Table 2. Correlation of cane characteristics and berry number for 'Willamette' and 'Puyallup' red raspberries.[z]

	Diam	Ht.	Topped ht.	Total berries	Berries per lat.	Amount topped
Diam	---	.71**	.25**	.45**	.47**	.59**[y]
	---	.78**	.04	.08	.29**	.51**
Height	.71**	---	.40**	.36**	.46**	.81**
	.78**	---	.03	.03	.28**	.67**
Topped ht.	.25**	.40**	---	.40**	.05	-.23**
	.04	.03	---	.52**	-.14	-.72**
Total berries	.45**	.36**	.40**	---	.60**	.12
	.08	.03	.52**	---	.41**	-.37**
Berries per lat.	.47**	.46**	.05	.60**	---	.45**
	.29**	.28**	-.14	.41**	---	.30**
Amount topped	.59**	.81**	-.23**	.12	.45**	---
	.51**	.67**	-.72**	-.37**	.30**	---

[z] Values in bold face type for 'Willamette', italicized values for 'Puyallup'.

[y] Double asterisks indicate correlation was significant at the 1% level.

Table 3. Correlation of cane characteristics and berry number for 'Willamette' red raspberry in British Columbia.

	Berries per cane	Berries per lateral	No. fruit nodes
Diam	.44**	.56**	-.18*
Height	.13	.38**	-.42**

*significant at 5%, ** significant at 1%.

number of canes per hectare. Our study did not include data on berry size or canes per hectare.

The original cane height, diam, and height of topping affected these components differently. Number of berries per cane for 'Willamette' was more closely correlated with diam than with height. Taller canes had more berries per lateral but fewer fruitful nodes and hence had a limited effect on total berries per cane. Since diam and height are closely related, the same interaction occurred with diam but to a lesser degree. We assume that cane vigor reduced the number of fruitful laterals for 'Puyallup' also, but this cultivar had more berries per lateral resulting in no significant correlation of either height or diam with total berries per cane.

Height of topping during the dormant season also affected yield. Higher topping of moderate to vigorous canes increased the number of fruiting laterals with only slight reduction of berries per lateral. The actual amount of top removed when pruning had a more positive effect on the number of berries per lateral than did the topping height. These relationships were referred to by Locklin (2) who found large diam (14 mm) canes tended to yield less than smaller diam (12 mm) canes. When the canes were woven to allow longer canes to be trained, yields kept increasing with diameter.

Although there was a definite relationship between cane vigor and berry number, this accounted for less than 25% of the variation in fruitfulness of the canes. Size of the canes, therefore, is only a partial measure of potential raspberry yield. Cane quality and other factors must also be considered in development of cultural practices for maximum production.

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Evaporative Cooling of 'Delicious' Apples – The Economic Feasibility of Reducing Environmental Heat Stress[1]

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Abstract. The response of 'Red Delicious' apples to low volume overtree evaporative cooling (EC) irrigation was studied over a 4-year period from 1969-72. While the amount of thermal load and irrigation system run-time varied from year to year, EC consistently resulted in fruit temperature reductions averaging 5.6°C (10.1°F) for the entire 509 hr the system operated over the 4-year period. In each of the 4 years, EC improved fruit quality; on the average increasing total reddish color 8%, solid red color 13%, soluble solids 1%, and fruit weight 22-g while reducing corking 8% and bitter pit 7%. The additional fruit coloration stimulated by EC concentrated harvest in the earlier portion of the harvest season. During the 4 years of the experiment, an additional 1/3 of the cooled crop was harvested, with sufficient solid red color to meet "extra fancy" U.S. grade, during the 1st 2 weeks of the seasons. Because of higher early-season prices, the concentrated earlier harvest of EC fruit is of considerable economic benefit. In locations where heat stresses are common, the use of EC and soil irrigation should be economically feasible.

As apple production increases in areas where unfavorable environmental conditions are common and growers move to higher density plantings, the need to alleviate heat and soil moisture stresses becomes more critical for commercial production of max yields of high quality fruit.

Van DenBrink and Carolus (7) tested the theory of evaporative cooling (EC) to modify plant temp. Soon after their work on low growing vegetable crops, Lombard et al. (3) reported that EC irrigation over the top of pear trees could alter micro-climate of a larger plant as well. They found that while air temp could be reduced and humidity increased, it was fruit temp that was reduced most. Gilbert and co-workers (2) showed that EC could reduce stress temp on larger canopied crops with

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their work on grapes. They reported reductions in air, leaf and fruit temp and an increase in humidity. In an earlier report of this experiment (4) EC was shown to cool apples. Fruit temp were reduced most; 11.1°C (20°F) during the warmest part of the day and averaged 4.4° - 6.7°C (8°-12°F) lower for the season. It was also shown that this fruit temp reduction improved fruit quality (5). Fruit size, soluble solids and fruit color were increased. Cork spot and bitter pit disorders were reduced. Fruit color increased to the point that more fruit could be harvested with color to meet grade earlier in the harvest season. No additional disease problems were encountered nor were any adverse effects of fruit breakdown noted. The objective of this report is to record the results of 4 consecutive years use of overtree evaporative cooling on apples in view of year-to-year environmental variability, and interpret the results in terms of economic feasibility of evaporative cooling use where environmental stresses are common.

Table 1. Overtree irrigation run-time and an average amount of fruit cooling while system was operating.

Year	System run-time		Avg amount of fruit cooling	
	Days	Hours	°C	(°F)
1969	41	157	6.7	(12.1)
1970	37	112	4.5	(8.1)
1971	118	62	5.1	(9.2)
1972	44	178	6.0	(10.8)
Average	35	127	5.6	(10.1)

Methods and Materials

This paper summarizes the results of 4 years comparison of an overtree low vol [.14 cm/hr (.056 in/hr)] evaporative cooling plot, an undertree, supplemental soil irrigation plot and a non-irrigated plot. Single, adjoining 30.5 x 30.5 m (100 x 100') plots were used for each treatment. The materials and methods used to monitor fruit temp are the same as those described in an initial, 2-year report on this study (4) except that in 1971 and 1972 fruit temp were monitored at the top and bottom of the tree under the tree canopy. At all fruit monitoring points each thermocouple wire was rigged with 4 sensing points connected in parallel to average the temp of 4 fruits at that level on the tree. Thus, at each fruit monitoring level (height or canopy location) on the tree, one of the 4 paralleled sensory points was placed on each of the 4 sides of the tree.

All random sample techniques, color based spot harvests and fruit quality evaluations were conducted as those described previously (5). All samples harvested for laboratory analyses were held in 0°C storage until analyses procedures were completed.

This experiment was not replicated because of the financial limitations. Data, however, were collected separately from each of the center 4 trees in each plot, and a mean for each plot obtained to remove tree variation. The 3 plots adjoined in the same row of trees to minimize location variation. Therefore, plot means are presented without the benefit of statistical analyses.

For the benefit of the reader, comparison illustrating seasonal variations, and calculated average responses for each of the 4 years (1969 to 1972) are reported. The data for 1969 and 1970 values were reported previously (4, 5). The 1971 and 1972 data and the economic interpretation were not previously reported.

Results and Discussion

The amount of heat stress varied from season to season. As a result there was considerable difference in the amount of evaporative cooling run time (Table 1). During the 4-year period 509 hr of run-time were accumulated; an average of 127 hr/season. Evaporative cooling irrigation consistently resulted in reduced fruit temp. Fruit cooling averaged 5.6°C (10.1°F) for the entire experiment. Average yearly fruit cooling varied from 4.5 to 6.7°C (8.1 to 12.1°F). This variability must be attributed in part to the differences in heat load. Average yearly fruit temp are the means of all locations monitored. Therefore, since the method of fruit monitoring was altered during the experiment, this could have influenced average yearly temp data. In 1969 only fruit at the top of the trees were monitored. In 1970 fruit on the periphery at both the top and bottom were monitored and in 1971 and 1972 fruit under the canopy were monitored in addition to top and bottom periphery fruit (see Methods). Thus, as the cooler "bottom" and "under canopy" fruit were monitored the average cooling value would be reduced. The max cooling is far greater; 8.3 to 11.1°C (15 to 20°F) than the average (4).

Fruit quality with EC was superior to soil irrigation or no irrigation (Table 2). The major effect of soil irrigation was on fruit size while color and physiological disorders were affected very little. The yearly and average fruit quality responses which resulted from the use of EC is shown in Table 3. In each year tested, EC gave a positive fruit quality response. Overall, EC increased "total reddish" color 8%, "solid red" color 13%, and soluble solids content 1%. Fruit firmness was reduced .09 kg (.2 lb.) but was highly variable. Fruit weighed an average of 22 g more and cork spot was reduced 8% and bitter pit 7% (Tables 2, 3). As with fruit temp response, variability in fruit quality can be attributed to seasonal variability in the heat load and timing of heat stress conditions.

Table 2. The effect of irrigation on the quality of 'Red Delicious' apples, (average 1969-1972).

Irrigation treatment	% Fruit color		% Soluble solids	Fruit firmness kg (lbs)	Fruit Size				Physiological disorder (%)	
	Total	Solid red			Wt/fruit g	Diam cm(inches)	Length cm(inches)	L/D	Cork spot	Bitter pit
No irrigation (control)	75	40	10.3	7.71 (17.0)	153	7.06 (2.78)	6.50 (2.56)	.921	16	15
Soil irrigation	77	43	10.9	7.58 (16.7)	162	7.32 (2.88)	6.83 (2.69)	.934	11	14
Evaporative cooling irrigation	83	53	11.3	7.62 (16.8	175	7.42 (2.92)	6.88 (2.71)	.928	8	8

Fruit color and soluble solids increases were the most consistent. Solid red color increases were greatest in 1969 and 1972. The 1969 season had the longest sustained period of intense heat stress encountered in the experiment which occurred during late June and all of July. A major portion of the 1972 stress period came just before and at the start of harvest when color developing was most critical. Changes in both color and soluble solids suggest that EC did advance fruit maturity slightly. Fruit size was increased markedly in 1969 but not affected at all in 1972. It appears that the earlier in the season the heat stress occurs, the greater the increase in fruit size.

Table 3. Fruit quality relationship between non-irrigated (control) and evaporative cooling samples, by years.[z]

Year	% Fruit color Total	% Fruit color Solid red	% Soluble solids	Fruit firmness kg (lbs)	Fruit size Wt/fruit g	Fruit size Diam cm(inches)	Fruit size Length cm(inches)	L/D	Physiological disorder (%) Cork spot	Physiological disorder (%) Bitter pit
1969	8	21	y	-.40	62	.76	.94	.030	0	1
				(-0.9)		(.30)	(.37)	.030	0	1
1970	9	8	1.0	.45	11	.30	.30			
				(+1.0)		(.12)	(.12)	.003	-11	-11
1971	7	8	1.3	.14	10	.30	.20			
				(+0.3)		(.12)	(.08)	-.004	- 9	- 4
1972	8	14	0.7	-.50	4	.51	.25			
				(-1.1)		(.02)	(.01)	-.003	-13	-11
Average	9	13	1.0	(-0.2)	22	.47	.42			
						(.14)	(.15)	.007	- 8	- 7

[z] Values indicate differences between treatment and control means.

[y] No soluble solids data collected in 1969.

Physiological disorders were rather consistently reduced by EC except for 1969 when no effect was noted. Both corking and bitter pit disorders are known to be related to Ca nutrition. Faust and Shear (1) have suggested that plant water stress restricts Ca movement into the apple fruit and thus increases the incidence of physiological disorders. The general reduction in physiological disorders shown here as a result of alleviating environmental stress thends to support their results. Calcium content of expanding apple fruits is known to be diluted as the fruit grows, and final Ca content at harvest is related to fruit size. The large fruit size increase which resulted from EC in 1969 could have diluted Ca content, thus resulting in no net effect on physiological disorders.

Fruit firmness was the most inconsistent respondent to EC (Table 3). There is no clear cut explanation for the highly erratic response of the firmness parameter nor any one line of reasoning which could account for all the variability. In 1969, certainly the greater fruit size could have contributed to the reduced firmness. In 1970 and 1971 where fruit size was affected only slightly, the improved internal integrity and texture which could have resulted from better plant water relations may have contributed to the increased firmness. The magnitude of the increase bears a direct relation to duration of stress conditions shown for 1970 and 1971 in Table 1. Firmness results and size data from 1972, however, do not fit this pattern (Table 3). One might envision a situation where the late season stress of 1972 retarded fruit maturity while cooled fruit continued normal maturity and softening processes, however, this explanation is at best highly speculative. These interpretations of the firmness variability are presented as possible explanations only, and are in no way intended to represent the final explanation.

The benefit of increased color development resulting from EC is shown in Table 4. Under heat stress conditions, the harvest of mature fruit must frequently be delayed because of insufficient color. The percent of the crop that could be harvested with sufficient solid red color to meet U.S. "extra fancy" grade early in the harvest season was substantially increased (Tables 4, 5). The average over the 4-year study, showed that after 2 weekly spot-pickings an additional 33% of the crop had been harvested where fruit was exposed to EC. Thus, fruit harvest can be concd in the early part of the harvest season and the total length of the season shortened by the added color stimulation of evaporative cooling (Table 4).

The additional amount of crop that has harvestable in the first 2 weeks of each season corresponded closely to the duration of heat stress period (Tables 1, 5). The concn of crop harvested during the first 2 weeks of 1972 is exceptionally high. This is apparently due to the fact that the major heat stress period of the season came just before and during the early part of the harvest season. This resulted in some color difference at the time of sampling for laboratory analysis (Table 3). As the heat stress continued during early harvesting, increased fruit color differences between treatments were observed thus accounting for the greater color difference suggested by spot-picking data in 1972 (Table 5) than was actually shown in preharvest sampling (Table 3).

Table 4. Percent of fruit harvested with two-thirds or more solid red color by weekly spot-pickings (average of 4 years).

Irrigation treatment	Week of the harvest season 1	Week of the harvest season 2 (1 + 2)[z]	Week of the harvest season 3	Week of the harvest season 4	Week of the harvest season 5
No irrigation (control)	19.7	28.2 (48.0)	42.0	8.5	1.5
Soil irrigation	38.0	36.2 (74.2)	29.8	4.5	1.5
Evaporative cooling irrigation	34.1	46.6 (80.7)	15.3	4.0	0

[z] Figures in parenthesis represent accumulated percent of crop harvested in 1st and 2nd spot-pickings.

In the region of apple production where these data were collected, there is a substantial market price advantage during the early part of the harvest season. This price advantage exists until other producing regions to the north begin harvesting. Market prices over the last several years have started at an average of $7.50/bu and dropped rather steadily throughout the season to around $3.50/bu at the close of a 5-week season. Percent of crop yield harvested by week, under the price structure described above, was converted to bushels harvested

Table 5. Additional percent of crop harvested after 2 weekly spot-pickings when EC irrigation used, as compared to control.

	Year	% of crop
	1969	32
	1970	20
	1971	16
	1972	63
Average	Average	33

Table 6. The effect of evaporative cooling on per acre gross return of apples, assuming 600 bu/A yield[z].

	Week of the harvest season and price/bu[x]							
Irrigation treatment	1 @$7.50/bu	2 @$6.50/bu	3 @$5.50/bu	4 @$4.50/bu	5 @$3.50/bu		Total gross return per 600 bu	Gross return adjusted for cork cullage[y]
No irrigation (control)	118 ($885)	170 ($1105)	252 ($1386)	51 ($230)	9 ($31)	=	$3637	$3055
Soil irrigation	168 ($1260)	217 ($1410)	179 ($985)	27 ($122)	9 ($31)	=	$3808	$3389
Evaporative cooling irrigation	205 ($1538)	279 ($1813)	92 ($506)	24 ($108)	0	=	$3965	$3648

[z] Figures on percent of crop harvested by week in Table 4 were transposed to bushels harvested and gross return by week at weekly prices shown. Yield was not adjusted based on fruit size increases in treated plots (Table 3) since increases were inconsistent (great some years to almost non-existent in others).

[y] Gross return reduced by percent of cork cullage shown in Table 2 -16% for non-irrigated and -8% of cooled (assume no return on culls).

[x] Price/bu of fruit assumed all tray packed; crop and figures are not adjusted for increased size of cooled fruit (these factors are small and would tend to counteract each other).

(assuming an average yield of 600 bu/A) and weekly gross dollar return/acre (Table 6) for the data shown in Table 4. These total gross return figures were then adjusted for the incidence of cork spot cullage shown in Table 2. Bitter pit does not appear until fruit is stored and therefore is not normally a cullage factor in fresh market. The difference in the per acre gross return, after cullage adjustment, is an average $583 more for EC fruit and $334 more for soil irrigated fruit for each year of the 4-year period studied. Certainly the apple growers who are going to invest in overtree irrigation will be the above average growers. For example, the orchard where this experiment was conducted has averaged 1000 bu/A over the 4 years of the experiment. Therefore, the $583/A added return figure for EC is probably a conservative one because of the yield base used. The per acre cost (based on purchase cost of $600/A excluding water source) of a permanent overtree EC irrigation system depreciated over a 25-year projected life of the system ($52/A/year, including 7% interest on investment) plus labor (low to none for automated EC and soil irrigation systems), power costs; $1.50/2.54 cm ($1.50/inch) = an annual average of 18 cm (7.1 inch) for EC and 11.4 cm (4.5 inch) for soil irrigation = $18 total, repair costs (1.5% of purchase = $9) and taxes (.6% of purchase = $4) is approx $83/A/year. Thus under a market price structure which favors early marketed fruit, the added returns resulting from the improved quality of EC fruit, in areas where environmental stress conditions are common, is substantial.

Because of the consistent improvement in fruit quality over the 4 years tested, and the resulting concn of crop harvest (with "good" fruit color) in the early part of the harvest season, the use of EC irrigation should be economically feasible in those apple producing regions where heat stress conditions are common and especially where premium pricing favors early marketing. In addition, the interaction of soil moisture conditions and EC with the response of certain biologically active chemicals, which also influence apple quality and maturity (6), may result in even greater grower interest.

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