (Stoke Seeds, Thorold, Ontario, Canada), as an intercropped vegetable, were sown in the soil of the same beds as cherry tomatoes. The specific transplanting/sowing dates are listed in Table 1. When transplanted to the high tunnels, the tomato seedlings had seven to eight true leaves and a height of 50 to 56 cm.

In each bed, the tomato seedlings were planted alternately in double rows spaced 30 cm apart, with in-row spacing of 110 cm (Fig. 1). This resulted in a planting density of $\approx 24,000$ plants/ha, which is within the

Fig. 2. Monthly variations in daily mean air temperature (A), soil temperature (B), and daily light integrals (DLI) (C) in high tunnels over the course of the 2015 and 2016 growing seasons. The error bars indicate the SEM values from the different days within each month.

optimal range recommended for greenhouse tomato production in Ontario (Ontario Ministry of Agriculture Food and Rural Affairs, 2005). The snow pea seeds were hand sown between tomato plants in 5-cm-deep holes (two seeds per hole) with four rows in each bed and in-row holes spaced 10 cm (Fig. 1). The snow pea seeds were at least 25 cm away from the tomato plants. This resulted in a seeding rate of $\approx 650,000$ seeds/ha. On some nights in May of both years, plastic mulching materials ($36 \times 4000 \times 9$ Black Taffeta EMB; Dubois Agrinovation Inc.) and non-woven fabrics (Novagryl 19GR/M2, $8.5 \text{ m} \times 100 \text{ m}$; Dubois Agrinovation Inc.) were used temporarily to protect tomato seedlings from killing frost. The tomato plants were trained to grow up a vertical string by a single stem. All side branches and suckers were removed at least weekly. The fruits were harvested once or twice weekly when they were fully red.

Basal fertilizers were incorporated in the soil of each plot before planting at rates of

300 and 500 kg·ha⁻¹ of General Purpose 4-3-9 and Blood Meal 12-0-0, respectively (BioFert Manufacturing Inc., Abbotsford, BC, Canada) based on recommendations from the fertilizer provider. Starting 8 weeks after transplanting, General Purpose 2.5-2-5 liquid fertilizer (BioFert Manufacturing Inc.) was applied by hand to the soil around each tomato plant at a rate of $\approx 182 \text{ L} \cdot \text{ha}^{-1}$ every 10 to 14 d. After transplanting/seeding, water was applied at up to $1.8 \text{ L} \cdot \text{m}^{-2}$ weekly, varying with weather and tomato crop needs at different growth stage. To prevent weeds, plastic mulch ($36 \times 4000 \times 9$ Black Taffeta EMB; Dubois Agrinovation Inc.) or straw mulch (layer thickness, $\approx 5 \text{ cm}$) was applied to each bed before tomato transplanting in 2015 and 2016, respectively. Crops were inspected weekly for insect and disease. All the cultural practices and materials used met Organic Products Regulations (Canadian Food Inspection Agency, 2009) and Organic Production Systems Standards (Standards Council of Canada, 2006).

Plant growth and development. The main stem length and 16 to 20 leaves of six to eight tomato plants were sampled from each plot every week in 2015 and 2016, respectively. The cluster position of the first open flower and first set fruit were recorded weekly for each plant. Fruit setting was defined as the formation of a fruitlet when its diameter reached $\geq 0.5 \text{ cm}$ (Abdul-Baki and Stommel, 1995). At the end of production, three plants in 2015 and four plants in 2016 were randomly selected from each plot to measure the main stem diameter at the second internode as well as the length and number of nodes on the main stem. The selected plants were then cut off above the first node and oven-dried at 65°C for 10 d to determine the aboveground vegetative dry weights.

Crop yield and quality. At each tomato harvest, fruits harvested from the same plants that were sampled for weekly growth measurements were graded as either marketable or unmarketable (with the latter being cracked, damaged, and diseased fruits) and then counted and weighed for each cluster on each plant. The cumulative number and weight of marketable fruits per plant were determined for each week during the harvest period. At the end of harvest, the percentage of marketable fruit yield was calculated based on both weight and number.

When the snow pea plants were $\approx 30\text{-cm}$ tall, 5- to 15-cm long shoot tips with one or two pairs of unfolded leaves were harvested every 10 to 14 d until flowers were opened on more than 50% of the pea plants (i.e., late and middle June in 2015 and 2016, respectively). After harvesting of the pea shoots was stopped, immature pea pods were harvested every other day until plant death in 2015. In 2016, when the pea shoot harvest ended, root rot disease started to spread among the pea plants. To reduce the risk of infecting the tomato plants, after removing the infected pea plants from high tunnels, all the remaining pea plants were pulled out and added to the straw mulch already present on the bed.

During the weeks of peak tomato harvest (i.e., sixth to ninth week of harvesting), a total of 24 marketable fruits (6 fruits/week) from each treatment were randomly sampled for their soluble solids content (SSC) using a digital pocket refractometer (PAL-1; Spectrum Technologies Inc., Aurora, IL). An additional 72 marketable fruits (18 fruits/week) from each treatment were randomly sampled for individual fruit weight determination, postharvest water loss evaluation, and dry matter content. After recording the initial fresh weights (FW_i), the sampled fruits were kept at 23°C for 4 d; then, the final fresh weights (FW_f) were recorded to determine the amount of postharvest water loss. The fruits were dried at 65°C to constant weight to determine the dry weight (DW). The post-harvest water loss (Eq. [1]) and dry matter content (Eq. [2]) of the fruits were calculated as follows:

$$\text{Postharvest water loss (\%)} = \frac{\text{FW}_i - \text{FW}_f}{\text{FW}_i} \times 100 \quad [1]$$

$$\text{Dry matter content (\%)} = \frac{\text{DW}}{\text{FW}_i} \times 100 \quad [2]$$

Climate parameter measurements and recordings. Weather parameters were measured continuously at 60-s intervals at the center of a representative high tunnel. Air temperature was measured 100 cm above-ground using sonic anemometers (81000; RM Young, Traverse City, MI) and recorded using data loggers (CR1000; Campbell Scientific, Logan, UT). Soil temperature was measured at a 11.4-cm depth using thermistors (PT916; Pace Scientific Inc., Mooresville, NC). To reduce shading from the plant canopy, solar radiation was measured between the middle two beds at heights of 150 cm in 2015 and 220 cm in 2016. Pyranometers (SRS-100; Pace Scientific Inc.) were used to collect the solar radiation data. Soil temperature and radiation data were recorded using XR5-SE data loggers (Pace Scientific Inc.). The calibration of all sensors was verified experimentally before deployment. These continuously measured and recorded raw environmental data were used for the calculation of daily average temperatures (including both air and soil temperatures) and daily light integrals. Figure 2 shows monthly variations of weather situations for the site.

Statistical analysis. Data were subjected to an analysis of variance using the Data Processing System Software (DPS, version 7.05; Refine Information Tech. Co., Hangzhou, China) and presented as means $\pm$ SE. Separation of means was performed using Duncan's new multiple range test at the $P \leq 0.05$ level.

Results and Discussion

Growth and development of cherry tomato plants. In intercropping systems, the

Fig. 3. Growth rates of the main stem of cherry tomato plants of intercrop and no intercrop treatments before fruit harvesting. Data are means $\pm$ SE ($n = 3$). Y, T, and Y $\times$ T indicate trial year, intercropping treatment, and interaction between trial year and intercropping treatment, respectively. NS, **, ***Denote treatment effects that are not significant or significant at $P \leq 0.01$ or 0.001 , respectively. Bars bearing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's new multiple range test. Stem extension rates (or leaf unfolding rates) were calculated as the average weekly increase of main stem length (or unfolded leaf number) during the period before harvesting.

Fig. 4. Flower opening (A) and fruit setting (B) progress of cherry tomato plants with intercrop and no intercrop treatments. Data are means $\pm$ SE ($n = 3$). Y, T, and Y $\times$ T indicate trial year, intercropping treatment, and interaction between trial year and intercropping treatment, respectively. NS, *Denote treatment effects on average flowering or fruiting rates over 6 weeks that are not significant or significant at $P \leq 0.05$, respectively. Legends followed with the same letters indicate the average flowering or fruiting rates are not significantly different at $P \leq 0.05$ according to Duncan's new multiple range test. Flowering or fruiting rates were calculated as the average weekly increase of flowering or fruiting clusters per plant over 6 weeks.

Fig. 5. Cumulative marketable fruit yield of cherry tomato plants with intercrop and no intercrop treatments. Data are means $\pm$ SE ($n = 3$). Y, T, and Y $\times$ T indicate trial year, intercropping treatment, and interaction between trial year and intercropping treatment, respectively. NS, *Denote treatment effects on total fruit yields (kg or no. of fruits/plant) over the whole harvesting period that are not significant or significant at $P \leq 0.05$, respectively. Legends followed with the same letters indicate the total fruit yields (kg or no. of fruits/plant) over the whole harvesting period are not significantly different at $P \leq 0.05$ according to Duncan's new multiple range test.

most meaningful individual crop growth rates may be analyzed in relation to resource capture and biomass conversion efficiency, particularly when resource competition (e.g., for light, nutrients, and water) may affect growth (Fukai and Trenbath, 1993). In the present study, there were no additional inputs of water and fertilizer for snow peas, which might potentially compete with cherry tomatoes for these resources rather than light. However, intercropping snow peas with tomatoes did not affect the stem extension rate or leaf unfolding rate of tomato plants before fruit harvesting compared with no intercropping treatment (Fig. 3). This indicates that intercropping snow peas did not result in any substantial resource (e.g., nutrients and water) competition for the tomato plants during their early growth stages.

Crop vegetative biomass at maturity is the integral of crop growth rate over the whole crop duration (Fukai and Trenbath, 1993). Vegetative biomass production is often examined by relating crop growth rate to plant and environmental factors (Fukai and Trenbath, 1993). In the present study, at the end of production season, the tomato plants intercropped with snow peas relative to no intercrop treatment did not differ in the final main stem length or node number, but they showed reduced main stem diameters and above-ground dry weights in 2015 rather than in 2016. One possibility for this difference between the two trial years may be the longer period over which the snow peas were intercropped with the cherry tomatoes in 2015 compared with 2016 (Table 1). Previous studies of sorghum/pigeon pea and cassava/soybean intercrops indicated that when the overlap period of two-crop growth became longer, the early-maturing crop reduced vegetative growth of the later-maturing one, likely due to competition for N (Fukai and Trenbath, 1993; Rao and Willey, 1983; Tsay et al., 1988, 1989). The N content ($\approx 2.14\%$) lower than critical value (2.8%) started to occur in the bottom leaves of cherry tomato crops at the end of pea shoot harvesting in 2015 in the present study. It is possible that competition for N occurred between tomato plants and snow peas during later growth stages of cherry tomato in 2015. At that time, pods, in addition to shoots, were harvested from intercropped snow peas. However, in 2016, only shoots were harvested from the intercropped snow peas, and intercropping stopped before the snow peas began producing pods. The pea pods (i.e., seeds) likely represented a larger N sink loss from the intercrop system than the pea shoots harvested (Stern, 1993).

The growth inhibition of tomato plants due to resource competition from intercropped snow pea may not have been too intensive, at least during the early stage (i.e., before fruit harvesting). This is indicated by the fact that neither flowering nor fruit setting of the tomato plants was delayed by intercropping with snow peas (Fig. 4). In contrast, in an intercropping system, when growth of the late-maturing component was decreased

Table 2. Morphological characteristics and biomass accumulation of high tunnel cherry tomato plants with intercrop and no intercrop treatments at the end of the production season.

Treatment	Main stem length (cm)	Main stem nodes (no.)	Main stem diam (mm)	Aboveground vegetative DW (g)
2015				
Intercrop	459 ± 4 ^a	63.0 ± 0.2 c	17.2 ± 0.2 b	128 ± 8 c
No intercrop	464 ± 4 a	64.8 ± 0.4 bc	19.1 ± 0.3 a	152 ± 7 b
2016				
Intercrop	447 ± 17 ab	65.7 ± 0.7 ab	16.9 ± 0.5 b	197 ± 13 a
No intercrop	435 ± 10 b	67.2 ± 1.0 a	17.8 ± 0.4 b	205 ± 6 a
ANOVA results				
Trial year (Y)	*	**	NS	***
Intercrop treatment (T)	NS	NS	**	*
Y × T	NS	NS	*	*

^aData are means ± SE.

^bThe values in the same column marked with the same letter are not significantly different at $P \leq 0.05$ according to Duncan's new multiple range test.

ANOVA = analysis of variance.

NS, *, **, ***Denote treatment effects that are not significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Quality parameters of marketable fruits in high tunnel cherry tomato with intercrop and no intercrop treatments.

Treatment	Avg fruit wt (g)	SSC (°Brix)	Dry matter content (%)	Postharvest water loss (%)
2015				
Intercrop	13.4 ± 1.9 ^a	6.4 ± 0.1 a	6.2 ± 0.1 a	4.9 ± 0.5 b
No intercrop	11.6 ± 0.5 a	6.2 ± 0.1 a	6.2 ± 0.1 a	5.4 ± 0.5 b
2016				
Intercrop	6.8 ± 0.4 b	6.3 ± 0.2 a	6.2 ± 0.3 a	14.4 ± 2.8 a
No intercrop	7.6 ± 0.5 b	6.0 ± 0.2 a	6.3 ± 0.2 a	13.6 ± 2.7 a
ANOVA results				
Trial year (Y)	**	NS	NS	***
Intercrop treatment (T)	NS	NS	NS	NS
Y × T	NS	NS	NS	NS

^aData are means ± SE.

^bValues in the same column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's new multiple range test.

SSC = soluble solids content; ANOVA = analysis of variance.

NS, *, **, ***Denote treatment effects that are not significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Fig. 6. Percentage of unmarketable fruits of cherry tomato plants with intercrop and no intercrop treatments. Data are means ± SE (n = 3). Y, T, and Y × T indicate trial year, intercropping treatment, and interaction between trial year and intercropping treatment, respectively. NS, *Denote treatment effects that are not significant or significant at $P \leq 0.05$, respectively. Bars marked with the same letter are not significantly different at $P \leq 0.05$ according to Duncan's new multiple range test. Percentages of unmarketable fruits were calculated based on the total weight or number of harvested fruits per plant over the whole harvesting period.

severely by the early-maturing crop, flowering was delayed greatly (Fukai and Trenbath, 1993). For example, flowering of pigeon pea was delayed 15 d when intercropped with sorghum due to a serious growth inhibition of pigeon pea (Natarajan and Willey, 1980).

Fruit yields of cherry tomatoes. Tomato fruit yields were not different between the intercrop and no intercrop treatments in either trial year (Fig. 5), despite the aboveground vegetative dry weight of tomato plants being reduced by intercropping snow

peas in 2015 (Table 2). The reduced non-harvested biomass of the tomato crop in the intercropping system might result in less sink capacity for the assimilate and greater assimilate partitioning into the harvested organ (i.e., fruit) during the later part of the growth period (i.e., after the end of intercropping), consequently leading to a higher harvest index (Fukai and Trenbath, 1993; Natarajan and Willey, 1980; Tsay et al., 1989). The proportion of the assimilate partitioned to the harvested organs in the sole crop might be suboptimal (i.e., can be potentially improved),

and luxury use of a photo-assimilate to support excessive vegetative growth might be remedied by intercropping (Fukai and Trenbath, 1993).

Previous studies have reported inconsistent intercropping effects on tomato yields, which were unaffected by intercropping with kale, onion, and lettuce but reduced by intercropping with maize and garlic (Liu et al., 2014; Ramkat et al., 2008). The negative intercropping effects on the yields may be partly related to synchronization of maximum requirements for growth resources by the intercropped species (Fukai and Trenbath, 1993). In the present study, snow peas had an earlier period of active growth (with a shorter duration) than cherry tomato (Table 1), which would suggest that snow peas are compatible for intercropping with tomatoes. The early-maturing snow pea plants could grow without interference from the late-maturing tomato crop, although the tomato crop might be affected somewhat (e.g., reduced stem diameter and vegetative biomass in 2015) by the associated snow pea crop. However, a long period for further growth after harvesting the snow pea crop should ensure good recovery and full use of available resources for the tomatoes (Fukai and Trenbath, 1993).

When intercropping an early-maturing legume with a long-duration nonlegume crop (e.g., perennial), the legume-fixed N may be available to the nonlegume crop (Fukai and Trenbath, 1993). In this case, the yield of the long-duration nonlegume crop may be

promoted by intercropping, which has been found in a soybean/cassava intercrop system (Cenpukdee and Fukai, 1992). Also, legume mulches or cover crops have been reported to increase marketable tomato yield because they provide additional N to the tomato crop via N₂ fixation (Campiglia et al., 2010; Sainju et al., 2001). No corresponding beneficial effects of intercropping with snow peas were observed on tomato yields (as well as leaf N level, at least in 2015) in the present study. Direct transfer of N from the legume (i.e., the release of plant available N from decaying roots and nodules) to the nonlegume crop (e.g., tomato) might not be rapid enough to be reflected in yields during a relatively short growing season (Peoples and Herridge, 1990). Although the possibility of rapid N transfer from exudation of living roots should not be ignored, cherry tomato/snow peas did not have an intimate association like that of legume mulch (or cover crop)/tomato (Campiglia et al., 2010; Peoples and Herridge, 1990; Sainju et al., 2001; Stern, 1993).

Fruit quality of cherry tomatoes. For vegetables such as tomatoes, fruit quality and fruit yield determine the final economic return because benefits from increased product quality can offset yield loss to some degree (Theunissen, 1997). In a tomato/garlic intercropping system under a plastic tunnel using organic medium cultivation, intercropping produced better fruit quality (e.g., the titratable acid, vitamin C, and dry matter contents) than did monoculture despite reducing the total tomato yield (Liu et al., 2014). In the present study, intercropping snow peas did not change any of the fruit quality parameters measured in cherry tomato compared with no intercrop during the 2 years of the trial (Table 3, Fig. 6). The difference between these two studies might have resulted from a higher degree of competition between the intercropped garlic and tomato for limited water supplies in the previous compared to the present study. It has been confirmed that water deficits, to some degree, can enhance fruit quality (Feres et al., 2003). In the present study, the time and frequency of water supply were based on the needs of the tomato plants, although the amount of water supply was similar for all the treatments. In this case, the water supply can meet the demands of the tomato plants in all the plots without inducing drought stress in this crop.

Comparison of gross returns. Intercropping conforms to organic production principles of making efficient use of land and crop inputs (Theunissen, 1997). However, choice of any cultivation system depends only on whether an acceptable income can be achieved by farmers (Theunissen, 1997). In the present study, the intercropping treatment not only led to similar marketable tomato yields as no intercropping treatment but also resulted in additional yields from snow pea crops ($\approx 1 \text{ t ha}^{-1}$ pea shoots and 7 t ha^{-1} pea pods in 2015 and 6 t ha^{-1} pea shoots in 2016). The additional yields in the intercropping system would potentially increase economic

returns compared with monocropping of cherry tomatoes in the high tunnels. However, intercrop systems also need more investments in per-unit production area inputs and labor. In the present study, the amount of fertilizer/water applied to the intercropping system was similar to the that of the monocropping system, although the supplies were based on the needs of cherry tomato crops because snow pea was not the primary crop. The only increased input in the intercropping system was snow pea seeds ($\approx 158 \text{ kg ha}^{-1}$ for each year). The only additional labor requirements for the intercropping system were mainly from seeding ($\approx 809 \text{ h ha}^{-1}$ for each year) and harvesting (≈ 656 and 454 h ha^{-1} in 2015 and 2016, respectively) of snow peas. The costs of seeds and labor vary widely according to many factors (e.g., geographic location, mechanization degree, labor, and seed sources). It is difficult to perform further economic analyses of the net return in the present study. Nevertheless, high tunnel growers must calculate all costs to determine if a cherry tomato/snow pea intercropping system would be economically viable. Ideally, intercropping systems are beneficial to farmers both in terms of economic returns and ecological production principles (Theunissen, 1997).

In summary, for cherry tomato production in an organic high tunnel system under the climate conditions of Southern Ontario, intercropping snow peas with tomatoes in the same beds without additional inputs of water and fertilizers for peas did not negatively affect the fruit yield and quality of the tomato crop. The shoots or pods harvested from the intercropped snow peas provided additional yields, which would potentially increase the income of high tunnel growers. The data suggest that within-row intercropping snow pea with cherry tomato without additional inputs of water and fertilizers for peas is viable, at least from an agronomical viewpoint, for organic high tunnel production in regions with climates similar to that of the experimental site.

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