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Shading Timing and Intensity Influences Fruit Set and Yield in Cranberry

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Abstract. **Cranberry (*Vaccinium macrocarpon* Ait.) vines were shaded with either 72% or 93% shadecloth (28% or 7% of full sun) for 1 month before flowering, after flowering, or before harvest. Fruit set was reduced by heavy shade (93%) before flowering in 1991 but not in 1992 or 1993. Heavy shade following flowering reduced fruit set in 1991 and 1992 but not 1993. The number of flowers per upright was generally not affected by shading but was reduced by prebloom shading at either level in 1993. Mean berry weight was usually conserved. Yield was reduced by shading at either level following flowering in 1991 and 1992. Shading just before harvest had no effect on the characteristics measured. Total nonstructural carbohydrate concentration was reduced to about half relative to the controls by either shading level at all treatment dates. Carbohydrate concentrations recovered to control levels by 4 to 8 weeks following removal of shading. Shading always reduced carbohydrate concentrations but did not always reduce fruit set or yield.**

Availability of carbohydrate resources is one potential limitation to fruit set and yield of cranberry (Birrenkott and Stang, 1990; Hagidimitriou and Roper, 1994). Previous research has shown that fruit set can be reduced if new growth acropetal to fruit or 1-year-old leaves basipetal to fruit were removed, thus removing sources of photosynthate, at critical times during flower or fruit development (Roper and Klueh, 1994; Roper et al., 1992).

Shading has been used to limit resource availability in other fruit crops (Byers et al., 1985; Chandler et al., 1992; Ferree and Stang, 1988). Reducing incident light by 10% to 20% in apple (*Malus domestica* Borkh.) tree canopies reduced fruit set (Doud and Ferree, 1980; Schneider, 1978). Patten and Wang (1994) showed that, as weeds absorb more of the photosynthetically active radiation (PAR) in cranberry beds, yield declined linearly.

In apples, the relationship between shading, yield, and nonstructural carbohydrate concentrations has been mixed. Hennerty and Forshey (1971) found that shading reduced fruit set, but nonstructural carbohydrate concentrations of shoots and spurs were not altered. Auchter et al. (1926) found a reduction in carbohydrates and fruit set following shading of half or entire apple trees.

Our research was undertaken to determine if shading cranberry vines at various times during the season would affect flower count, fruit set, fruit size, yield, and nonstructural carbohydrate concentrations in uprights.

Materials and Methods

Experiments were conducted in a mature bed of ‘Searles’ cranberry at DuBay Cranberry Co., Stevens Point, Wis. Shade was imposed by stretching shadecloth, which provided either 72% or 93% shade, over heavy wire cages, which were 1 m long × 0.5 m tall × 0.5 m wide. Incident light under and outside of the shade frames was measured periodically using a ceptometer (Decagon Devices, Pullman, Wash.). Air temperatures inside and outside of the shading frames were measured using fine wire thermocouples attached to a data logger (model 21x; Campbell Scientific, Logan, Utah) for 10 days in July 1991.

Each year, shading treatment periods were prebloom (≈15 May to 15 June), postbloom (≈15 July to 15 Aug.), and preharvest (≈15 Aug. to 15 Sept.). The shading frames were removed during flowering (≈15 June to 15 July) to avoid interference with insect pollination. Shading treatments were randomly assigned to plots and replicated six times.

In spring, before the first shading treatment was imposed, two plastic rings attached to a stake, each enclosing 81 cm², were placed in each plot. All uprights within each ring were

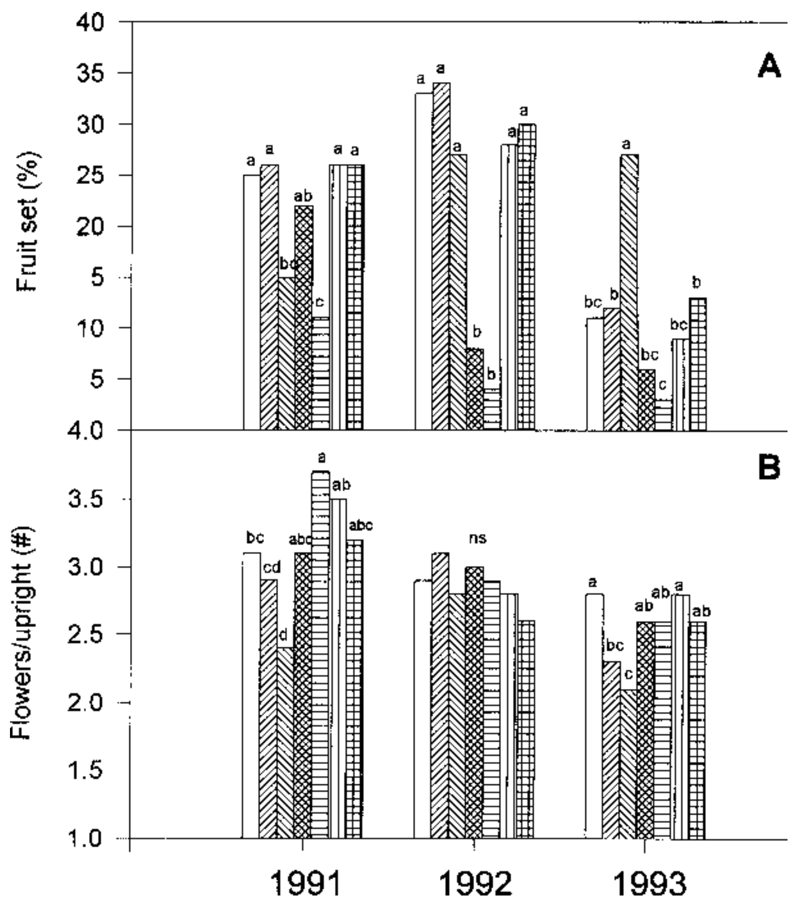

Fig. 1. Effect of two levels of shading (93% and 72%) during the pre- and postbloom and preharvest periods of fruit development of ‘Searles’ cranberry on (**A**) fruit set and (**B**) flower count per upright. Mean separation within each group at $P \leq 0.05$ determined by protected least significant difference. n = 6. ▭ Control, ▨ 72% prebloom, ▧ 93% prebloom, ▩ 72% postbloom, ▤ 93% postbloom, ▥ 72% preharvest, and ▦ 93% preharvest.

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cut in the fall. From these samples, fruiting and nonfruiting uprights, total flower count, flowers per upright, and fruit count were recorded. In addition, fruit set, fruit fresh weight, and mean berry weight were determined for each ring. In 1992 and 1993, rings were set in the plots from the previous year, but not in the same location, and the same data as previously described were collected.

At the conclusion of each shading period, samples, consisting of current-season uprights with fruit removed, were collected from shaded and nonshaded plots (control) for carbohydrate analysis. These samples were dried, ground, and analyzed by high-performance liquid chromatography as described by Hagidimitriou and Roper (1994).

Data were analyzed as a completely random design. Number of uprights per ring was used as a covariate for data analysis involving uprights.

Results and Discussion

Actual incident PAR under the shaded frames was reduced by 79% and 92% of full sun. Photosynthetic light saturation for cranberry occurs at $\approx$1400 mmol·m^{-2}·s^{-1} PAR (Hagidimitriou, 1993); both shading treatments reduced incident light on leaf tissues below this level. Continuously monitoring between 15 and 26 July 1991 showed air temperatures of the two shaded treatments to be within 1C. Air temperature in the nonshaded control plot was similar to those in the shaded plots at night but were 4 to 7C warmer during the day. Uprights growing under the shade covers for 4 weeks were slightly etiolated.

Fruit set was reduced by 93% prebloom shading in 1991 but not in 1992 or 1993 (Fig. 1A). Light prebloom shading (72%) did not reduce fruit set any year. Heavy postbloom shading reduced fruit set in 1991 and 1992 but not 1993. However, in 1993 fruit set was numerically lowest for this treatment. Light postbloom shading reduced fruit set in 1992. The latest shading treatment (preharvest) at either shading level did not reduce fruit set compared to the control in any year.

The number of flowers per upright generally was not affected by shading treatments (Fig. 1B). However, flower count per upright was reduced by 93% prebloom shading in 1991 and by both levels of prebloom shading in 1993. Flower count per ring (adjusted using total upright count as a covariate) was reduced only in 1991 by heavy prebloom shading (data not shown). Reductions in yield are not a function of a reduction of flower count per upright or per area because flower initiation takes place the year before flowering and fruit set. However, flower count per upright apparently can be reduced in some situations by shading before flowers open.

Mean berry fresh weight was reduced in two instances: heavy prebloom shading in 1991 and heavy postbloom shading in 1992 (Fig. 2A). Mean berry weight was not affected in 1993. This result is consistent with other studies that show conservation of berry size when resources are limited (Roper and Klueh, 1994; Roper et al., 1992).

Yield was reduced by postbloom shading of either level in 1991 and 1992. Yield was reduced also by 93% prebloom shading in 1991. Yield was low in 1993 and not affected by any treatment (Fig. 2B). Preharvest shading did not affect yield in any year. In general, yield followed the same pattern as fruit set (Figs. 1A and 2B) but differed from flowers per upright or per ring or fruit size. This result suggests that yield was limited primarily by fruit set and less by fruit size or flower count per sample, which supports the work of Eaton and Kyte (1978).

When plots were examined the year following shading, no treatment effect was noted in 1992 or 1993, which suggests that treatment effects were short lived. No data were collected for 1994. Although flower bud formation for the following year occurs during the postbloom and preharvest treatments, no carryover effect was discernible.

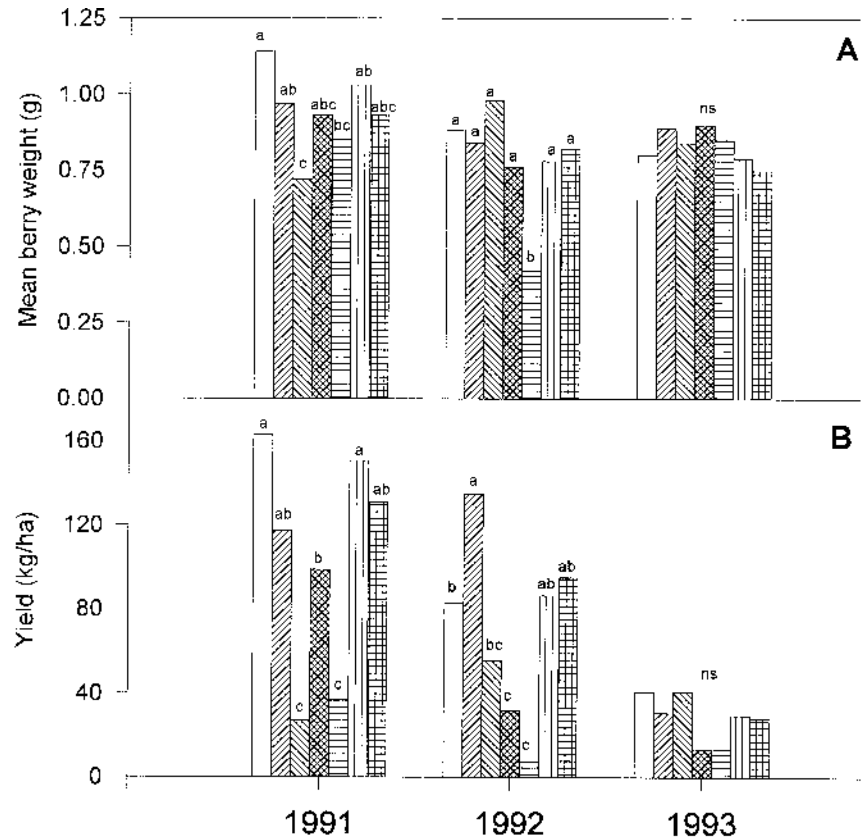

Fig. 1. Effect of two levels of shading (93% and 72%) during the pre- and postbloom and preharvest periods of fruit development of 'Searles' cranberry on (**A**) mean berry weight and (**B**) yield of cranberry. Mean separation within each group at $P \leq 0.05$ determined by protected least significant difference (n = 6). Control, 72% prebloom, 93% prebloom, 72% postbloom, 93% postbloom, 72% preharvest, and 93% preharvest.

Table 1. Effect of shading (pre- or postbloom or preharvest) at two levels on carbohydrate concentration of 'Searles' cranberry, 1993 (n = 6).

Sampling date	Shading intensity and timing (%)	Total soluble sugars (mg/100 mg dry wt)	Starch (mg/100 mg dry wt)	Total nonstructural carbohydrate (mg/100 mg dry wt)
16 June	0	3.46 a[z]	10.42 a	13.88 a
	72 (prebloom)	2.90 b	6.50 b	9.40 b
	93 (prebloom)	2.16 c	3.05 c	5.21 c
26 Aug.	0	3.57 a	1.13 a	4.70 a
	72 (prebloom)	3.59 a	1.37 a	5.00 a
	93 (prebloom)	3.65 a	1.54 a	5.19 a
	72 (postbloom)	2.20 b	0.07 b	2.27 b
	93 (postbloom)	2.03 b	0.02 b	2.06 b
27 Sept.	0	5.28 a	0.67 a	5.96 a
	72 (prebloom)	5.29 a	0.82 a	6.11 a
	93 (prebloom)	4.86 ab	0.61 a	5.47 a
	72 (postbloom)	5.10 ab	0.70 a	5.80 a
	93 (postbloom)	5.35 a	0.55 a	5.91 a
	72 (preharvest)	3.81 c	0.24 b	4.05 b
	93 (preharvest)	3.12 d	0.14 b	3.26 b

[z]Mean separation within date and column at $P = 0.01$ by protected least significant difference; n = 6.

Reduction of the concentration of nonstructural carbohydrates was evident at the end of each shading treatment (Table 1) (within each sampling date control vs. last two lines significant at $P \geq 0.01$). In some cases, heavy shading reduced soluble sugars and starch concentrations more than light shading. Four to 8 weeks of ambient sunlight allowed carbohydrate concentrations to return to control levels. Data for all three years were similar, so only 1993 data are shown. Control carbohydrate concentrations were similar to seasonal values reported for cranberry (Hagidimitriou and Roper, 1994). Nonstructural carbohydrates are highest in early spring before flowering, lowest near fruit set, and begin to recover before harvest.

The relationship between carbohydrate concentration and fruit set or yield was inconsistent. Shading always reduced carbohydrate concentrations but did not necessarily reduce fruit set and yield. Preharvest shading would not be expected to reduce fruit set, because by the time this treatment was imposed, fruit were already set. Postbloom shading began when nonstructural carbohydrates were lowest (Hagidimitriou and Roper, 1994), and this treatment would be expected to reduce fruit set. Heavy postbloom shading reduced fruit set all three years; light shading had an effect only in 1992. Because there was an inherent lag between earliest fruit setting and imposition of the postbloom treatment, the effect of shading may not have been as great as it would have been if shading had been imposed earlier.

Weather was likely a factor in this research: 1992 was hot and dry early and cool and wet in the fall; 1993 was cool with record rainfall. Fruit set and yield were likely limited by poor weather in 1993, exclusive of the treatments imposed.

This research supports other cranberry research suggesting that the fruit set period is a critical time for resource limitation. Any factors that might limit resource availability during and immediately following the fruit set period has the potential to reduce fruit set and yield.

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