Trellising System and Cane Density Affect Yield and Fruit Quality of Red Raspberry

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Abstract. Trellising and cane density treatments were applied to vigorous raspberry (*Rubus idaeus* L.) cv. Titan plants in Southern Ontario to determine their effects on yield, yield potential, and canopy microclimate during the 1997 and 1998 seasons. The trellising treatments compared were hedgerow (control), V-trellis, and single-sided shift-trellis (shift-trellis). Cane densities (9, 16, 23, and 30 canes/m²) were established before budbreak each season. The treatments significantly affected yield and yield components. Path analysis indicated that interrelationships among yield components were significantly affected by trellising system. In the second season, plants trained on the V-trellis yielded more than did those in a hedgerow system, while those trained on a shift-trellis had the lowest yield because of a smaller fruiting framework. Fruit quality was lower on the shift-trellis than in the other two systems. These differences were related to light penetration into the three canopies. While an optimum cane density was not found for any system, the maximum cane density (30 canes/m²) produced the highest yields. Yield potential per cane decreased as cane density increased; however, the increase in cane number compensated for this decrease, resulting in an increase in total yield per unit area. Fruit quality also decreased as cane density increased, but cane density did not affect canopy microclimate.

In dense raspberry canopies, the simultaneous existence of both primocanes and floricanes results in strong competition for light between the canes (Wright and Waister, 1982a). This has many implications for productivity, including increased disease incidence because of reduced air circulation, slower drying, and limited penetration of pesticides (Goulart and Demchak, 1993; Stiles, 1994), as well as lower picking efficiency (Stiles, 1995), all of which result in lower yield and yield potential (Cameron et al., 1993). A trellising system is often used to increase exposure to light, which can increase yield (Crandall, 1980; Oydvin, 1986), and to divide the canopy for increased air circulation (Goulart and Demchak, 1993) permitting faster drying and improving picking efficiency (Oydvin, 1986).

The introduction of the single-sided shift-trellis (shift-trellis) into bramble production presents new opportunities in canopy management and harvesting efficiency (Stiles, 1995). The shift-trellis is a dynamic system, in which canes are placed in a horizontal position ini-

tially, then moved to an upright position at fruiting. Fruiting laterals are displayed on the outside of the trellis, while primocanes grow on the opposite side. Harvest efficiency, disease reduction, accurate deposition of pesticides, and avoidance of sun scald are potential advantages of the system.

The shift-trellis was designed for use with semi-erect blackberries (*Rubus fruticosus* Auct.), which have a vigorous growth habit, and can easily form a full curtain of fruit (Galletta and Himelrick, 1989). A variation of the shift-trellis was designed for this experiment in order to evaluate the concept for use with summer-bearing red raspberries.

In the hedgerow system commonly used in the Northeast, primocanes and floricanes intermingle throughout the canopy. Plants grown in this system are inefficient, since many leaves are shaded and produce little photosynthate (Crandall, 1980). Air circulation is restricted and penetration of pesticides can be limited (Goulart and Demchak, 1993). The intermingling of the canes also obscures much of the fruit and makes harvest difficult (Nehrbas and Pritts, 1988; Stiles, 1989). Despite these disadvantages, many growers use the hedgerow system because of its ease of management and low cost.

The V-trellis separates the two types of canes by anchoring the fruiting canes at an angle to outside wires and separating them from the primocanes, which grow into the center of the row. While the V-trellis increases yield over the hedgerow system (Goulart and Demchak, 1993; Nehrbas and Pritts, 1988) several disadvantages of the system have been noted. Shading of canes causes early leaf ab-

scission, favoring the development of fungal diseases (Stiles, 1994), and fruiting laterals can grow toward the center of the canopy, making harvest difficult.

The fruitfulness of a raspberry planting can be influenced by the density of the canes (Crandall et al., 1974) and competition between canes (Buszard, 1986; Wright and Waister, 1982a). Recommended cane density in Ontario is 10–15 canes/m (Louws, 1996) in the hedgerow system. Cane density per hectare will vary with row spacing, but row widths commonly vary between 30 and 100 cm. Once canes are trellised and competition between vegetative and fruiting canes is reduced, cane densities may increase beyond the current recommendation. To our knowledge, the interaction between trellising system and cane density has not been reported in the literature.

The objectives of this experiment were to: 1) evaluate the yield potential and picking efficiency of three trellising systems; 2) determine the interaction of cane density and trellising system; and 3) determine if incidence of cane disease is affected by trellising system.

Materials and Methods

Plant material. A 3-year-old commercial planting of the red raspberry, cv. Titan, was used. The planting was located south of Campbellville, Ont., on a slight slope. The plants were established in the field in 1995, and had been trained to a hedgerow system. The canes were vigorous, with an average height and diameter of 137 cm and 11 mm, respectively, in 1997, and 123 cm and 9 mm, respectively, in 1998, before treatments began. Prior to beginning this experiment, the incidence of disease in the planting was negligible. Rows were planted on 2.5-m row centers in an east-west orientation. Two rows in the middle of the planting were chosen for the experiment, as they had the necessary cane densities and were bordered by adjacent guard rows. Two replications were located in each row. Full bloom occurred on about 28 June 1997 and 1 June 1998. Standard management practices for Ontario were followed (Louws, 1996).

Treatments. The experiment was designed as a factorial with three trellising systems and four cane densities. A randomized complete-block design was used with four replicate plots each 2 m long.

Density treatments were applied at the beginning of May, and were calculated on a m² basis. Row width was ≈65 cm, and therefore linear densities in the row of 6, 10, 17, and 23 canes/m were translated into densities of 9, 16, 23, and 30 canes/m² within the row. The current recommended cane density in Ontario is 10–15 canes/m (Louws, 1996).

Trellising treatments consisted of the hedgerow, the V-trellis, and the single-sided shift-trellis. Canes in the shift-trellis treatments were placed in the horizontal position prior to budbreak, then reorientated on 2 July 1997, following full bloom, according to Stiles's (1995) recommendations for blackberry. In 1998, the shift-trellis was shifted on 21 May, at the beginning of bloom. The V-

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trellis and the hedgerow treatments were applied shortly after the beginning of budbreak, when laterals were <10 mm long. Trellising systems remained in place until canes were removed for growth analysis after harvest. Primocanes were allowed to grow freely within the 0.65-m row width.

Yield. Yield was measured on a 1.0-m length of row in the center of each 2-m plot. Fruit were harvested on alternate days. Quality of fruit was high and all fruit were considered marketable. Total weight was measured at each harvest, and average fruit weight was calculated as sample weight (1 pint $\approx$ 0.55 L) divided by fruit number per sample.

Growth analysis. Following harvest, six floricanes were removed at random from the center meter of each plot for growth analysis. Each fruiting cane was cut at soil level and then divided into three equal lengths (i.e., upper, center, lower) to determine lateral number, total lateral length, node number, and percentage of budbreak for each section. Percentage of budbreak was determined by dividing lateral number by node number in each section of the cane.

Disease rating. Disease incidence was estimated during growth analysis by counting the number of disease lesions that penetrated through the bark between 60 and 100 cm on one side of the cane (180°). Lesions were not classified as to causal organism.

Fruiting zone temperature and duration of leaf wetness. To determine the effects of trellising and cane density on microclimate within the canopy, temperature and cane wetness were monitored in one replication of the experiment between 6 June and 22 Nov. 1997, and 1 June and 15 Aug. 1998. Temperatures were measured with a LI-COR Soil Thermistor (model 1000-15) connected to a LI-COR LI-1000 datalogger (LI-COR, Lincoln, Nebr.). Cane wetness was approximated using a cylindrical wetness sensor (length = 18 cm, diameter = 1 cm) made of plexiglass with a 2.5-cm sensing length. Sensors were placed in the center of the canopy at a height of 80 cm, with the exception of the V-trellis, where sensors were placed in the north fruiting wall. Total duration of wetting for each rain incident, and minimum, maximum, and average temperature over each 24-h period from noon to noon were calculated for each treatment.

Light penetration into the canopy. The photosynthetically active radiation [photosynthetic photon flux density (PPFD)] was measured in the center of the canopy at four heights: ground level, 50 cm aboveground, 100 cm aboveground, and above the canopy. Percentage of full sunlight penetrating the canopy was calculated at each height. In 1998, measurements were taken during canopy development on 7 May and 14 May.

Radiation measurements were taken with a 1-m long LI-COR Line Quantum sensor (model 191SA) and Quantum Sensor (model 190SA), connected to a LI-COR LI-1000 datalogger. The line sensor was placed at the various heights in the canopy, while the quantum sensor was placed above the canopy to determine the intensity of full sunlight. Both sensors recorded

radiation over a 5-min period before being moved to the next location. Light levels at each position were determined as a percentage of full sunlight above the canopy. All light measurements were taken on cloudless days.

Fruit quality. Fruit quality in each plot was determined on two dates in 1997, and on one date in 1998. One-pint ($\approx$ 0.55 L) samples from plots were stored in plastic bags in a chest freezer until analysis. Berries were crushed and the juice was strained and analyzed for soluble solids, pH, and titratable acidity. Percentage of soluble solids of sampled berries was determined using a hand-held refractometer (0% to 25%; Fisher Scientific, Nepean, Ont). The pH of the juice was determined with a temperature-compensated pH meter (Waterproof pH Testr 1, Cole-Palmer, Vernon Hills, Ill.). Titratable acidity was determined by mixing 10 mL of juice with 90 mL of distilled water and titrating with 0.1 N NaOH to a pH of 7.0, according to the protocol of Perkins-Vecz and Nonnecke (1992). Titratable acidity was then calculated as amount of citric acid (g) in 100 mL of juice.

Picking efficiency. Picking efficiency was measured on 25 and 31 July, and on 6 Aug. in 1997, and on 13 and 17 July in 1998. Two people were timed as they picked each 1-m plot. Total fruit weight per plot for that date was divided by the time required for picking, in order to calculate a picking efficiency ($\text{kg}\cdot\text{h}^{-1}$) for each treatment.

Analysis of data. Analysis of variance, including least square means and 95% confidence limits, were completed using the General Linear Model technique in SAS (SAS Institute, Cary, N.C.). Normality of data was tested using the Shapiro-Wilk W-test.

Path coefficient analysis (Sokal and Rohlf, 1995) was used to determine relationships among yield components. Data were combined across years, transformed logarithmically for linearity, and standardized to a mean of zero. Path diagrams were based on multiple regression equations to reflect the dependent structure of the components.

Results

Early in the season light attenuated more quickly in the hedgerow than in the V-trellis at all cane densities (data not shown). Once the primocanes had reached a height of $\approx$ 70 cm, light penetration into the canopy was similar in both trellises, as the plants had filled the area between outside wires.

Yield. Trellising system had no overall effect on yield per m^2 in 1997. In 1998, yield for the shift and V-trellises was $\approx$ 59% and

119% of that of the hedgerow, respectively (Table 1). Cane density had a significant linear effect on yield per m^2 in both years (1997: $r^2 = 0.52$, $b = 160.04$) (1998: $r^2 = 0.22$, $b = 136.25$). Yield response to increasing cane density for the V-trellis, hedgerow, and shift-trellis was 162, 201, and 66 g per cane per m^2 , respectively, in 1998 (Fig. 1A). The yield contributed by each additional cane with increasing cane density resulted in an increase in yield per m^2 . Yield per cane declined linearly within each trellising system with increasing cane density (Fig. 1B).

Fruit number. Increases in yield in both years were accompanied by a concomitant decrease in fruit number per cane, but an increase in fruit number per m^2 . Differences were particularly evident in the second year, when plants trained to the shift and V-trellises produced 62% and 123% as many fruits per cane, and 58% and 120% as many fruits per m^2 , respectively, as did those grown as hedgerows (Table 1; Fig. 1C). Number of fruit per m^2 increased in a positive and linear manner as cane density increased (Fig. 1C). For each unit increase in cane density, however, fruit per cane decreased by 56, 49, and 21 fruits for the hedgerow, V-trellis, and shift-trellis, respectively (data not shown).

Fruit size. Average fruit size was not affected by trellising system (Table 1); however, a negative, linear decrease in fruit weight was observed in all trellising systems as cane density increased (Fig. 2).

Growth analysis. On the lower portion of the cane, the shift and V-trellis produced fewer fruitful nodes than the hedgerow in 1997 (data not shown). In 1998, the V-trellis had a lower percentage of fruitful nodes (Table 2) than did the hedgerow and the shift-trellis.

On the center portion of the cane, the shift-trellis had a lower percentage of fruitful nodes, fewer laterals, and more nodes per cane than did the hedgerow in 1998 (Table 2), whereas the V-trellis produced similar characteristics to the hedgerow with the exception of lateral length. Number of fruitful nodes ($r^2 = 0.13$, $b = -0.06$) and total lateral length ($r^2 = 0.21$, $b = -2.96$) each decreased linearly as cane density increased.

On the upper portion of the cane, the shift-trellis produced fewer fruitful nodes, and fewer and shorter laterals than did the hedgerow in 1998, whereas these characteristics were similar in the V-trellis and hedgerow systems (Table 2).

Path coefficient analysis. The interrelationships among yield components in the V-trellis differed from those in the other two systems. In the hedgerow and shift-trellis, cane density had

Table 1. Main effects of trellising system on yield, fruit size, fruit number per cane, and fruit number per m^2 of 'Titan' red raspberry in 2 years.

System	Yield ($\text{kg}\cdot\text{m}^{-2}$)		Fruit size (g)		Fruit no./cane		Fruit no./ m^2	
	1997	1998	1997	1998	1997	1998	1997	1998
Hedgerow	2.8	6.1 b ^c	3.2	3.2	53 a	83 b	1143 a	1509 b
Shift	2.0	3.6 c	3.3	3.3	37 b	51 c	723 b	875 c
V-trellis	3.0	7.3 a	3.3	3.3	56 a	103 a	1144 a	1817 a
P	0.239	<0.001	0.208	0.194	0.014	<0.001	0.005	0.016

^aMean separation within columns by *t* test, $P \leq 0.05$.

Fig. 1. Effects of trellising system and cane density on (A): yield per m² (SE = 575 for all bars except V-trellis at 30 canes/m² where SE = 664), (B) yield per cane (SE = 33 for all bars except V-trellis at 30 canes/m² where SE = 38), and (C) fruit number per m² (SE = 133 for all bars except V-trellis at 30 canes/m² where SE = 154) of 'Titan' red raspberry in 1998.

the greatest effect on total yield (Fig. 2 A and B), while in the V-trellis, cane density had a more significant effect on fruit size than on total yield (Fig. 2C). Fruit size did not affect yield in the V-trellis, but did affect yield in the other two systems. Number of laterals per cane had no significant effect on either fruit per lateral or total yield in the V-trellis, but significantly affected yield in both hedgerow and shift-canopies (Fig. 2 A and B). The number of fruit per lateral had no effect on fruit weight in the V-trellis, but had a significant and negative effect in the other two systems.

While cane density had a significant negative relationship with number of fruit per lateral in the shift-trellis (Fig. 2B), there was no significant relationship between those two components in either the hedgerow or the V-trellis. In the hedgerow, number of laterals per cane was not affected by cane density, but was negatively affected in both the shift-trellis and the V-trellis.

Disease. Incidence of disease was not significantly affected by trellising system or cane density in either 1997 or 1998, although disease levels in the planting were extremely low at the beginning of the experiment.

Canopy microclimate. No significant differences were found in air temperature or drying time between trellising systems or cane densities.

Fruit quality. Generally, quality of fruit from the V-trellis was either comparable with or higher than did that of fruit from the hedgerow. The shift-trellis produced lower quality fruit than did the hedgerow on two of three sampling dates (Table 3). Increasing cane density reduced soluble solids ($r^2 = 0.08$, $b = -0.023$).

Picking efficiency. Significant differences in picking efficiency were found on only two of the five dates of measurement over 2 years (data not shown). On 31 July 1997 the shift-trellis was only 5% more efficient to pick than

was the hedgerow (2.8 kg·h⁻¹), while the V-trellis was 3% more efficient. However, 1 week later, the shift-trellis and V-trellis were -4% and +4% as efficient to pick, respectively, as was the hedgerow. The width of the row was 65 cm, requiring that canes on the opposite side of the fruiting wall in the shift-trellis be bent at an angle >45° in order to be tied onto the wire when canes were shifted. Laterals from those canes terminated in the center of the trellising system, making the fruit very difficult to reach. In contrast, fruit from the V-trellis were located primarily at the edges of the canopy.

Discussion

The greater yield of the V-trellis and hedgerow vs. the shift-trellis can be attributed to an increased number of fruits per cane, similar to the findings of Nehrbas and Pritts (1988) in their work with trellising systems. Several other researchers (Braun and Garth, 1984; Crandall et al., 1974, 1980; Swartz et al., 1984; Waister and Barritt, 1980; Wright and Waister, 1982b) have also attributed yield increases to greater fruit number. In raspberry, primocane dry weight increases steadily until the peak of fruiting (Fernandez and Pritts, 1994), indicating that carbohydrate stress may lead to floral abortion (Kinet, 1977), which reduces fruit number and hence yield. The greater light penetration in the V-trellis would reduce carbohydrate stress, allowing the plant to maintain fruit number.

Trellising can improve vegetative growth, thereby enhancing yield potential. The canes in the V-trellis system had significantly longer laterals on the center portion than did those in the hedgerow, and had a slightly higher percentage of fruitful nodes on the center portion of the cane, as well as a trend toward more and longer laterals on the upper third of the cane. These growth advantages led to a larger potential fruiting area in the V-trellis than in the hedgerow because of higher light levels for both the primocanes and floricanes in the earlier part of the season. The additional vegetative growth on these canes that were orientated to optimize light distribution may have produced additional carbohydrates for the plant that contributed to higher yields.

The yield advantage of the V-trellis over the hedgerow was low relative to previous comparisons (Goulart and Demchak, 1993; Nehrbas and Pritts, 1988), due in part to the extreme vigor of the plants used in this experiment. Early in the season, the canopy on the V-trellis had completely filled the allotted space, and looked very similar to that of the hedgerow. The yield increase in the V-trellis, therefore, must have been due to increased light penetration at the beginning of the season. Following the last date of light measurement (14 May), the canopies were extremely dense, and a light meter could not be inserted without causing damage to the plants and equipment. Unfortunately, light measurements could not be taken in the upright canopy position of the shift-trellis because of the density of the laterals.

Fig. 2. Diagrammatic representation of the interrelationships among yield components for 'Titan' red raspberry as determined from path analysis. (A) Hedgerow system; (B) Shift-trellis system; (C) V-trellis system. *, **, ***Significant at $P \leq 0.05$, 0.01 , or 0.001 , respectively.

Generally, at the lower cane densities, the V-trellis allowed light to penetrate farther into the canopy than did the hedgerow, which would have favored photosynthesis. The V-trellis had higher light levels than did the hedgerow throughout the canopy above 50 cm, or 1 m at higher densities.

The lower yield produced on the shift-trellis than on the V-trellis and hedgerow can be attributed in part to low light levels observed in the shift-trellis prior to shifting. When the canes were laid out horizontally in the spring, about half of the nodes faced downward, and received only minimal light. As a result of the horizontal orientation, only 59% of the nodes on the center portion of the cane formed laterals, vs. 75% for the hedgerow and 79% for the V-trellis. On the upper third of the cane, only 32% of nodes formed laterals, vs. 45% and 46% for the hedgerow and V-trellis, respectively. The canes in the shift-trellis produced fewer laterals on the center and upper portions of the cane, decreasing yield potential on the most productive portion (Dale, 1989). Previous research has pro-

duced differing results concerning the effects of horizontal training of raspberry canes. Braun and Garth (1984) found that training canes horizontally did not influence yield, while Goulart and Demchak (1993) increased the yield of 'Titan' red raspberries by 32% over the hedgerow by training the canes horizontally. Palmer et al. (1987) determined that horizontal canopies intercepted more light than did vertical ones, and therefore should yield better. However, the training systems in these studies were not dynamic, and did not involve the shifting of the canopy.

Timing of canopy movement for the shift-trellis was critical. In the first year of this study, the shift-trellis yielded significantly less than the other two systems because of problems at the time of trellis shift. When the trellis was shifted at the end of bloom as recommended (Stiles, 1995) primocane growth (i.e., height and number) severely interfered with the proper placement of the canes by obstructing full movement of the canes to their final position on the opposite side of the canopy. Yield potential was lost

when the laterals were broken during the shifting phase. The problem was only partially overcome by shifting the trellis at the beginning rather than at the end of bloom in the second year of the study. Primocane interference is a serious limitation to the use of the shift-trellis for raspberry production because of the prolific production of primocanes. While primocane suppression may partially address this limitation, the suppression of the first flush of primocanes in Eastern Canada caused yield reductions of 15% to 35% (Sullivan and Dale, 1989). The problem of primocane interference may also be addressed by using a biennial system of cane management (Dale, 1989). However, the high cost of the framework may prohibit the use of the alternate-year system where economic return is lower than for the hedgerow.

Path coefficient analysis indicated that the V-trellis generally had fewer negative relationships among yield components than did the other two systems. The influence of cane density on total yield in the V-trellis was smaller than in the other two systems and indicated that the response of yield components to increasing cane density differed among systems. As cane density increased in the hedgerow and the shift-trellis, yield potential per cane decreased at a greater rate than in the V-trellis. This response explains why yield was less subject to increased cane density in the V-trellis than in other systems. The number of fruit per lateral did not have a negative effect on fruit size in the V-trellis, and changes in fruit size and number of laterals per cane had no effect on yield. This characteristic of plants in the V-trellis suggests that high yield can be achieved even when environmental conditions greatly affect individual yield components (Wright and Waister, 1982).

The shift-trellis was designed to improve picking efficiency, but efficiency was better on only one out of five dates. The single-sided fruiting wall on the shift-trellis increased picking efficiency (5%) only during maximum fruit load. Generally, differences between picking efficiencies were nonsignificant during most of the fruiting period.

Increased fruit quality is related to improved light environment in the trellising system (Palmer et al., 1987; Swartz et al., 1984). In 1997, probably because of low levels of light reaching the inner fruit as they matured, the shift-trellis produced fruit with lower sugar levels and higher pH than did the V-trellis. The structure of the shift-trellis resulted in most berries growing in the shade, which reduced sunscald but also reduced berry quality (Swartz et al., 1984). In 1997, many primocanes shaded the fruiting wall, decreasing light to the fruiting canes and reducing soluble solids (Swartz et al., 1984). These differences in fruit quality between the shift-trellis and the other trellising systems were not observed in 1998 because of decreased primocane interference resulting from an earlier shift, as well as the removal of many primocanes from the front wall of the canopy to facilitate management.

No differences in leaf drying time or canopy temperature were found among trellising sys-

Table 2. Effects of trellising system on characteristics of 'Titan' red raspberry floricanes in 1998.

System	Lateral length (cm)	Lateral no.	Node no.	% Fruitful nodes
<i>Lower portion of cane</i>				
Hedgerow	126	3.0 a ²	8.3	36.6 a
Shift	114	3.2 a	8.2	38.6 a
V-trellis	115	2.6 b	8.6	31.2 b
P	0.405	0.032	0.624	0.020
<i>Center portion of cane</i>				
Hedgerow	234 b	6.4 a	8.5 b	74.6 a
Shift	205 b	5.8 b	9.7 a	58.7 b
V-trellis	258 a	6.7 a	8.5 b	79.1 a
P	0.006	0.020	0.001	<0.001
<i>Upper portion of cane</i>				
Hedgerow	186 a	8.6 a	19.1 b	45.1 a
Shift	171 b	6.6 b	20.6 a	33.7 b
V-trellis	208 a	9.1 a	19.4 b	45.8 a
P	0.033	0.007	0.002	<0.001

²Mean separation within columns and portion of cane by *t* test, $P \leq 0.05$.

Table 3. Effect of trellising system on soluble solids (SS), pH, and titratable acidity (TA) of 'Titan' red raspberries on three harvest dates.

System	22 July 1997			6 Aug. 1997			11 July 1998		
	SS (°Brix)	pH	TA (g/100 mL)	SS (°Brix)	pH	TA (g/100 mL)	SS (°Brix)	pH	TA (g/100 mL)
Hedgerow	4.7 b ²	3.9 c	2.0	8.5 a	3.1	1.5	9.0 a	4.0 c	2.0
Shift	5.0 b	3.4 b	2.0	7.4 b	3.1	1.6	8.3 b	3.5 b	2.1
V-trellis	5.7 a	2.9 a	2.0	8.5 a	3.0	1.6	9.0 a	2.9 a	2.0
P	0.006	0.020	0.675	<0.001	0.380	0.386	0.002	0.005	0.519

²Mean separation within columns by *t* test, $P \leq 0.05$.

tems or cane densities in either 1997 or 1998. Incidence of disease was also unaffected by trellising system and cane density. This planting had very low levels of disease prior to beginning the experiment, and intensive control measures continued over the course of this research. Increased cane density contributes to high disease load in raspberries (Goulart and Demchak, 1993) because lack of air circulation limits drying. However, in this study with good disease management practices, disease pressures could be minimized even at high cane densities. Increasing disease incidence with higher cane densities could be expected in management systems with minimal pesticide usage.

Our data contradict the current recommendation for cane density of 10–15 canes per m of row in the hedgerow system (note that no row width is specified) (Louws, 1986), and an optimal cane density was not found for any of the trellising systems in this study (Fig. 1). However, as density increased in 1998, several important components of yield decreased, including fruit weight, lateral number, and center cane bud emergence (with the exception of the hedgerow system, where total lateral number on the center portion of the cane increased as density increased). As cane density increased, canes in all systems had smaller fruit, and fewer fruits per cane on fewer and smaller laterals, probably because of reduced light penetration. However, yield did increase because the increase in fruit number per m² of row as cane density increased more than compensated for decreases in the other yield components. Other researchers (Crandall et al., 1974, 1980; Odyvin,

1980) have also found that increased density increased yield; however, densities studied were lower than the highest density in this experiment. While Dale (1989) suggested that a minimum cane density for optimization of yield exists independent of trellising system, the decrease in additional yield response of the shift-trellis from 23 to 30 canes/m² suggests otherwise. Our data suggest that cane density can be increased to maximize yield and yield components in some systems.

The use of the V-trellis increased yield and yield potential in 'Titan' red raspberry by increasing light penetration into the canopy, while the shift-trellis decreased yield, yield potential, and fruit quality, and had no consistent effect on picking efficiency. The shift-trellis is not recommended for use on red raspberries, given its performance and inherent management difficulties. These results lead us to conclude that the full potential of raspberry plantings in the Northeast are not being realized because of low cane densities and the use of the hedgerow system. The use of the V-trellis, combined with higher cane densities, should increase the yield of such plantings.

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