Intercropping Winter Greens between Blackberry Rows for Year-round High Tunnel Production

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SUMMARY. A decrease in available farmland worldwide has prompted interest in polyculture systems such as intercropping where two or more crops are grown simultaneously on the same land to increase the yield per farm area. In Alcalde, NM, a year-round intercropping system was designed to evaluate organically produced blackberry cultivars (*Rubus*, subgenus *Rubus*) and winter greens in a high tunnel over a 2-year period. Two floricane fruiting blackberry cultivars, Chester Thornless and Triple Crown, were grown intercropped with 'Red Russian' kale (*Brassica napus*) and 'Bloomsdale' spinach (*Spinacia oleracea*) in a high tunnel. In an adjacent field, the planting of blackberry was repeated with no winter intercrop and no high tunnel. Both cultivars of blackberry were harvested July to September, and fresh weights were measured to determine suitability to the intercropping system in the high tunnel. Both species of winter greens were harvested January to April, and fresh yield weights were measured to discern fitness as possible intercrops in this system. Row covers were used for kale and spinach, and air temperatures were monitored November to April inside the high tunnel. High tunnel temperatures were within acceptable ranges for the production of greens with the use of rowcovers. Yield data from this study indicates that 'Triple Crown' blackberry outperformed 'Chester Thornless' blackberry in both the high tunnel and field trials with significant difference in the second season. Additionally, blackberry yields from both cultivars were observed to be higher in the field than in the high tunnel for both years. High temperature damage to high tunnel berry canes was noticed for both cultivars, with observed yield decreases in the second year in the high tunnel. Overall, this study indicates that the phenology and climate needs of the two winter greens and blackberry cultivars were not compatible for sustaining year-round organic high tunnel production.

Diversifying agriculture and finding ways to sustainably feed more people with ever-shrinking farmland has become increasingly important. One option to increase production on limited farm space is to use intercropping systems. Intercropping is the process wherein two or more crops are grown in the same plot to more efficiently use space (Andrews and Kassam, 1976). In addition to not competing for light and space, plants used in an intercropping system must be temporally and physiologically compatible for this growing method to work.

Other options for increasing crop production include using rowcovers and high tunnels for season extension (Lamont, 2009). High tunnels are low-cost structures used for season extension and to protect high-value specialty crops from sudden dips in temperature or damage from high winds and hail (Belasco et al., 2013; Ward and Bomford, 2011). Because high tunnels are heated with passive solar energy, they do not use electricity and are ideal for the cold winters of northern New Mexico, where there is ample sunlight to warm the air in high tunnels even when temperatures fall below freezing (Hecher et al., 2014). In New Mexico, high tunnels can be constructed for as little as $2 to $3 per square foot, making them more economically viable than greenhouses for many small-scale farmers (Walker et al., 2012). Investing in a high tunnel means a farmer may produce crops earlier and can expect to produce longer with the ability to charge premium market prices (Carey et al., 2009). Studies conducted in New Mexico growing blackberry cultivars in high tunnels have shown blackberry to produce 1 to 3 weeks earlier and produce over a longer period than those grown in fields (Yao et al., 2018). In similar high tunnel studies, blackberry yields have more than doubled with the use of high tunnels while reducing pest pressure and lowering the need for pesticide applications (Demchak, 2009; Rom et al., 2010).

Winter greens were chosen for their high market value when grown organically and their suitability to cooler temperatures and frost tolerance (Ernst et al., 2012; Heyduck et al., 2019; Johnny's Selected Seeds, 2019; Walker et al., 2012). In this study, 'Red Russian' kale and

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
0.0283	ft^3	m^3	35.3147
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
28.3495	oz	g	0.0353
305.1517	oz/ft^2	$g \cdot m^{-2}$	0.0033
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

'Bloomsdale Long Standing' spinach were selected as the annual winter intercrops. The temperature range for optimal production of kale is between 45 and 60 °F (Johnny's Selected Seeds, 2019). The temperature range for optimal spinach production is between 60 and 65 °F with lethal minimum temperature being 0 and 5 °F (Walker et al., 2012). Kale grows to a mature leaf size in 50 d, whereas spinach grows mature-sized leaves in 45 d (Walker et al., 2012). Similar maturity rates and harvest methods make the greens compatible for this intercropping study where plots of both greens were often harvested at the same time. These two greens species were also chosen because they could be direct seeded in autumn under the dormant blackberry canes and harvested multiple times in the "cut and come again" method (Voyle, 2014). High tunnel growing also consistently produces high-quality produce because it can prevent crop stress by maintaining a more controlled growing environment (Lamont, 2009). Previous surveys of commercial growers have shown that high tunnels may be beneficial for the production of winter greens worldwide by protecting crops from inclement weather and through season extension (Lamont, 2009). The use of high tunnels in other states with similar climates to that of northern New Mexico have been successful in growing blackberry, kale, and spinach (Borrelli et al., 2013; Lamont, 2009; Lamont et al., 2003; Yao et al., 2018). In addition, kale, spinach, and blackberry are already being grown and sold in local farmers' markets in northern New Mexico.

In previous studies, growers report that cane fruit grown in high tunnels also produces higher quality fruit with a longer shelf life than field grown berries (Lamont, 2009). Both cultivars of blackberry are floricane-fruiting, meaning that they grow productive floricanes off of 1-year-old primocanes (Galletta et al., 1998a). Blackberry, like other cane fruit, are perennials and require a period of winter dormancy with a gradual increase in temperatures to break dormancy and promote bud formation (Black et al., 2008). The primocanes must maintain good vine health over the winter dormancy to be able to bud out into fruitful floricanes the following spring (Black et al., 2008). Blackberry has a lethal minimum temperature of 0 °F, after which canes will exhibit damage and be less fruitful (Yao, 2018). To be fruitful, blackberry needs a dormancy period with 300 to 900 chilling hours spent in temperatures below 45 °F (Stanton et al., 2007). Blackberry canes can live for 15 years and are productive for 9 years, depending on cultivar and cultivation practices (Takeda et al., 2002). The goal of this study was to determine the functionality of growing winter greens and blackberry in an organic year-round intercropping high tunnel production system. The objective was to evaluate yield and quality of two blackberry cultivars in an organic open field without any intercropping and in a high tunnel intercropped with kale and spinach.

Materials and methods

Location. The intercropping system consisted of two winter growing seasons of kale and spinach, from Oct. 2016 to May 2017 and Oct. 2017 to May 2018, and two summer growing seasons of blackberry, from June to Sept. 2017 and June to Sept. of 2018, and was located at the Sustainable Agriculture Science Center of New Mexico State University in Alcalde, NM (lat. 36.0889°N, long. 106.0536°W, elevation 5680 ft). The average low temperature for the area is 15.3 °F in January and the average high is 89.2 °F in July (Weather Atlas, 2019), and the average rainfall ranges from 0.4 to 1.9 inches per month. The U.S. Department of Agriculture (USDA) plant hardiness zone for Alcalde is zone 6a (USDA, 2019). The high tunnel and the field used in the study are USDA organic certified and managed accordingly. The soil was a Fruitland sandy loam (coarse-loamy, calcareous, mesic Typic Torriorthents) with 1.6% soil organic matter in the top 6 inches of soil and the soil pH was previously reported at 7.9 to 8.0 (1:1 water extraction) (Yao et al., 2018). The high tunnel used in this trial was constructed 9 ft height, 16 ft width, and 40 ft length (640 ft^2). Straight side walls and end walls were made from dimensional lumber with two double doors, one set at each end, and a 4-ft side wall that was rolled up in summer months. The roof pitch was constructed out of bent, 2-inch, polyvinyl chloride pipes. The entirety of the high tunnel was glazed with heavy weight, woven plastic treated with an ultraviolet light inhibitor with a light transmission of 88% (SOLAROOF 172; J&M Industries, Ponchatoula, LA). The high tunnel was oriented roughly north to south, and the doors were located at the north and south ends.

Field and high tunnel blackberry. Two perennial cultivars of blackberry, Chester Thornless and Triple Crown, were chosen for this study because they are grown by local farmers and have performed well in nearby high tunnel trials (Yao, 2018). Two identical plantings of blackberry were planted in the field and in the high tunnel. Blackberry rows consisted of two semierect, floricane-producing cultivars, Triple Crown and Chester Thornless blackberry, planted in randomized blocks (Fig. 1). There were three blocks within each location. Two blocks contained two experimental units with three plants each, and one block contained units with two plants each. Each row of blackberry contained eight plants 5 ft apart within row spacing. Rows were 8.5 ft apart. Canes were planted in May 2011 from cultured tissue (Yao et al., 2018). Canes of both 'Chester Thornless' and 'Triple Crown' blackberry for both the field and high tunnel were trained onto trellises. Each trellis was 5 ft tall and in a single centralized line down each row of the semierect vines. Spent floricanes were pruned out of central cane masses in mid-April for field plants. High tunnel spent floricanes were pruned in mid-November to provide adequate light infiltration for the winter greens intercrop. Lateral cane growth of both cultivars was secured to the trellises throughout the summer growing season in both planting locations.

High tunnel winter greens. For the winter greens used as the intercrop in the high tunnel, organic kale and organic spinach seeds were purchased from organic seed companies. The greens were not repeated in an intercropping field without a high tunnel due to temperatures being too low for survival. Before planting the greens, the high tunnel soil was prepared 1 ft away from the existing 'Triple Crown' and 'Chester Thornless' blackberry canes via rototilling, compost (New Mexico Compost;

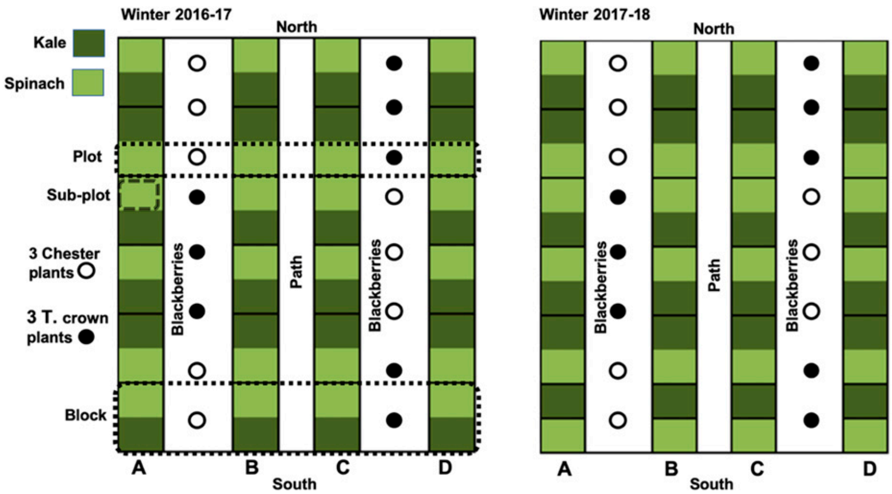

Fig. 1. High tunnel map for two winter seasons 2016–18 in high tunnel with kale, spinach, and two blackberry cultivars, Triple Crown (T. crown) and Chester Thornless (Chester). Kale and spinach subplots, plots, and blocks are defined with dotted lines. Blocks used in winter greens analysis consist of a plot of spinach and a plot of kale.

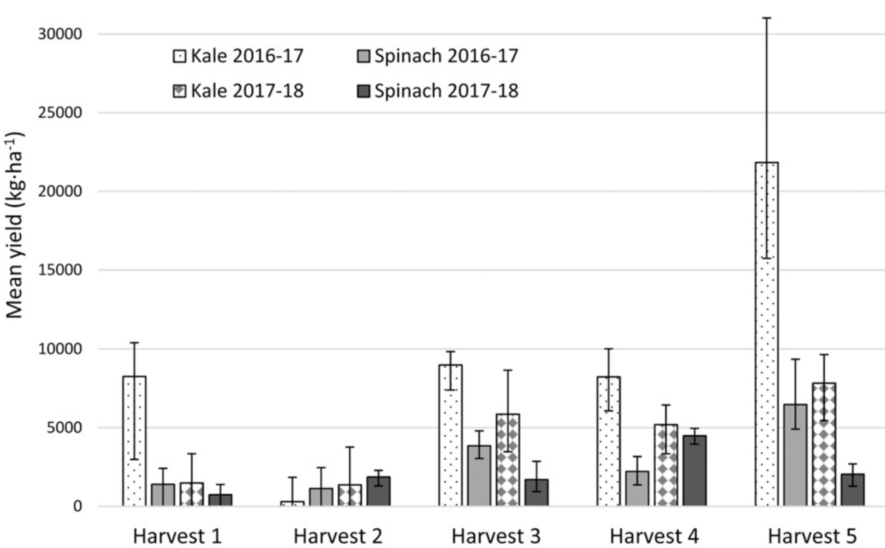

Fig. 2. Kale and spinach mean yields by harvest in fresh weight for winter seasons 2016–17 and 2017–18. Harvest times ranged from 18 Jan. to 14 Apr. 2017 and 19 Jan. to 20 Apr. 2018, respectively. Error bars display minimum and maximum yields for each plot at each harvest; 1 kg·ha^{-1} = 0.8922 lb/acre.

Soilutions, Albuquerque, NM) was applied before each winter season at a volume of four 5-gal buckets per row and the area was leveled with a rake. Four beds were formed 2 ft wide and 36 ft long (72 ft^2) and were orientated north to south. For the randomized block plantings, each bed was divided into twelve 2.5-ft-long winter green subplots, and a plot was made up of four horizontal subplots (Fig. 1). The four beds were oriented north to south. Each block consisted of a pair of plots, with six blocks total in the high tunnel (Fig. 1).

Kale and spinach seeds were direct seeded in randomized plots at the base of the two rows of dormant blackberry canes on 17 Oct. 2016 and 17 Oct. 2017. Seeds were planted individually in three rows inside of individual subplots at a rate of 0.3 g per subplot for kale and 5 g per subplot for spinach. Drip tape was installed on top of the bed in the high tunnel to irrigate both crops. Plants were thinned to one per inch of row and transplanting of winter greens was performed on 9 Nov. 2016 and 11 Nov. 2017 to fill gaps in rows.

For both winter seasons in the high tunnel, wire hoops were installed over crops and a permeable, fabric rowcover applied for added temperature protection (N-Sulate Frost Protection Blanket; DeWitt Co., Sikeston, MO). Sides of the high tunnel were rolled down. Weeding between rows was done by hand as needed throughout the duration of the study.

Temperature monitoring. Data loggers (HOBO U12-011; Onset Computer Corp., Bourne, MA) were installed over the greens inside the high tunnel. One air temperature probe was placed inside the high tunnel outside of the rowcovers, and one was placed under a rowcover inside the high tunnel. Two probes were also placed outside the high tunnel on the north and south end. All air temperature probes were placed ≈12 inches above the soil surface. Air temperatures were recorded from 11 Nov. 2016 to 18 Apr. 2017 and from 11 Nov. 2017 to 18 Apr. 2018. Data loggers recorded temperatures every 30 min, 24 h per day, and for 159 d.

Fertilizer application and fertigation. Blackberry canes and winter greens in the high tunnel were irrigated and fertigated through drip tape. Eight additional lines were added in the high tunnel each winter, two lines per greens row, and removed after the last winter greens' harvest. For the greens, organic fish fertilizer with 2N–1.7P–0.8K (Neptune's Harvest Fish Fertilizer; Neptune's Harvest, Gloucester, MA) was diluted by adding 32 fl oz of fish fertilizer to 35 gal of water resulting in 7 oz/ft^2 that was subsequently pumped through 0.5-inch-diameter polyethylene drip tape spaced 10 inches apart from each other. In both summers, fertigation with the same fish emulsion was done every 3 weeks from 12 June 2017 (14 June 2018) through 2 Aug. 2017 (3 Aug. 2018) in both field and high tunnel blackberry canes. In addition, before planting the winter greens in the high tunnel, 1 ft^3 of composted dairy cow manure (1N–0.9P–1.7K) was distributed evenly throughout the high tunnel soil.

Data collection. The number of new buds was counted on 9 June

2017 and 9 June 2018. Canes were assessed visually for damage, and buds were counted if green tissue had emerged from the bud. In the second year, three 1-ft-long sections of canes were selected randomly two times each winter from both cultivars in both locations for bud dissection.

Blackberry fruits were harvested throughout the summer season, one to three times per week as needed. Both cultivars were harvested when fruit was mature. In the 2017 season, berries were harvested from 6 July to 29 Sept. In the 2018 season, berries were harvested from 9 July to 20 Sept. Berries were considered ripe enough for harvest when 75% of the drupelets per fruit appeared dark purple and pliable under gentle pressure applied with touch. Berries with pest damage were also included if half or more of the drupelets were present at the time of harvest. Fresh berry weights were recorded per plant in grams.

Both kale and spinach were harvested by individual subplot when height requirements were met. Kale was harvested when 75% of the plants in the subplot were 8 inches tall, and spinach when 75% of the plants in the subplot were 3 inches tall. The plants were cut using the "rule of thumb" method leaving the active growth point 1 to 2 inches from soil level. This allowed for "cut and come again" harvests to grow back from the small, undeveloped leaves in the center.

Each subplot's fresh weight was taken and recorded in grams. At the end of each harvest, three collective 40-g samples were taken from the yield of kale and spinach and were dried in an oven at 149 °F for 48 h. Heights of subplots were taken every 3 weeks to schedule harvest dates. Heights were taken from the soil level to the top of the natural highest point on the plant. This was repeated in three locations of the subplot and averaged.

Data analysis. For the kale and spinach, plot totals were analyzed by year using a mixed model with species as the fixed effect and fitting an unstructured covariance with blocks. The fitted covariance structure accounted for the block design and fitted separate variances to the two species. In both years, the last kale harvest was deemed unmarketable. Both total yields and total marketable yields were analyzed using SAS software (version 9.3; SAS Institute, Cary, NC). Alpha was set for 0.05 and each year was analyzed separately.

For the blackberry, in separate analyses by year, cultivars were compared using a mixed model with fixed effects for cultivars, location, and the cultivar × location interaction. The model accounted for the blocking and subsampling with random effects for block within location and for the experimental unit which was identified as cultivar × block (location). Using this model, cultivars were compared within each location. Alpha was set for 0.05 and analyses were conducted using SAS software (version 9.3).

Results and discussion

Kale and spinach. The harvest dates were dependent on plant height and only differed by 1 d between years for the first four harvests; however, the fifth harvest varied by 6 d (Table 1). No control kale and spinach were planted outdoors of the high tunnel with or without an intercropping with blackberry since the study took place in the winter, and the conditions are not conducive to their growth. In the 2016–17 season, the total kale amount harvested for all plots was (± SE) 47,613 ± 3559 $kg \cdot ha^{-1}$, whereas the second season produced 21,713 ± 2295 $kg \cdot ha^{-1}$ (Fig. 2; Table 2). However, over the course of the high tunnel trial, kale took less time to harvest in the "cut and come again" method. Observations during both years' fifth harvest included kale bolting and aphids (Aphidoidea) clustering on the kale inflorescences. In addition to observed minor pest damage, the kale leaf cuticles appeared to increase in waxiness and the petiole became elongated and more ridged as the kale bolted. Bolting kale traits were incongruous with kale being sold in local markets and, for the sake of this study, was therefore deemed unmarketable. Because leaf quality was low for kale in the last harvest, the yield analysis was done with and without the last kale harvest for both years (Table 2). Therefore, marketable kale was only (± SE) 25,777 ± 1354 $kg \cdot ha^{-1}$ the first season and 13,886 ± 1690 $kg \cdot ha^{-1}$ the second season.

In each harvest, for both years, the spinach displayed consistent marketable quality in all harvests, and the total yield of spinach was marketable for both seasons. For the 2017–18 season, the total yield for spinach was (± SE) 15,045 ± 1113 $kg \cdot ha^{-1}$ (Table 2), and the 2017–18 season produced 10,800 ± 513 $kg \cdot ha^{-1}$. As an observation, the corner plots in the high tunnel were lower yielding than the remaining plots due to not reaching marketable heights. This edge effect applied to both the kale and the spinach plots for both years. The lower yielding edge plots may have suffered in quality due to growing in the coolest and shadiest portions of the high tunnel.

'Triple Crown' and 'Chester Thornless' blackberry live bud count and cane health. In early Dec. 2017, dissected dormant buds observed were green with complete, undamaged leaf primordia from both cultivars in the field (Fig. 3A) and the high tunnel (Fig. 3B). High tunnel buds dissected in early January were breaking dormancy (Fig. 3C), and by early February, some buds contained dead tissue (Fig. 3D). However, the open field buds did not show any sign of breaking early dormancy in January or dead tissue in February.

Actively growing live buds appeared more prolific on both cultivars in the field both years when measured on 9 June 2017 and 9 June 2018. In the field, 'Chester Thornless' blackberry and 'Triple Crown'

Table 1. Kale and spinach harvest dates for 2 years of high tunnel production in an intercropping system with blackberry in Alcalde, NM.

	Winter 2016–17		Winter 2017–18	
Harvest	Date	DPS	Date	DPS
1	18 Jan. 2017	93	19 Jan. 2018	94
2	2 Feb. 2017	108	3 Feb. 2018	109
3	2 Feb. 2017	128	23 Feb. 2018	129
4	23 Mar. 2017	157	23 Mar. 2018	157
5	14 Apr. 2017	180	20 Apr. 2018	185

DPS = days postseeding.

blackberry had 75 and 91 live buds per plant, respectively, in 2017, and 36 and 105, respectively, in 2018. In the high tunnel, the number of live buds was observed to be lower. ‘Chester Thornless’ and ‘Triple Crown’ blackberry had 4 and 23 live buds per plant, respectively, in 2017, and 6 and 28, respectively, in 2018. In both the field and high tunnel, ‘Triple Crown’ blackberry showed more live bud development and faster flowering rates than ‘Chester Thornless’ blackberry in both years, but no formal comparison was made. As an observation, ‘Triple Crown’ blackberry vines broke bud dormancy more quickly, starting in late May, and canes appeared to leaf out more rapidly and close canopy with more vigor than ‘Chester Thornless’ blackberry vines.

By spring, both cultivars in the high tunnel showed signs of canes dying back from winter damage with dried, brown tips localized on the top of most canes. At the time of bud count in June, both cultivars in the field showed complete break of bud dormancy, but in the high tunnel, live buds were localized in the bottom section of canes. Plants in the high tunnel were observed not to have any active buds or fruit production on the top of the canes for the summer harvests of both 2017 and 2018 resulting from improper growth.

‘Triple Crown’ and ‘Chester Thornless’ blackberry fruit yield. ‘Triple Crown’ blackberry was earlier producing in the high tunnel and field settings for both years compared with ‘Chester Thornless’ blackberry (Fig. 4). Inside the high tunnel, the earliest harvests for ‘Triple Crown’ blackberry were on 6 July 2017 and 9 July 2018, whereas ‘Chester Thornless’ blackberry harvests were on 13 July 2017 and 11 July 2018, 7 and 2 d later than ‘Triple Crown’ blackberry, respectively. In the field, the harvests for both cane cultivars were later than those in the high tunnel (Fig. 4). The first ‘Triple Crown’ blackberry harvests were on 13 July 2017 and 16 July 2018, 11 and 7 d earlier than ‘Chester Thornless’ blackberry harvests, which were on 24 July 2017 and 23 July 2018.

Peak harvests were noted by highest mean yields per cultivar and location and varied by year (Fig. 4). The peak 2017 harvest in the high

Table 2. Mean plot total season yields versus mean plot marketable yields of spinach and kale (n = 6).

Winter 2016–17 [mean ± SE (kg·ha^{-1})][z]		Winter 2017–18 [mean ± SE (kg·ha^{-1})]	
Total kale	47,613 ± 3559	Total kale	21,713 ± 2295
Marketable kale[y]	25,777 ± 1354	Marketable kale	13,886 ± 1690
Total spinach	15,045 ± 1113	Total spinach	10,800 ± 513

[z]1 kg·ha^{-1} = 0.8922 lb/acre.
[y]Only some of the total kale harvested was marketable.

Fig. 3. Dissected live buds from the field and high tunnel blackberry canes: (A) healthy field bud, (B) healthy high tunnel bud, (C) high tunnel budbreaking dormancy, and (D) high tunnel bud with dead tissue.

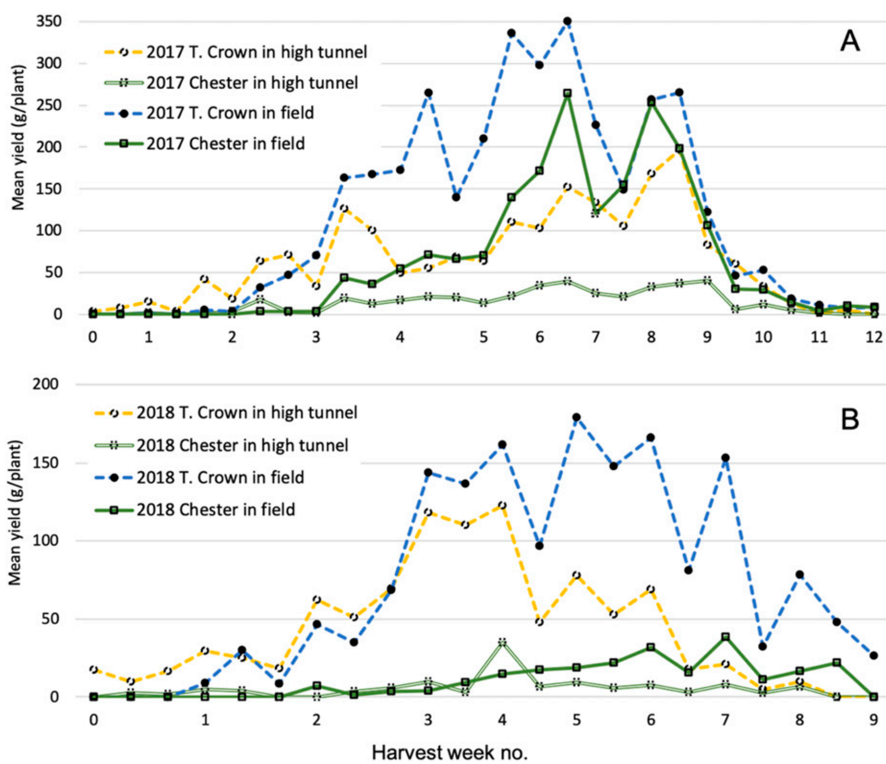

Fig. 4. Blackberry yield data by week for 2017 (A) and 2018 (B) as mean fresh weight per plant by cultivar (T. Crown = Triple Crown, Chester = Chester Thornless) in field and high tunnel. Harvest week number indicates number of harvest times per week, depending on availability of ripe berries; 1 g = 0.0353 oz.

Table 3. Blackberry cultivar seasonal yield means in high tunnel and field from Summer 2017 and Summer 2018 with minimum (min) and maximum (max) values (n = 8).

Location	Cultivar	2017 Mean yield (g/plant)[z]	2017 Yield (min, max)	2018 Mean yield (g/plant)	2018 Yield (min, max)
High tunnel	Triple Crown	1888	(262, 4152)	950	(0, 1991)
	Chester Thornless	412	(99, 699)	119	(0, 346)
	Difference ± SE[y]	1471 ± 599 (P = 0.07)		825 ± 222 (P = 0.02)	
Field	Triple Crown	3425	(1365, 4922)	1647	(515, 2905)
	Chester Thornless	1858	(644, 3572)	232	(0, 715)
	Difference (±SE)[y]	1539 ± 599 (P = 0.06)		1439 ± 222 (P < 0.01)	

[z]Means, minimum and maximum reported are raw SAS total means using the Means procedure (SAS version 9.3; SAS Institute, Cary, NC); 1 g = 0.0353 oz.
[y]Difference with standard error was significant at α = 0.05 using a "mixed" model procedure (SAS version 9.3).

tunnel was 2 Sept. 2017 for 'Triple Crown' blackberry and 7 Sept. 2017 for 'Chester Thornless' blackberry. The peak of the 2017 season in the field was 21 Aug. 2017 for both 'Chester Thornless' and 'Triple Crown' blackberry. The peak of the 2018 season in the high tunnel was 7 Aug. 2018 for both 'Triple Crown' and 'Chester Thornless' blackberry. The peak of the 2018 season in the field was 13 Aug. 2018 for 'Triple Crown' blackberry and 27 Aug. 2018 for 'Chester Thornless' blackberry.

The first year did not show a significant difference in the two blackberry cultivar yields. The mean yield (grams per plant) was not significantly different between cultivars in the high tunnel and the field, with (± SE) 1471 ± 599 (P = 0.07) and 1539 ± 599 (P = 0.06), respectively (Table 3). In 2018, the mean yields per plant between 'Chester Thornless' and 'Triple Crown' blackberry in the high tunnel and field were significantly different (Table 3). Among the two cultivars, the mean yield per plant difference was (± SE) 825 ± 222 (P = 0.02) in the high tunnel and 1439 ± 222 (P < 0.01) in the field. Consistent with previous research growing the same plants within the same high tunnel as the current study, 'Triple Crown' blackberry produced higher yields than 'Chester Thornless' blackberry in the high tunnel and the field (Yao et al., 2018). In 2017, the total mean for 'Chester Thornless' blackberry in the high tunnel was only ≈22% of the field mean. The total mean for 'Triple Crown' blackberry in the high tunnel was 55% and 58% in 2017 and 2018, respectively, of the total mean in the field (Table 3). With both cultivars, the high tunnel environment could have negatively affected fruit yield.

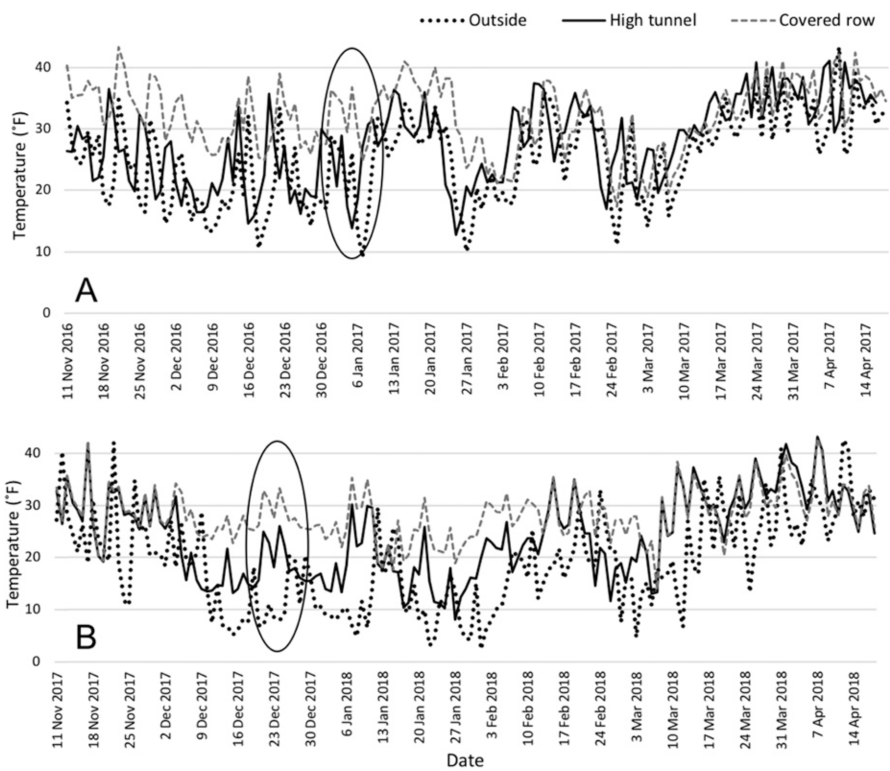

Fig. 5. Minimum air temperatures outside, inside high tunnel, and inside high tunnel under rowcover for the (A) 2016–17 and (B) 2017–18 growing seasons. Ovals indicate times where the covered rows were 15 and 20 °F warmer than the outside air in the 2016–17 and 2017–18 growing seasons, respectively; (°F – 32) ÷ 1.8 = °C.

Temperatures. Overall air temperatures were warmer inside the high tunnel and even warmer under rowcovers in both winter seasons. The extreme high tunnel maximum temperature in the 2016–17 winter season was 97.8 °F on 18 Feb. 2017, whereas the extreme high tunnel maximum temperature in 2017–18 was 104 °F on 27 Mar. 2018. These temperatures might explain the observation that blackberry canes inside the high tunnel may have been breaking dormancy early due to high temperatures during the winter growing seasons of both years. The lowest outside minimum temperature in the 2016–17 winter growing season was 9.1 °F on 7 Jan. 2017, whereas the lowest outside minimum temperature was 2.5 °F in the winter of 2017–18 on 1 Feb. 2018 (Fig. 5). Due to their passive solar heating, there is still an inability to regulate temperatures beyond providing ventilation by opening the doors and sides of the high tunnel.

The covered rows maintained the highest minimum temperatures consistently for both winter growing seasons. Through the 2016–17 winter season, the rowcovers kept the air up to 15 °F warmer than the outside air and up to 20 °F warmer in the 2017–18 season (Fig. 5). Kale has optimal growth at temperatures between 60 and 70 °F according to Johnny's Selected Seeds (2019). For the growth of spinach, the optimal temperature is 67 °F (Ernst et al., 2012). The increased degrees of warmth provided by the high tunnel and the rowcovers was sufficient to allow growth of kale and spinach through the both winter seasons.

However, because of the lack of low temperatures in the high tunnel, blackberry canes of both cultivars inside the closed high tunnel appeared not to receive adequate chilling hours for optimal growth. Even though field and high tunnel blackberry canes were exposed to similar maximum temperatures (Fig. 6), the field canes did receive exposure to lower temperatures than the high tunnel canes (Fig. 5). The result was cane and bud damage, observed at different times during the season (Table 4), due to premature budbreak as the high tunnel canes were subjected to warmer air temperatures and fewer chilling hours. Chilling for blackberry occurs between 40 and 50 °F, whereas consistent temperatures over 60 °F have negative effects on bud initiation and growth, thus making it harder for the plant to readjust to cooler chilling temperatures needed to continue dormancy (Longstroth, 2013). Depending on the cultivar, the amount of chilling time needed for the buds to be dormant over winter will range from 200 to 1400 h (McWhirt, 2016; Salgado and Clark, 2015; Takeda et al., 2002). Every season, dormancy is required before new growth can continue from the perennial crown (Takeda et al., 2002). In previously reported field studies on 'Chester Thornless' and 'Triple Crown' blackberry in Oregon, 'Chester Thornless' blackberry was higher producing due to its superior cold hardiness (Galletta et al., 1998a; Galletta et al., 1998b). In contradiction, other high tunnel trials in New Mexico indicated the opposite where 'Triple Crown' blackberry consistently out-produced 'Chester Thornless' blackberry with the sides of the high tunnel rolled up (Yao et al., 2018).

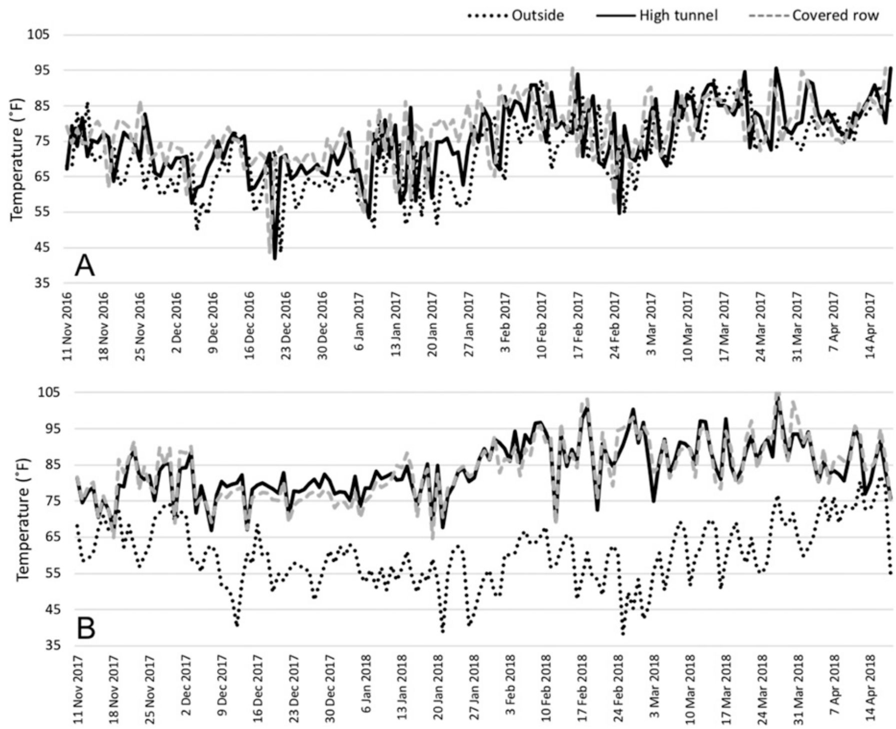

Fig. 6. Maximum air temperatures outside, inside high tunnel, and inside high tunnel under rowcover for the (A) 2016–17 and (B) 2017–18 growing seasons; (°F – 32) ÷ 1.8 = °C.

Table 4. Average blackberry live buds per bush by location, cultivar, and year counted in June for each year.

		2017	2018
Location	Cultivar	Live buds (no./bush)	
High tunnel	Chester Thornless	4	6
	Triple Crown	23	28
Field	Chester Thornless	75	36
	Triple Crown	91	105

This leads to the conclusion that the cold hardiness for 'Chester Thornless' blackberry also may make it less tolerant to warmer temperatures in winters, making it less suitable for an intercropping high tunnel system where the sides of the high tunnel are kept down the entire winter season. In this study, observed mean yields per plant in the high tunnel were consistently and substantially lower than the corresponding field mean (Table 3). Even when the sides are rolled up, internal temperatures are higher in the early spring, creating an earlier blackberry harvest according to a study by Yao et al. (2018). The sides were kept down in the early spring of this study for the kale and spinach season, which may have caused a negative effect on blackberry yield. In other studies with primocane fruiting blackberry, flowers of high tunnel cultivated plants exhibited decreases in pollen competence of up to 75% due to high temperatures (Stanton et al., 2007). The possible temperature-induced low pollen competence may be responsible for the observed low drupelet density of some berries in this study.

Conclusion

Kale and spinach intercropped between floricane fruiting blackberry in a closed high tunnel, as carried out in this study, showed that the crops under consideration are not compatible for intercropping. Despite the temperatures under the rowcovers inside the high tunnel being adequate for the winter greens (Ernst et al., 2012; Heyduck et al., 2019), the damage produced to the blackberry buds and overall health was detrimental. Considering that blackberry chilling requires temperatures below 50 °F and winter greens prefer temperatures above 60 °F, one option would be to monitor temperatures under the rowcovers and in the high tunnel to provide ventilation to the high tunnel by opening the doors and sides when it gets too warm. Although the high tunnel intercropping system was not replicated, the damage to the blackberry cane buds inside the high tunnel caused fruit yields to suffer both in amount and quality beyond what was made up for with the limited blackberry season extension afforded by the high tunnel. In conclusion, for an intercropping system to be successful, the phenology of annual crops, like kale and spinach, and floricanes, like blackberry, must have similar environmental and cultivation requirements. Only then can they grow and produce in the same high tunnel microenvironment. However, if the temperatures in the high tunnel are monitored, these crops still hold potential to be grown together if the high tunnel sides are opened more often when temperatures are not cold enough for blackberry dormancy, while the winter greens are covered earlier in the season using rowcovers. In the future, to maximize farm space, high tunnels in combination with rowcovers may increase year-round production for farmers by intercropping crops that can be grown sequentially like cane fruits and greens or fruit trees and root vegetables.

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