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AN ENERGY-CONSERVING SYSTEM FOR ORCHARD COLD PROTECTION*

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ABSTRACT

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The possibility of protecting an orchard against cold by enclosing it under a screen cover was studied in a preliminary field test. At the onset of freezing temperatures, water was sprinkled on the screen, forming a continuous sheet of thin ice. The screen and ice cover effectively reduced heat loss from the experimental enclosure. Simulated twig temperatures were 2°—10°C warmer inside the enclosure during a variety of weather conditions, with outside air temperatures as low as −20°C. When outside air temperatures were −5°C, the inside simulated twig temperature could be held above the critical level for even tender blossoms by briefly sprinkling water under the screen at 10- to 15-min intervals. Although a screen cover and sprinkler system would be expensive to install, it could provide excellent cold protection and would be less expensive to operate than conventional orchard heaters and wind machines. Cooler daytime temperatures under the screen suggest the additional possibilities of dormancy control and reduced evapotranspiration.

INTRODUCTION

Heaters fueled with petroleum-based products are often used to protect orchards against cold weather. Normally 40—70 heaters per hectare are needed, though the number can be reduced in localities where temperature inversions are favorable for wind machines (Kepner, 1951). Individual wind machines may affect 3 or 4 ha, but, like heaters, they are expensive to install and operate (Bates, 1972). The high costs, coupled with fuel shortages, air and noise pollution regulations, and labor problems are increasing the interest in overhead sprinkling for frost protection. The initial investment for overhead sprinklers may be less than that for orchard heaters and wind machines. Sprinkler operating costs during a frost period are usually much

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lower than heating costs, but the possibility of serious tree damage from ice loads is a major disadvantage. Pipe freezing, poor water supply, and drainage may also create problems.

Other possibilities for cold protection include artificial fog machines, foam generators, and chemical sprays to make buds and blossoms more hardy. Under ideal conditions, orchard air temperatures may be raised 1° or 2° C with fog generators, but light winds tend to move the fog away from the trees. Brewer et al. (1972) concluded that fog machines are not yet commercially feasible, but Bartholic (1974) was optimistic following tests of a new high pressure system. Foam generators have been limited to protecting vegetation growing a few centimeters above the ground. Burns (1973), reviewing the tests of chemical sprays for cold protection of citrus trees, concluded that there are still no satisfactory commercial products. This conclusion also apparently applies to deciduous orchards, though it is an area of active research and advances may be forthcoming.

The major obstacle encountered in orchard cold protection is the rapid energy loss, 25 ly/h (Valli, 1970), resulting from convection of warm air out of the orchard and longwave radiation from the trees and soil to the cold night sky. The study reported here explores the possibility of reducing the heat loss by enclosing the orchard in metal screen. Sprinklers could be used to close the holes in the screen with a film of ice at the onset of freezing temperatures, thus reducing the longwave loss and convection of warm air.

EXPERIMENTAL TECHNIQUES

The enclosure shown in Fig.1 was studied during the winter of 1973/74. It was located in south-central Idaho about 100 m from a National Weather Service Instrument Station that provided continuous records of the 30-cm air temperature and hourly averages of windspeed at 3.65 m. Though various types of plastic covers have been suggested for frost protection by many others (including Ferraria, 1970; Brand et al., 1973; Smith, 1973) aluminum window screen with square openings approximately 1.5 mm on a side, supported on a metal conduit frame, was used in this study. The conduit was approximately 2 cm in diameter, and formed a frame covering an area of 4.5 × 6.5 m. Cross-members in the frame made rectangular sections approximately 2.25 m on a side. Each of these rectangles was braced with galvanized crosswires. The frame was supported with steel posts at 8 points around its perimeter. The sides of the enclosure were made from black plastic sheeting supported by a wire 1 m above the ground. The enclosure was tight at the ground surface, but a number of gaps several centimeters wide were left between the top of the plastic sides and the conduit frame that supported the screen.

The temperature at 6 points was recorded continuously with thermocouples encased in 4-cm lengths of nylon tubing 2 mm in diameter. Soil temperatures were measured at the 2-cm depth. Artificial tree twigs were

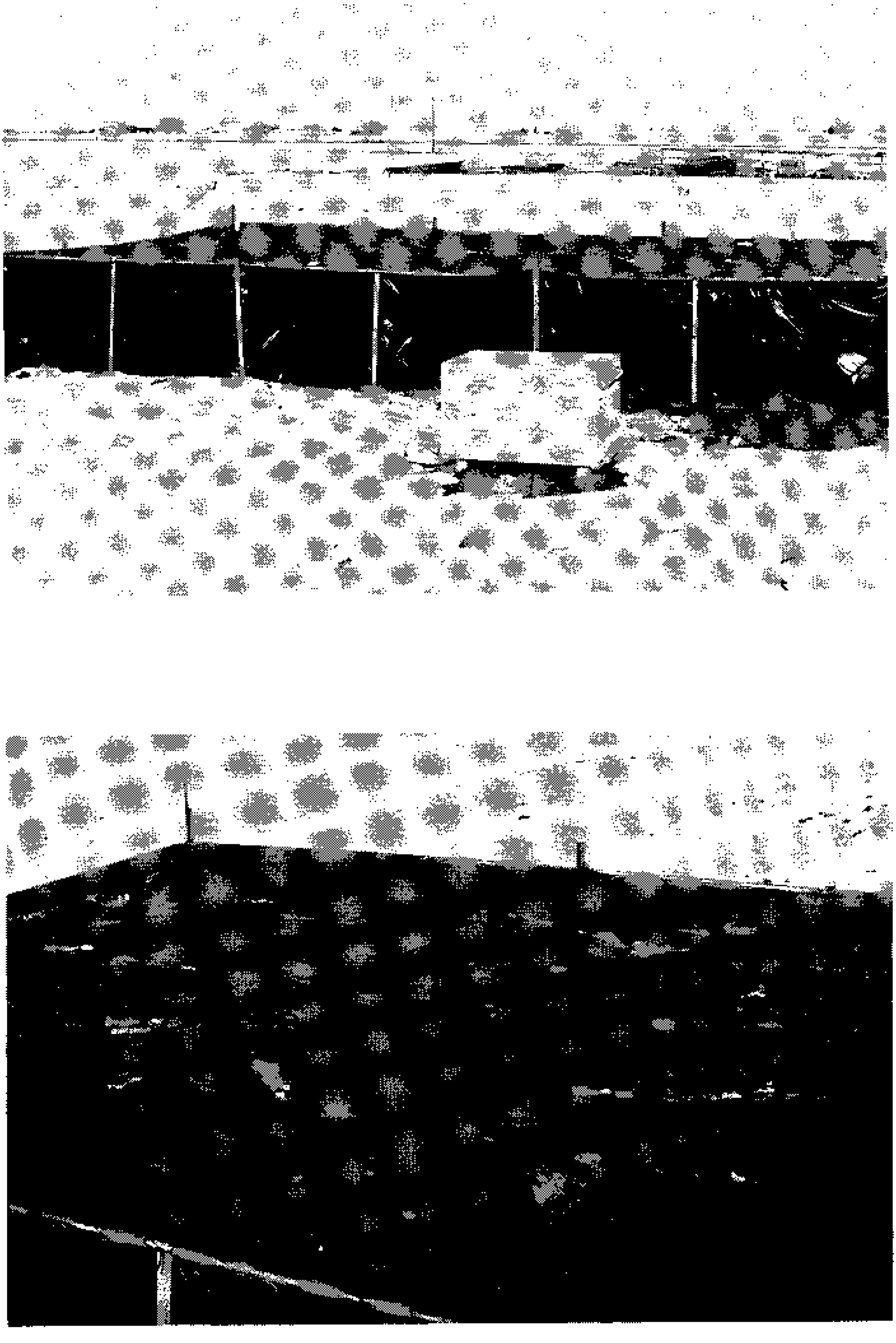

Fig. 1. The study site and enclosure with a close-up of the top showing ice on the screen and some sublimation along the edge.

simulated by taping the nylon tubes to the top of 48-cm stakes, leaving the tubes with the thermocouples in their tips extending vertically 2 cm above the top of the stakes. Two of the artificial twigs were placed inside the enclosure, while 1 and sometimes 2 were used outside for a control.

On a few selected days and nights the space under the screen was divided with a plastic sheet into 2 equal sections approximately 4.5 × 3.3 m on a side so that different conditions could be created and studied within the enclosure.

Frost did not form spontaneously on the screen, but ice was easily initiated by sprinkling when the air temperature reached 0°C. Two or three applications of 1 or 2 mm of water during a 30-min period produced a complete ice cover.

RESULTS AND DISCUSSION

Effects of the screen ice cover

Fig.2 shows the effect on temperatures inside the enclosure caused by a 2- to 4-mm thick ice cover on the screen during a variety of climatic conditions. The degree of cold protection afforded the simulated tree twigs depended on the cloud cover and windspeeds. The most unfavorable conditions encountered are shown in Fig.2A. Exchange of outside air with that in the enclosure was rapid because of the air passing through the gaps between the top of the plastic walls and the screen. The effect of the ice roof on longwave radiation was small because of the heavy night cloud cover.

Fig.2B shows an intermediate situation in which the cloud cover and windspeeds were less. This is more representative of the conditions that injure dormant flower buds and twigs during cold winter nights, and the 5°C protection could be important.

Fig.2C shows near optimum conditions for protection with ice on the screen. The air was calm, the sky was clear, and the ice on the screen was insulated by 4 cm of snow.

Occasionally the outside simulated twig temperature was warmer than that inside the enclosure (Fig.2D). This resulted from light wind and a favorable temperature inversion. When the air was calm, the outside temperature occasionally dipped 2°C below freezing before being warmed by air transferred from higher levels. The dewpoint temperature of the air was near −5°C during this period, and probably caused some evaporative cooling inside the enclosure as liquid water was readily available on the soil surface. The National Weather Station official temperature at the 30-cm level was consistently lower than the twig temperatures during this night, apparently because the Weather Station instrument shelter shielded the temperature sensor from some of the advective energy brought in by light wind.

The critical minimum temperature for many fruit blossoms is −1° to −2°C (Ballard and Proebsting, 1972). Fig.2 suggests that an ice cover alone will not always provide enough protection, and some additional heating may be required. On the other hand, the enclosure used in this study may not have been as effective as a screen and ice cover over a large area, because the heat loss through the sides would be proportionately less (Brand et al., 1973). A large enclosure might also be constructed with fewer open gaps.

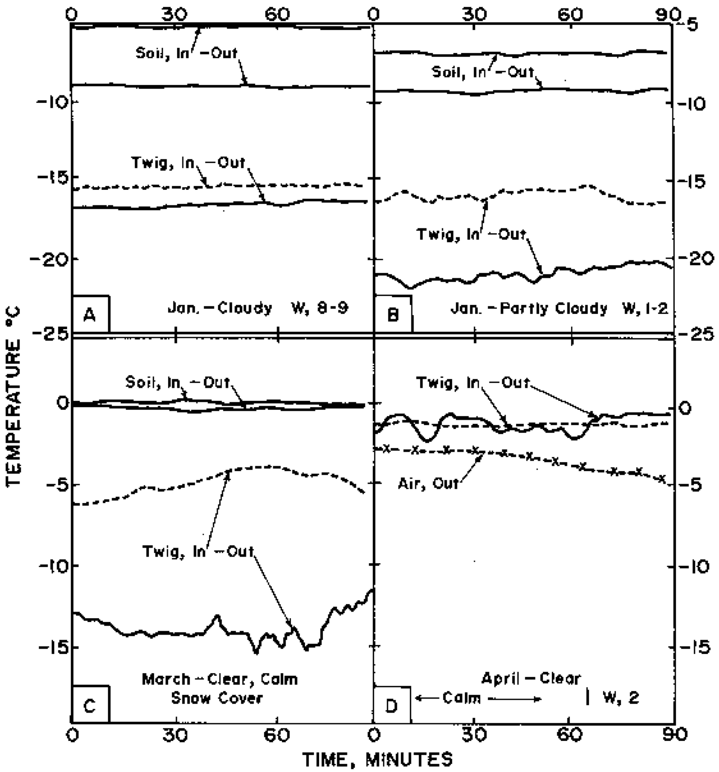

Fig.2. The effects of the ice-covered screen on night temperatures during different weather conditions. The solid line represents simulated twig temperatures outside, the dashed line twig temperatures inside, and the dashed line with crosses, the National Weather Service 30-cm air temperature. Curves for inside and outside soil temperature at the 2-cm depth are labeled, and average windspeeds are indicated in m/sec.

Heating with sprinklers under the screen and ice

One of the least expensive sources of heat below 0°C is the release of latent energy from freezing water. Warming due to water sprinkled under the screen is shown in Fig.3 during a variety of weather conditions. The temperature rise in Fig.3A followed sprinkling approximately 2 mm of water under the screen, and then 15 min later flooding the soil surface with 1 cm of water. Effects of a similar treatment under different weather conditions are shown in Fig.3B. A single light sprinkling was almost as effective as flooding the soil surface, and much more efficient in terms of water used. When air temperatures are

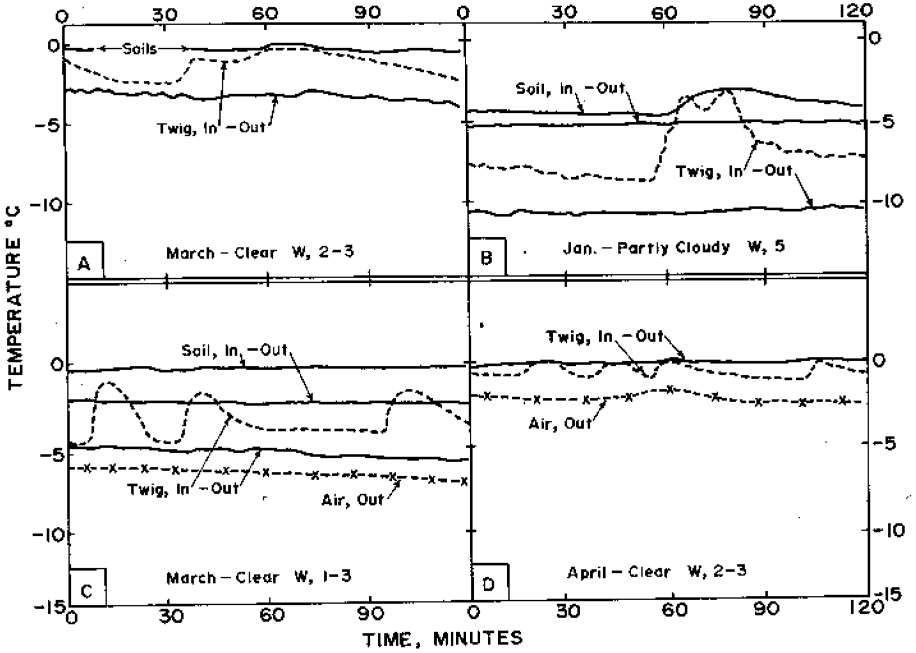

Fig.3. Effects of sprinkling on night temperatures under the ice-covered screen. Curve designations are the same as those given for Fig.2. Abrupt rises in the dashed curve resulted from releasing water inside the enclosure.

below −5° C, a sheet of ice forms rapidly over water ponded on the soil surface, and although freezing continues, the latent heat becomes increasingly insulated from the air in the enclosure by the ice sheet.

The effects of repeated light sprinklings (1—2 mm) inside the enclosure are shown in Fig.3C and D for 2 other nighttime conditions. Weather during the test in Fig.3D was similar to that described for Fig.2D. Each 3- to 5-min period of sprinkling was effective for about 15 min and quickly raised the simulated twig temperature above the critical level for most tender blossoms, even when outside temperatures were below −5° C. Under moderate freeze conditions, the ice and screen should reduce the orchard's heat loss to less than 10 ly/h, based on calculations by Brand et al. (1973) of heat loss through a plastic cover. Ten langleys per hour is less than half the loss from an unprotected orchard, and water applications of 1 mm/h under the screen should be adequate for an efficiently designed system.

Daytime effects of the screen

The screen also caused significant differences in the daytime temperatures of both the soil and the simulated twigs. Fig.4A illustrates the lower inside temperatures during a clear, warm winter day with low windspeeds. The cooler

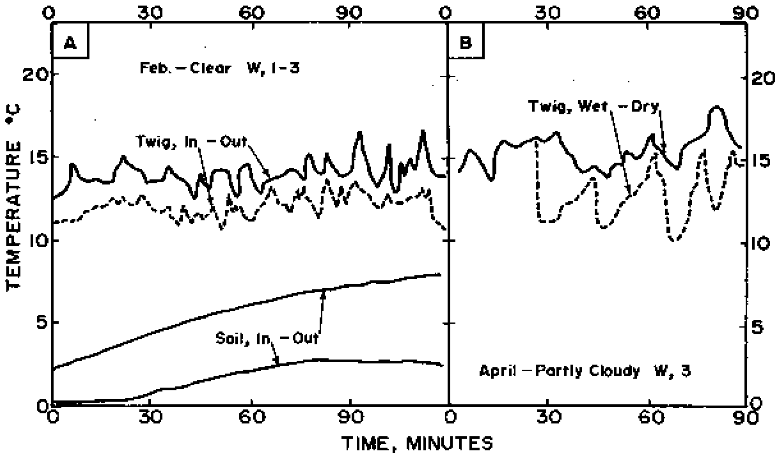

Fig.4. Effects of the screen (A), and screen plus sprinkling (B) on the temperature during warm afternoons. Curve designations are the same as those given for Fig.2 except the solid line in section B is the inside simulated twig temperature in the section that was not periodically sprinkled.

daytime temperatures in the enclosure during the winter would help prevent the loss of cold hardiness in twigs and buds. While many trees gradually develop a tolerance for very low temperatures, this hardiness may decrease rapidly during one or two warm afternoons and severe damage can follow from a cold, clear night (Hermann and Alden, 1971; Howell, 1974).

Anderson et al. (1973) have used sprinklers to keep deciduous trees cool during warm periods in the winter and early spring. Holding buds near the wet bulb temperature on warm days keeps them more hardy and delays blossoming until later in the spring when frost is less likely. Fig.4B shows that sprinkling the simulated twig under the screen at 15-min intervals on a warm April afternoon decreased the temperature. The benefits would be the same as those noted by Anderson et al. (1973), except that less water would be needed because of shading and lower evaporation rates.

Cooler daytime twig temperatures during the winter are also desirable for peach trees in warm climates where the minimum temperature requirements for breaking dormancy do not always occur. Partial shading during hot periods in the summer may be desirable, too, in some localities.

Incoming radiation under the screen was reduced about 25% in the photosynthetically active wave range of 400—700 nm, which is not very different from glasshouses. The reduction of incoming radiation could lower the evapotranspiration during the summer, but it might also affect the growth of some species.

Occasionally the simulated twig temperature under the screen was warmer during the daytime than the twig temperature outside. This occurred when the sun was shining through the ice cover, evidently developing a small "glasshouse" longwave radiation trap. As soon as the ice melted from the screen, inside temperatures dropped below those on the outside. On warm afternoons in April, the simulated twig temperature inside the enclosure occasionally rose above that outside. This may have been caused by radiation and sensible heat transfer from the black plastic walls which became quite warm on the sunny side and thus would be an artifact so far as a large installation is concerned.

Cost factors and energy inputs

Installing a screen cover would be expensive. Assigning a solid set sprinkler system will have a base cost of 1, the expense of installing heaters and/or wind machines will have a base cost approaching 2, while the base for screen cover materials will be near 4. Installation and supports for the screen cover might well add 2 more cost units. On the other hand, the screen cover has a number of important potential advantages shown in Table I. Operating costs during cold nights would be relatively small because of the potential for automation and the low fuel requirements for intermittent light sprinkling. Weston (1973), studying the relative cost of sprinklers, frost pots, and pressure oil burners, found the annual operating costs of overhead sprinklers to be less than 30% of the cost of fuel heating, even under relatively mild conditions requiring only 30 h protection per year. If the price of petroleum-based fuel continues to increase, Weston's (1973) analysis suggests that the higher initial cost of the screen system might well be offset within 4 or 5 years of operation. For example, 2,000—3,000 l of fuel oil/ha a night may be required for protection (Kepner, 1951). Because the screen and sprinkler system would be much less expensive to operate, it might be used in areas that are now considered economically unfeasible for fruit production because of marginal climates. In some of these marginal areas the land is less expensive, which would reduce the total investment ratio of a screen and sprinkler system compared to heaters and wind machines on higher priced land in milder areas.

Though the ice cover on the screen provided several degrees C of frost protection under most weather conditions, additional energy input under the screen may be necessary on cold nights when the vegetation is in a critical stage. Intermittent sprinkling underneath the screen will probably be the least expensive method for providing energy, although there are other possibilities. Because the soil surface stays near 0° C when it is wet, mixing the air under the screen with some type of fan could possibly increase air temperatures. In this study, use of a 20-cm fan in one section of the enclosure when it was divided in half was not very effective, probably because the gaps between the screen and the plastic allowed too much exchange with the outside air. Nevertheless, mixing might be considered in other situations, particularly when the screen cover is several meters above the soil surface.

TABLE I

Potential advantages and disadvantages of the sprinkler and screen cover system for orchard cold protection

Potential advantages		Potential disadvantages	
(1)	Low operating costs	(1)	High initial cost
(2)	Low energy inputs	(2)	Shading during the growing season?
(3)	Protection against radiant and sensible heat loss	(3)	Possible damage from hail and snow?
(4)	Low water sprinkling requirements	(4)	Insects and pollination?
(5)	Reduced evapotranspiration		
(6)	Automation possibilities		
(7)	Dormancy control		
(8)	Cold protection during dormancy		
(9)	Hot weather protection		
(10)	Insect and bird control?		
(11)	Hail protection and wind damage?		

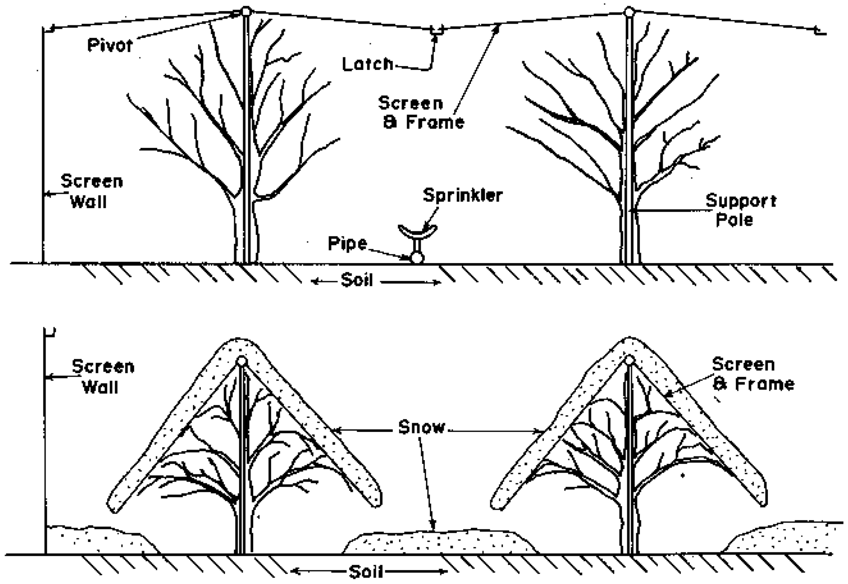

Fig.5. Diagram of a possible screen and sprinkler system for orchard cold protection.

CONCLUSIONS

Enclosing an orchard under a metal screen cover would be expensive, but if petroleum-based fuel costs continue to rise, as well as land values in the areas now suitable for fruit production, the use of screen with a sprinkler system may become economically feasible. A large degree of cold protection is possible, and a screen cover does have a number of potential advantages not inherent to orchard heaters and wind machines (Table I).

Prototype systems like the one sketched in Fig.5 need to be studied in areas with different climatic conditions. Information is particularly needed on:

(1) The effects of screen shading on growth and production.
(2) The effects of a screen cover on ecological systems associated with fruit production, particularly with respect to insects and disease.
(3) The specifications for the most efficient screen size and support system.
(4) The specifications for optimum sprinkler design.
(5) The details associated with automation and special management techniques.

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