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Evaporative Cooling as an Oregon Alternative in Frost Protection System of Pears

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SUMMARY

Oregon trials in evaporative cooling for bloom delay for frost avoidance of pears indicated that the cheapest is a spray or impact sprinkler system designed for .15 inches/hour or 50-60 gal/min/acre. These systems could serve also for icing for frost protection and summer irrigation. The system should be operated intermittently 1&1/2 to 2 minutes every 5-minute period to obtain 20 gal/min/acre for proper evaporative cooling. The cooling should begin at a base temperature of 45°F controlled thermostatically from Jan. 15 to Apr. 15 to delay bloom for 14 days. Other methods or systems tried, i.e., growth regulators and white latex paint, have been less effective for bloom delay.

Factors affecting bud temperature depression with evaporative cooling were, in order of decreasing importance, air temperature, vapor pressure deficit, wind velocity and least, solar and net radiation.

Bloom delay affected several components of tree performance. Low tree yields occurred the year after bloom delay due to poor return bloom. The bloom reduction was caused by the higher seed content in fruit from late blooming trees. Fruit maturity was delayed only 2&1/2 days while fruit size was delayed 8 days for every 14 days in bloom delay. Misting and sprinkling delayed pear psylla egg laying and lowered leaf N. More importantly, delayed bloom increased the chance of fireblight infection if bloom occurs when daily mean temperature exceeds 60°F. Because of poor tree performance and increased fireblight infection, bloom delay is not a recommended practice for avoiding frost hazards in pear production.

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EVAPORATIVE COOLING AS AN OREGON ALTERNATIVE IN FROST PROTECTION SYSTEM OF PEARS

Porter B. Lombard, John Wolfe, and Margaret D. Collins

Frost has plagued the fruit industry of Bear Creek Valley in southern Oregon almost every spring during bloom and small fruit stages. The pear industry lost a large portion of the crop from frost in 1954, 1968, 1970, and 1972, when frost reduced the pear crop about 50 percent. Frost not only has reduced the crop level but has increased cullage from misshapened fruit and frost rings.

Frost protection has been accomplished with various methods but with considerable cost and risk to losing part of the crop. To protect against frost, orchard heating with oil heaters, wax heaters, propane heaters, and pressed wood, has been the most common method. Wind machines to circulate warmer air above the orchard through the trees have been used rarely in the valley because of the high capital cost, and poor temperature inversion. But, overhead sprinklers which must freeze ice on the tree throughout the night to release heat from freezing have been installed in nearly 20 percent of the orchards. These protection methods must maintain an air and/or bud temperature above the critical temperature at which frost would damage the bloom or young fruit.

All of the orchard heating methods require a larger release of energy to produce the required heat (3 to 5 million BTU per acre) and because of increasing energy shortage, the protection costs have increased rapidly during the last five years, nearly a triple increase for oil and gas heating methods. Comparable cost and energy used in these frost protection systems is given in Table 1.

TABLE 1. Comparative cost[1] and energy used in conventional frost protection methods in southern Oregon

Frost protection methods	Ave. hours in cold orchards	Fuel used per season/ac. (3/4 gal/heater)	Operational cost plus overhead per acre	
			Hourly	Seasonal
Return stack-oil heaters 15 hrs at 20/ac plus 26 hrs at 35/ac	41.4	837	$19.87	$822.
Pressurized oil heaters	34.9	671	19.83	692.
Propane gas heaters	34.9	642	13.55	473.
Wind machines				
single 90 bhp/8ac	60.0	94	4.14	249.
dual 125 bhp/12ac	60.0	250	7.36	442.
Wind machines oil heaters: single 90 bhp plus 20 heaters per acre	60 (wind mach) 26 (heaters)	290	6.33	380.
Sprinklers (65 gal/min) used for irrigation also (4.6 hp/ac = 3.43 kw/ac)	89.4	25	2.00	179.

[1]Costs are based on 1979-80 prices: labor @ $3./hr, oil: 70¢/gal, gasoline: 80¢/gal, propane: 38¢/gal. Cost includes lighting, filling and cleaning labor, fuel and depreciation.

None of these systems are designed to give complete frost protection. Therefore, crop loss or injury from frost may occur on low temperature nights with well designed systems. Any centralized system such as pressurized oil and gas or overhead sprinklers must rely on continuous supply through a pump. A breakdown in the oil or water source essentially terminates the frost protection. The limitations and high initial cost of these systems have brought about an interest in a new development, delay of bloom to escape frost danger.

BLOOM DELAY TO ESCAPE FROST DAMAGE

The period of pear bloom and young fruit are the stages most susceptible to low temperatures, particularly below 29°F. Pears have bloomed from March 15 to May 1 in southern Oregon. A mean full bloom date for various pear varieties:

Variety	Mean Full Bloom Date
Anjou	April 9
Bartlett	April 13
Seckel	April 14
Comice	April 16
Bosc	April 17

The frequency of nights requiring frost protection during a season has been related to bloom season; the mean frequency of spring nights requiring frost protection is 13 nights per year in southern Oregon. When Anjous were in full bloom before April 9, 64 percent of the seasons (14/22) required protection on more than 13 nights; only 11 percent of the seasons (2/18) required as much protection when bloom occurred after April 9. Also, the pear crop has been influenced by earliness of bloom. Seasons with an early bloom (if Anjou bloomed before April 9) have had less than average crop 54 percent of the time and only 22 percent of the seasons with late bloom had below average crop. Therefore, a late bloom season should improve chances for an above average pear crop.

The probability of low temperatures (28°F and lower) through April remains quite high. The probability drops considerably after May 1 (Table 2). In fact, the most severe low temperatures usually have occurred during the third week of April (April 14 through April 21). Therefore, to escape the danger of frost injury and to increase cropping, pear bloom in southern Oregon should be delayed until the end of April, about a 14-day delay.

TABLE 2. Historical probability of low night time temperature below 29°F in Bear Creek Valley

Periods	% of nights with temperatures below 29°F
March 14-31	22.5
April 1-15	12.0
April 16-30	9.9
May 1-13	0.7

Bud development has been delayed several ways. One has been the delay with growth regulators, e.g. Alar, Ethrel, etc. which have delayed bloom only four days when applied the previous fall. However, none of the growth regulators has delayed bloom enough to escape frost (Table 3).

TABLE 3. Influence of growth regulators for bloom delay of pear trees (1974-75)

Treatment (previous fall)		Delay of bloom (days)		Yield (tons/ac)	
Material	conc. (ppm)	1974	1975	1974	1975
Ethrel	500	1.7	1.3	8.5	5.9
Ethrel	1,000	2.4	Adv. 0.7	2.4	6.3
Cycocel	1,000	0.6	Adv. 2.1	9.7	4.7
Cycocel	2,000	1.8	Adv. 1.7	8.5	8.5
Alar	1,000	4.4	2.2	8.5	10.8
Alar	2,000	4.4	3.8	9.7	14.6
MH 30	1,000	1.2	Adv. 0.6	8.5	6.7
MH 30	2,000	0.8	Adv. 3.0	7.3	7.5
Control	-	0	0	8.5	6.8

Of the two methods tried in Utah, low soil temperatures, and restricted sap movement in the tree trunk, neither have been effective and both have caused considerable tree injury. A fourth method used by Utah researchers (Anderson et al. 1976) includes a model and program to delay bloom of fruit trees by evaporative cooling in early spring. They began the cooling after the chilling requirements were met in the winter. The dates at which chilling requirements were met have been determined in southern Oregon by using their model (Richardson et al. 1974) and from pear bouquets placed at room temperature to check for fruit bud development. These dates have ranged from December 15 through January 15.

The Utah team used a base temperature of 45°F to begin cooling of fruit buds because a growing degree model used by the team indicated the rate of bud development increased between 45 and 77°F with little development below 45°F. However, our approach was to calculate the rate of bud development from historical temperature data in southern Oregon and then decide what base temperature should be used for delaying bloom about 14 days. If we assumed that the cooling system would cool the bud about 5°F, it was found that from the climatic data that a base temperature of 45°F would give the appropriate delay bloom of 14 days. If a warm prebloom season occurred to give an early bloom of Mar. 29, then evaporative cooling above a base of 45°F would delay bloom until Apr. 16 (an 18-day bloom delay). But, during an average blooming season, the delay from evaporative cooling above 45°F would be from Apr. 12 to Apr. 23 (11-day delay). Then, in a cool season when late bloom is predicted, evaporative cooling above 45°F would delay bloom two days. During the same late spring, cooling at higher base temperature would give too little bloom delay while cooling at a lower base temperature would be too much. Therefore, 45°F was used as a base temperature in the last three seasons of bloom delay studies. Cooling in southern Oregon could start in late Jan. since maximum temperatures in Jan.

are seldom more than 45°F (30-year-old mean maximum in Jan. is 44.2 but 51.8°F in Feb.).

Predicting the pear bloom period from temperatures early in the season could be desirable for adjusting the base temperature or determining when to cool. The Utah model was used for this purpose but the results have been less accurate than in Utah because of the possible marine influence in western Oregon. However, prediction of ensuing frost danger from an early season may be too late to begin cooling. In fact, the Utah team (Anderson et al. 1975) found that early cooling (during the first two-thirds of the growing degree hours) is the most effective time for delaying bloom. Therefore, cooling should be started in late Jan. and early Feb. and continued until mid-Apr. to delay bloom to late Apr.

METHODS OF EVAPORATIVE COOLING

The principal method of evaporative cooling used in Utah and other parts of the country has been sprinklers, chiefly impact sprinklers (Anderson, 1975; Buchanan, 1977; Bauer, 1976; Lipe, 1977) with intermittent sprinkling to save power and water. However, it was thought that a method of preventing the warming of buds by solar radiation might be a possibility. The methods tried were:

(1) white paint on the trees to reflect the radiation. (But white latex paint of 50:50 mix with water applied in Jan. delayed bloom only 5 or 6 days for Bartlett and Bosc trees, and some bud injury occurred from the paint.)

(2) and misting to produce a fog for reflecting most of the radiation. (But fog never developed during the day when misting. Therefore, no effective radiation reflection occurred from the misting.)

The mist system was adapted and used during the three years of trials for evaporative cooling after the system was redesigned for better coverage, using nozzles of .05 gallons per minute spaced 5 feet on laterals 25 feet apart, and for lower pump pressures of 80 to 120 pounds per square inch to eliminate the necessity of special pumps (Wolfe et al. 1976). The mist system was used in a large, mature Bosc and Bartlett trees, 25 x 25 feet, and in a hedgerow Bosc and Bartlett orchard 12&1/2 x 5 feet spacing. Mist nozzles were placed along the tree row near the top of trees to cover the trees. The 1975 trials indicated that the mist system was effective and uniform in delaying bloom, about 15 days for Bartlett and eight days for Bosc (Table 4).

TABLE 4. Water requirements for evaporative cooling for bloom of pear trees in southern Oregon. Water applications were from mid-Jan. to mid-Apr. in 1976 and 1977, but late Feb. to early Apr. 1978; systems were turned off when control trees were in full bloom. Base temperature was 45°F except for the impact sprinklers in 1975 when base temperature was 50°F

Evaporative cooling method	Plots: tree age, density, variety	Water usage for bloom delay (acre-in/acre) per 1-day delay 1976	1977	1978	Ave.14 day
Mist-.05 gal/min. nozzles	Mature 70/Acre Bartlett	1.6	2.3	2.5	29.9
Mist- "	Hedgerow 720/Acre Bartlett	1.6	3.2	2.5	33.6
Mist- "	Mature 70/Acre Bosc	3.0	3.7	-	45.3
Mist- "	Hedgerow 720/Acre Bosc	3.0	3.5	-	45.5
Sprinklers-rotating	Mature 70/Acre Bartlett	2.6	2.6	-	36.4
Sprinklers- "	Mature 70/Acre Bosc	5.1	4.1	-	64.4
Spray-Ein-Tal	Mature 70/Acre Bartlett	-	-	1.1	15,4
Spray- "	Mature 70/Acre Bosc	-	-	1.3	18.2
Sprinklers-impact	Mature 70/Acre Anjou, Bartlett	3.1 (1975)			43.5

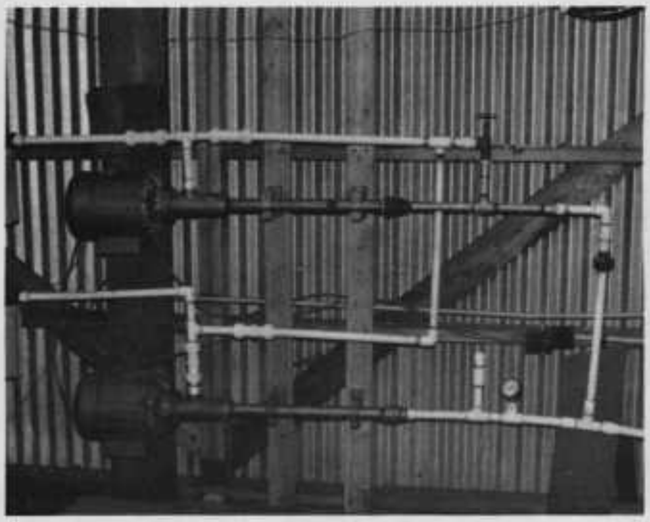

Figure 1.

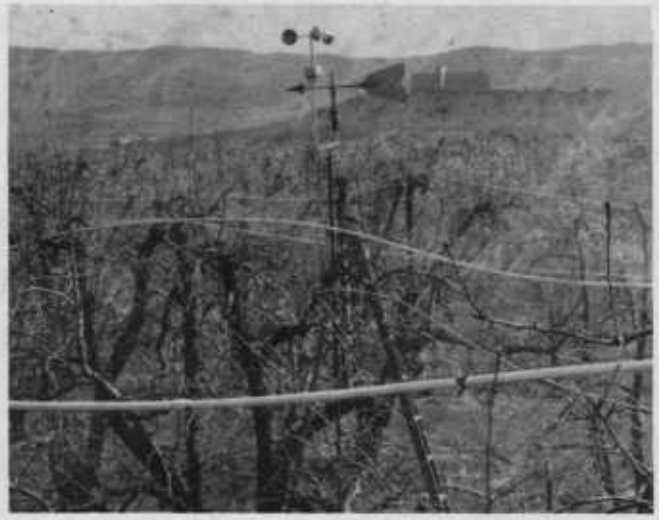

Figure 2.

Figure 3.

Figure 1. High pressure pumps used for cold water misting.

Figure 2. Mist system on 3/4 inch PVC laterals laid on top of mature pear trees for evaporative cooling (Note bloom on trees in background out of the misted area).

Figure 3. Mist system on 3/4 inch PVC laterals laid on top of a pear hedgerow for evaporative cooling (Note bloom on trees in background out of misted area).

A low pressure sprinkler system of 15 psi also was tried; a rotating sprinkler head with a nozzle was mounted in the top of each tree, spaced 25 x 25 feet, in 1976-1977. The sprinklers were cycled two minutes on and three minutes off during the same period. In 1978 another sprinkler system which used a spray nozzle (Ein-tal) in each tree at 30 psi was installed. The rotating sprinkler system was not as effective in bloom delay, using 22 and 42 percent more water than the mist (Table 4). But the Ein-tal spray nozzle system used 56 percent less water than the mist system in 1978. The latter system appears to be the most efficient of the three in operation for bloom delay. An impact sprinkler in a commercial pear orchard was used in 1975 without intermittent operation at a base temperature of 50°F.

PHYSIOLOGICAL EFFECTS FROM EVAPORATIVE COOLING

Factors Affecting Bud Temperature Depressions.

Various environmental factors were monitored while the mist and sprinkler systems were operating. A statistical analysis determined which factors had an important effect on the degree of evaporative cooling of the buds. The rate of water application could be expected to have a large effect on cooling up to a certain point, but rates of application were not programed into this relationship.

Air temperature seemed to have the most influence on cooling in the mist system of the large trees. In other words, on the warmer days, more misted water was evaporated, giving greater bud temperature depression. However, the temperature depression of the sprinkled bud had greater correlation with air temperature than the misted bud.

Dryness of the air (expressed as vapor pressure deficit or VPD) was the next most influential factor affecting temperature depression. The drier the air, the more evaporative cooling there was. However, instead of a direct relationship, the correlation of bud temperature depression and VPD was negative in all three plots. A possible explanation of the negative correlation could be interdependence of another "independent" variable, air temperature. Also, VPD could be associated with a high wind velocity but at higher temperatures.

Wind velocity above 4 mph reduced the degree of cooling in the misted plots. Although wind may tend to increase evaporation, it can bring a large quantity of heat into the area. Apparently the increased wind evaporation from the wind cannot overcome the additional heat. More efficient cooling in the misted block was obtained when the wind blew across the lines from the west and perhaps the mist was more uniformly distributed that way. No effect from wind direction or velocity was found in the sprinkled trees.

Solar and net radiation was found to have the least effect on bud temperature depression within the mist or sprinkler plot. But solar radiation had a positive effect on bud temperatue depression under the white paint indicating that the white latex paint would have the greatest influence on bloom delay under sunny conditions.

Effects of Delaying Bloom on Frost Injury.

Low temperatures during bloom caused frost injury in the field when a minimum of 27.5°F occurred April 10 , 1977, without frost protection. Bartlett and Bosc trees in the control plots were in bloom and early bloom stages, respectively. The stages of bud development of delayed plots were in tight cluster, separated cluster, and early pink. Essentially, little injury occurred on the delayed bloom but considerable frost injury in flower kill and frost rings occurred in all control plots (Table 5).

TABLE 5. Effect of bloom delay by evaporative cooling on frost of Bartlett and Bosc trees. (Frost occurred April 10, 1977)

Plots: Trees, Variety, Treatment	Days delayed	Stage of develop.	temp. (°F)	Frost injury: % flower kill	Frost injury: % fruit w/frost ring
Mature trees					
Bartlett					
Mist	18	Cl. sep.	27.5	0	0
Sprinkler	11	E. Pink	27.5	1	0
Control	0	Full bl.	27.5	10	16
Bosc					
Mist	11	Tight bud	27.5	0	0
Sprinkler	7	Cl. sep.	27.5	0	0
Control	0	Popcorn	27.5	6	8
Hedgerow trees					
Bartlett					
Mist	11	Cl. sep.	27.5	0	1
Control	0	Full bl.	27.5	76	36
Bosc					
Mist	10	Tight bud	27.5	0	0
Control	0	Pink	27.5	8	0

However, bud hardiness was decreased in the mist-delayed bloom plots as noted in Table 6.

TABLE 6. Effect of bloom delay by evaporative cooling on frost injury of Bartlett (Hardiness test in controlled temperature box after mist system was turned off)

Hardiness test stages	Percent of frost injury at: 26.6°F Control	26.6°F Mist	24.8°F Control	24.8°F Mist
Tight bud	0	40	5	55
Pink bud	5	55	35	72
Bloom	10	65	44	82
Petal fall	92	82	95	94

The hardiness tests were conducted after the mist was off for the season. Therefore, the loss of hardiness probably was caused by warmer conditions when the misted buds developed after the system was shut off. The loss of hardiness in the misted plots, although not detected under field frost, could be a problem at temperatures below 27°F.

Effects of Delaying Bloom on Pear Cropping, Fruit Size and Maturity.

The delay in bloom of pear trees seldom increased harvest yield and, in fact, cropping was reduced significantly during the plot years (Table 7). Yields of both Bartlett and Bosc plots were reduced about the same percentage of time. The reduced yields were surprising since increased fruit set was expected to occur on these plots. But, generally, there was about an equal number of plot years with an increased and decreased set (Table 7).

TABLE 7. Effect of bloom delay by evaporative cooling on pear cropping, 1976-78

Plots: Variety Trees, Treatments	Percent in which a significant change occurred compared with the control					
	Fruit set		Return bloom		Yield	
	Inc.	Dec.	Inc.	Dec.	Inc.	Dec.
	- % plot years -					
Bartlett						
Mature - mist	25	75	25	75	0	75
Mature - sprinkler	25	25	25	75	0	75
Hedgerow - mist	50	0	0	50	33	0
Bosc						
Mature - mist	50	0	25	75	0	25
Mature - sprinkler	50	0	0	75	0	75
Hedgerow - mist	0	0	0	0	0	50
Average						
Both varieties	35	20	15	65	5	52

However, the return bloom was significantly reduced in the majority of the plots (65 percent). Therefore, reduced yields from delayed bloom occurred chiefly because of lower return bloom although an increase in fruit set did offset some of the yield reduction in the Bartlett hedgerow misted plot.

The poor return bloom after a year of bloom delay on pears was believed to occur because of the increased seed content in the fruit during the season when bloom delay occurred. Studies on pear and apple trees have showed reduced fruit bud formation on spurs and limbs during a year when the fruit had high seed content. That is, high seeded fruit reduces fruit bud formation and consequently the return bloom for next year's crop. Sampling at harvest for seed content seemed to substantiate this observation because 69 percent of the plot years had a significant increase of seed content (Table 8).

TABLE 8. Effect of bloom delay by evaporative cooling on seed content and fruit size of pears, 1975-78

Plots: Variety Trees, Treatments	Percent in which a significant change occurred compared with the control			
	Seed content		Fruit size at harvest	
	Inc.	Dec.	Inc.	Dec.
	- % plot years -			
Bartlett				
Mature-mist	33	33	0	100
Mature-sprinkler	100	0	66	33
Hedgerow-mist	0	0	33	66
Bosc				
Mature-mist	100	0	0	100
Mature-sprinkler	100	0	0	100
Hedgerow-mist	50	0	50	50
Average Both varieties	69	6	24	76

However, both crop load and seed content probably were the contributing factors in the level of return bloom, so a reduced crop with high seed content could be followed by good return bloom. The high percentage of plot years with increase seed content increases the likelihood of poor return bloom and consequently reduced yields.

Fruit maturity during harvest also was delayed. However, more importantly, reduced fruit sizes occurred in 76 percent of the plot years for the delayed plots (Table 8). Generally, fruit sizes were delayed about eight days for every 14 days in bloom delay, much longer than the 2&1/2 day delay in pear maturity determined by pressure testing. Therefore, harvest of pear orchards with delayed bloom should wait for fruit sizing but at the danger of harvesting overmature fruit.

In summary, bloom delay has reduced pear tree cropping because of poor return bloom and small fruit sizes at harvest. Fruit set was not increased significantly to overcome poor return bloom. Fruit maturity was not significantly delayed.

Effects of Bloom Delay on Pear Pests.

Two pests were monitored during the 1976 and 1977 spring seasons. There was a delay of ovipositioning (egg laying) of pear psylla in the misted and sprinkler plots when the systems were operating. However, afterward, psylla egg laying and larva development were as great in the delayed plots as in the control plots. Bee activity also was reduced during the mist system operation.

Bloom occurred late enough in 1977 to escape the frost damage (Table 5), but bloom in the mist and sprinkler plots occurred during April 21-23 when daily mean temperature was above 60°F and when fireblight inoculum was active. Therefore, there was a 100 to 250-fold increased infection of fireblight (*Erwinia amylavora*) on Bosc trees delayed by mist (Table 9). Also, some blight infection was found in trees with delayed bloom during 1976 and 1978, but these infections were easy to control. Because of the increased danger of fireblight infection, bloom delay to escape frost danger cannot be recommended without blight monitoring and diligent spraying of a bactericide.

TABLE 9. Effect of bloom delay on fireblight strikes on pear trees in 1977

Treatments	Plot-Variety	Fireblight (strikes/tree)	Bloom stage during April 21-23, 1977 (mean temp. 60°F)
Mist	Mature-Bartlett	.01	5-50% bloom
Sprinkler	Mature-Bartlett	.33	90-100% bloom
Control	Mature-Bartlett	0	Petal fall
Mist	Hedgerow-Bartlett	.57	50-90% bloom
Control	Hedgerow-Bartlett	0	Petal fall
Mist	Mature-Bosc	23.90	1-30% bloom
Sprinkler	Mature-Bosc	.66	50-90% bloom
Control	Mature-Bosc	.06	Petal fall
Mist	Hedgerow-Bosc	10.23	1-30% bloom
Control	Hedgerow-Bosc	.004	75-100% bloom, P.F.

METHODS OF EVAPORATIVE COOLING FOR BLOOM DELAY

Plans of various systems used for evaporative cooling are listed in Table 10. Spacing of the systems is based on a tree distance of 25 x 25 feet. Other tree spacing requires a different lateral or nozzle spacing for proper coverage with rotating or spray sprinklers. The radius of coverage of these sprinklers is about 10 to 12 feet, sufficient for a 25 x 25 foot orchard spacing. Decreasing the distance between laterals and nozzles would increase gallonage per acre, which would increase the effectiveness of the evaporative cooling. However, the effective cooling rate per acre appears to be about 20 to 28 gallons/minute for the mist and sprinklers which can be adjusted by intermittent operation as in the case of the sprinklers. Historically, the impact sprinklers have been operated intermittently from

10 to 50 percent of the time in a 5 to 10-minute cycle (Anderson et al. 1975; Lipe et al. 1977; Bauer et al. 1976). The capacity of the rotating and spray sprinklers could be increased easily to 65 gallons/minute/acre to maintain a precipitation rate of .15 inch/hour, considered the minimum rate for icing for frost protection (Wolfe et al. 1971). However, these two systems should be tested for frost protection before using them for this purpose, but they could be used for irrigation either at lower or at higher rates depending on nozzle spacing. The mist system could not be used effectively for frost protection or for irrigation.

TABLE 10. Systems tested for evaporative cooling for bloom delay

	Evaporative cooling systems			
		Sprinklers		
Items	Mist	Impact	Rotating (Buckner)	Spray (Ein-tal)
Pump pressure (psi)	80-120	45	15	30
Capacity of system gal/min/acre	19	65	47	51
Nozzles				
gal/min	.05	3.80	.65	.70
number per acre	360	17	72	72
spacing on laterals (ft)	5	50	25	25
cost per nozzle	$3.25	$6.80	$6.50	$0.50
Laterals				
spacing	25	50	25	25
pipe size for 1000 ft. run	1.5"	3"	2"	2"
laterals over trees	yes	no	possible	possible
Rizers in trees	no	yes	either	either
Operational requirements for bloom delay:				
Base temeprature °F	45	50	45	45
Operation:	contin-uous	contin-uous	inter-mittent 2 min/5 min	inter-mittent 2 min/5 min
Rate (gal/min/acre)	19	65	19 ave.	20 ave.
Water usage for 14-day bloom delay (acre-inches/acre/season)	38.6	43.5	50.4	16.8

Comparative cost and energy requirements of various systems are given in Table 11.

TABLE 11. Comparative cost and energy use of various systems for bloom delay to avoid frost and systems for frost protection

Systems	Approx. installation cost	Evaporative cooling requirements for 14 day bloom delay: Total hours of operation	Operational cost per season: Without irr. @ 3.12/hr	Operational cost per season: With irr. @ 2.00/hr	Fuel use/seaso (gallons of oil)
Bloom delay		- per acre-			
Mist (continuous)	$2,200	915	$ 2,855	$1,830	257
Impact sprinkler (continuous)	1,200	303	945	606	84
Rotating sprinkler with rizers (intermittent)	1,370	1,226[1]	612	392	56
Spray sprinklers with rizers (intermittent)	940	373[1]	189	119	16
Frost protection for average severe frost hazard orchard					
Impact sprinkler	1,200	89	278	179	25
Wind machines	1,500	60	249	-	94

[1]Actual system operation is 2/5 of total hours.

Installation cost of the mist system is about twice the sprinkler systems; the Ein-tal spray system is the cheapest. Greatest differences in cost of installation are reflected in the nozzle cost and number of nozzles per acre (see Table 10).

Operational cost and energy consumption vary considerably among the systems. The mist system had the highest and the spray sprinkler had the lowest cost and energy usage. The spray system has an operating cost for the season less than to the mist system used in Ohio of $240/acre (Robertson et al. 1978). Operating the systems on an intermittent basis can effectively reduce cost and energy requirements as noted for the two sprinkler systems which were operated intermittently. The energy cost for the impact sprinkler can be reduced significantly under intermittent operation; the general method used by researchers in other parts of the country (Anderson et al. 1975; Bauer et al. 1976; Lipe et al. 1977; Buchanan et al. 1977). However a rate of at least 20 gallons/minute should be maintained overall to give effective cooling (impact sprinklers at 65 gallons/minute would require 1&1/2 minutes on for every 5 minutes). The mist system as designed could not be operated intermittently without reducing the cooling effectiveness.

The amount of water used during the season varied from 17 to 50 acre-inches per acre for 14-day delay (Table 10) which is in the range of water used in another location for the same purpose (Stang et al. 1978). Although the location in Texas (Lipe et al. 1978) used an equivalent of 10 acre-inches for 14-day delay of bloom on peaches, indicating that areas with less humidity and more wind may require less precipitation ratio because of the greater evaporative cooling. But sprinkling to ice the trees for frost protection during a severe frost season in southern Oregon (100 hours/season) would use less water (15 acre-inches) than for evaporative cooling (17 acre-inches for the spray sprinkler). Besides less seasonal water usage, the impact sprinkler for icing could operate for less and use less energy per season than the evaporative cooling methods except for the spray sprinklers (Table 11).

Operation of the Evaporative Cooling System for Bloom Delay.

The trials in Oregon and experience of other researchers indicate the best results for bloom delay by evaporative cooling to avoid frost damage in southwest Oregon are:

Systems: Sprinklers, impact or spray designed with a rate of .15 inches/hour or 50-65 gallons/minute/acre (these systems ordinarily would be designed for frost protection requiring 10 times the storage capacity in the orchard and double the storage capacity of the season in the region as compared to an irrigation requirement).

Operations:
1) Intermittent operation of 1&1/2 to 2 minutes per 5-minute period for 20 gallons/minute/acre average rate.
2) Base temperature of 45°F controlled thermostatically.
3) Start between January 15 and January 30.
4) End when non-cooled trees are in full bloom or April 15.

Problems and possible solutions:
1) Fireblight infection on the delayed bloom should be protected with frequent streptomycin or copper applications when 60°F mean temperature is reached during bloom period.
2) Poor return bloom and crop yield could be avoided in solid variety blocks by less influence of cross-pollination on seed content.
3) Reduced fruit size at harvest could be improved by more frequent irrigations and delayed harvest with the danger of overmature fruit, an 8-day delay of harvest for every 14-day delay of bloom.
4) Overmature fruit could be avoided by delaying harvest only 2&1/2-day delay for a 14-day delay of bloom.
5) Low leaf nitrogen can be increased by greater application rates of nitrogen fertilizer but leaf levels should be watched.
6) Increased susceptibility of frost damage of buds, bloom, or young fruit, which should be monitored to indicate critical temperatures for frost protection.
7) Wet soil conditions solved by better drainage.

CONCLUSION

Bloom delay of pears for frost avoidance is not a recommended practice because of poor tree performance particularly due to low return bloom and yield, but also from reduced fruit size. Delay of pear bloom enhances the possibility of fireblight infection.

Various evaporative cooling systems were evaluated for operational cost and water and energy uses. Misting at pressures of 80 to 100 psi cost the most to operate and used the greatest energy compared with a low pressure spray-sprinkler or rotating sprinkler system (45 to 60 psi). The spray sprinkler system was the cheapest to operate and used the least amount of water and fuel under an intermittent operation.

Overhead sprinklers used for icing the trees for frost protection operated for less cost and used less energy and water during the season than when used for evaporative cooling to delay bloom in southern Oregon.

LITERATURE CITED

Anderson, J. L., G. L. Ashcroft, E. A. Richardson, J. F. Alfaro, R. E. Griffin, G. R. Houson, and J. Keller. 1975. Effects of evaporative cooling on temperature and development of apple buds. J. Amer. Soc. Hort. Sci. 100:229-231.

Bates, E. and P. Lombard. 1978. Evaluation of temperature inversions and wind machine on frost protection in southern Oregon. Ore. Agr. Exp. Sta. Special Report 514. pp. 20.

Bauer, M., C. E. Chaplin, G. W. Schneider, B. J. Barfield and G. M. White. 1976. Effects of evaporative cooling during dormancy on 'Redhaven' peach wood and fruit bud hardiness. J. Amer. Soc. Hort. Sci. 101:452-454.

Buchanan, D. W., J. F. Bartholic, and R. H. Biggs. 1977. Manipulation of bloom and ripening dates of three Florida grown peach and nectarine cultivars through sprinkling and shade. J. Amer. Hort. Sci. 102:466-470.

Collins, M. D., P. B. Lombard, and J. W. Wolfe. 1978a. Effects of evaporative cooling for bloom delay on 'Bartlett' and 'Bosc' pear tree performance. J. Amer. Soc. Hort. Sci. 103:185-187.

Collins, M. D., P. B. Lombard, and J. W. Wolfe. 1978b. The effects of evaporative cooling for bloom delay on 'Bartlett' and 'Bosc' pear fruit maturity and quality. J. Amer. Soc. Hort. Sci. 103:187-189.

Lipe, W. N., O. Wilke, and O. Newton. 1977. Freeze protection of peaches by evaporative cooling in the post-rest, pre-bloom period. J. Amer. Soc. Hort. Sci. 102:370-372.

Richardson, E. A., S. D. Seeley, D. R. Walker, J. L. Anderson, and G. L. Ashcroft. 1975. Pheno-climatography of spring peach bud development. HortScience. 10:236-237.

Robertson, J. L. and E. J. Stang. 1978. Economic feasibiligy of over-tree misting for bloom delay in apples and peaches. J. Amer. Soc. Hort. Sci. 103(2):242-245.

Stang, E. J., D. C. Ferree, F. R. Hall, and R. A. Spotts. 1978. Overtree misting for bloom delay in 'Golden Delicious' apple. J. Amer. Soc. Hort. Sci. 103:82-87.

Wolfe, J. W., R. H. Brooks, P. B. Lombard. 1972. Measurement of the frost protection capability of a sprinkler irrigation system in an orchard. Ore. Agr. Exp. Sta. Special Report 346. pp. 45.

Wolfe, J. W., P. B. Lombard, and M. Tabor. 1976. The effectiveness of mist versus a low pressure sprinkler system for bloom delay. Transaction of The ASAE 19:510-513.