Table 6. Correlation coefficients for thatch thickness, spring greenup, and spring deadspot with sucrose in rhizomes of bermudagrass at three dates in late winter – early spring, 1976, Columbia, Missouri.

	Correlation coefficient			
		Spring greenup		Spring deadspot
Date	Thatch	April 14	May 19	June 2
March 8	0.12	0.30*	0.23	–0.33**
April 22	0.31*	–0.05	–0.05	–0.17
May 10	0.09	0.13	–0.06	0.02

*,**Significant at 5% (*) or 1% (**) levels.

In conclusion, our observations show that rhizomes of bermudagrass vary widely among cultivars in numbers and form. These factors should be considered in choosing cultivars for specific uses and environments. Thatching tendency also varies among cultivars, and the depth of thatch was associated negatively with spring greenup. Spring deadspot was less severe where entries utilized stored carbohydrate and greened early.

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Conserving Water in Sprinkling for Frost Protection by Intermittent Application[1]

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Additional index words. frost protection, water conservation, cold protection, overhead irrigation, pulsing

Abstract. **Adjustment of the sprinkling application rate to existing atmospheric conditions to conserve water may be accomplished by turning systems on and off. The maximum off period that is tolerable is calculated. It is the sum of time required to freeze the applied water plus time during which the ice coated plant parts cool to the critical temperature. Values of the off period for typical frost conditions are proportional to wind speed and wet bulb temperature. Field test results indicate intermittent sprinkling provides a method to reduce water consumption in sprinkling for frost protection.**

During sprinkling for frost protection, an interval between wettings naturally occurs in most sprinkling systems currently in use because the sprinkler heads rotate. Two sprinkling rate models, one by J. A. Businger (2) and a related one by J. F. Gerber and D. S. Harrison (4), include equations which determine the maximum time which may elapse between wettings which does not allow the plant part to cool below the critical temperature where damage occurs. Pulsing sprinkling systems by turning them on and off to achieve greater efficiency, i.e. use less water for adequate protection, was suggested by Martsolf (5). By pulsing, a system becomes a variable rate system with which the application rate may be varied to meet existing atmospheric conditions. Minimizing the application rate helps reduce limb breakage from ice-buildup and "wet feet" associated with sprinkling for frost protection.

Materials and Methods

Determination of the appropriate pulsing cycle. Pulsing takes advantage of the margin between 0°C and the critical temperature by turning the system off between wettings and allowing the plant part to cool toward the critical temperature (Fig. 1). This off period must be sufficiently long to conserve water, but not so long that the plant part cools below the critical temperature. It is the sum of the time required to freeze the applied water (t_1), and time during which the ice-coated plant part cools to the critical temperature (t_2).

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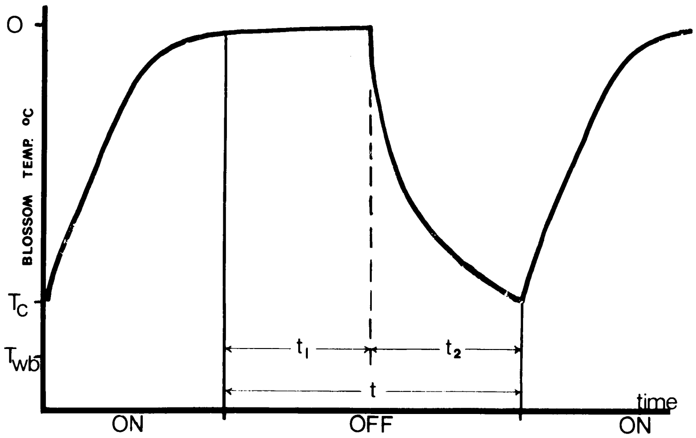

Fig. 1. Theoretical blossom temperature during pulsing where t_1, freezing period, plus t_2, cooling period, equal t, the total off period of the pulsing cycle. T_c is critical temperature of the blossom and T_{wb} is wet bulb temperature.

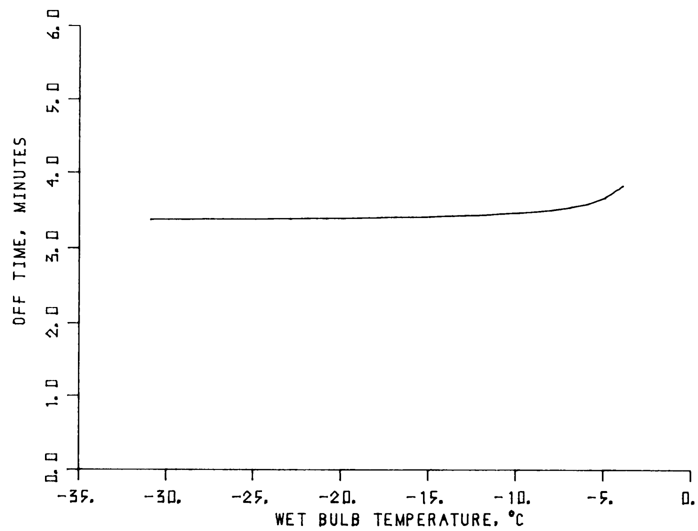

Fig. 2. Maximum off time for a pulsing cycle as a function of wet bulb temperature.

The equation to determine off time published by Businger (2) is the same as the equation used here (Eq. 1), except for 2 changes. First, the dry leaf temperature (T_1) was replaced by the critical temperature (T_c) in determining the freezing period, t_1, because the plant part is at the critical temperature, not dry leaf temperature, when this freezing period begins. Second, the dry leaf temperature was replaced by the wet bulb temperature (T_{wb}) in determining the cooling time, t_2, because the plant part is cooling toward the wet bulb temperature (9).

To use Eq. 1, the following assumptions are made.

1. Water arrives at the plant at 0^oC, completely liquid (4).
2. Radiation balance does not change due to sprinkling.
3. Temperature remains at the triple point of water until all water is frozen.
4. Temperature of the ice-covered plant part is uniform. Possible thermal gradients in the plant part or ice coating are neglected.

The shape, heat capacity and size of the plant part being protected may be varied in the determination of the off time by varying the parameters used to calculate the convective heat transfer coefficient, h_c, i.e. the Nusselt number, Nu, heat capacity, C, and characteristic dimension, D. The local moisture content of the air is designated through the wet bulb temperature, T_{wb}.

$$t = t_1 + t_2 = \frac{0.06}{A(T_o - T_c)} + \frac{C}{AL_i} \ln \frac{T_o - T_{wb}}{T_c - T_{wb}} \quad \text{[Eq. 1]}$$

In Eq. 1, T_o is 0^oC; T_c is critical temperature determined as in Ballard, et al. (1); L_i is the latent heat of fusion; T_{wb} is the wet bulb temperature and C is the heat capacity of the plant part taken to be 0.2 cal/(cm^2 ^oC). A is a composite of the radiative, convective, and evaporative heat transfer coefficients.

$$A = (2/L_i)(h_r + h_c + h_e) \quad \text{[Eq. 2]}$$

The radiative heat transfer coefficient h_r, equals $4\sigma T_a^3$ (3, 6) (σ = Stefan-Boltzmann constant = 1.355×10^{-12} cal/(cm^2 secK^4)).

There are numerous sources in which one can find methods for determining the convective heat transfer coefficient, h_c, (1, 2, 5, 6, 7). A procedure described by Monteith (7) and Gates (2) is followed here. The coefficient h_c forms part of the Nusselt number, Nu, a nondimensional value describing the ratio of the characteristic dimension, D, to the boundary layer thickness, d. Since $d = c/h_c$ (7),

$$h_c = \frac{c\,Nu}{D} \quad \text{[Eq. 3]}$$

where c is the thermal conductivity of air (at 0^oC, c = 5.78×10^{-5} cal cm^{-1} sec^{-1} C^{-1}). Gates (2) and Monteith (7) present the following evaluation for Nu for the case of a flat plate in forced convection in laminar flow:

$$Nu = .664\,(Re)^{1/2}\,(Pr)^{1/3} \quad \text{[Eq. 4]}$$

where Re = Reynolds number = (vD)/u (v = wind velocity, u = kinematic viscosity = 0.133 cm^2/sec) and Pr = Prandtl number = ($C_p\, \rho$ u)/c, (Cp = specific heat of air, ρ = density of air). Once the Nusselt number has been determined h_c may be calculated from Eq. 3.

Monteith (7) and McAdams (5) also present equations to determine Nu for cylinders and spheres in forced convection.

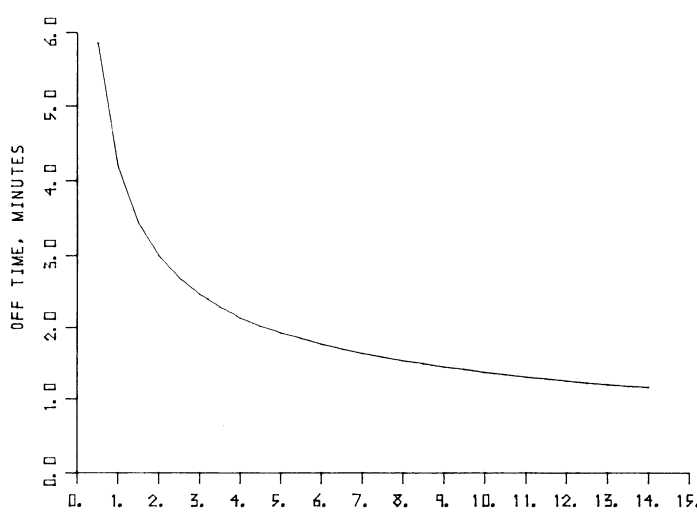

Fig. 3. Maximum off time for a pulsing cycle as a function of wind speed.

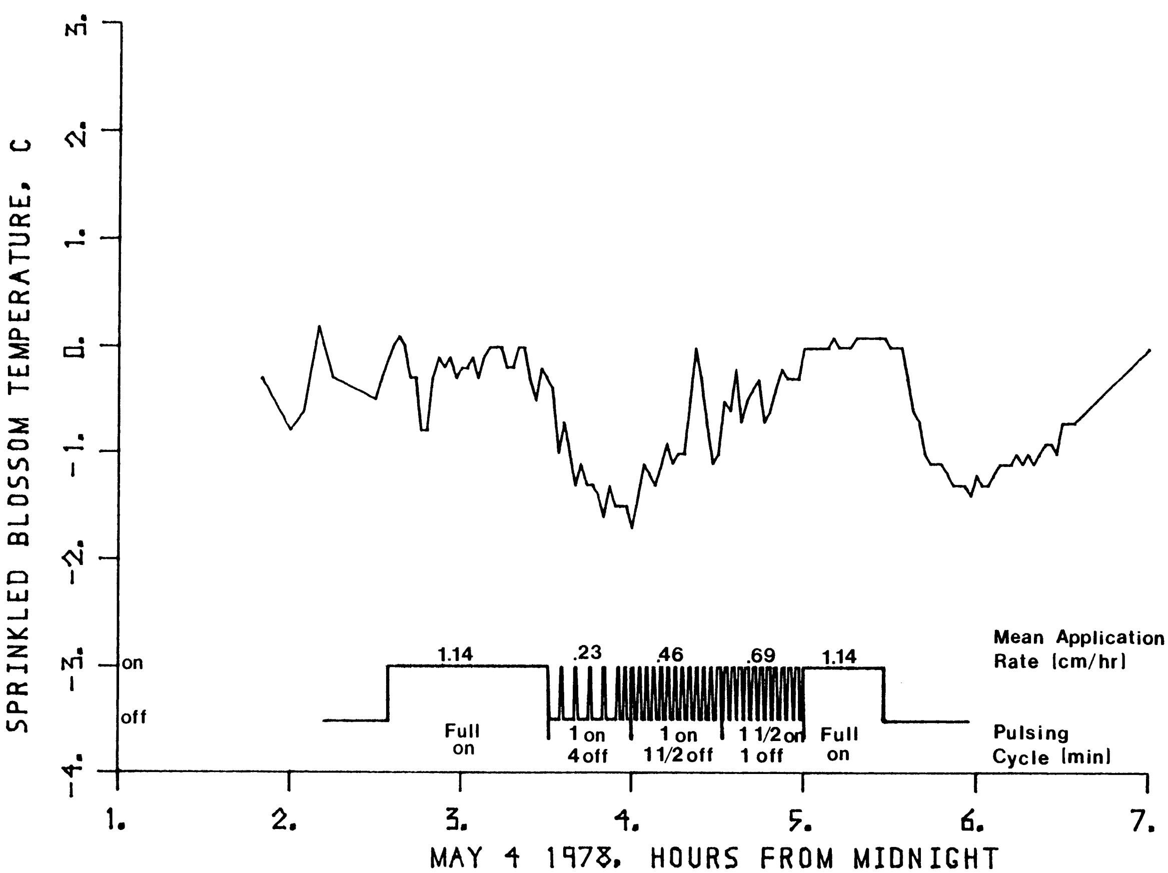

Fig. 4. Sprinkled blossom temperature, mean application rate, and pulsing cycle vs. time during a 1978 frost.

These are useful in considering twigs (cylinders) and blossoms on young fruit (spheres).

The method used to calculate the evaporative heat transfer coefficient, h_e is as follows:

$$h_e = LE/(T_c - T_a) \quad \text{[Eq. 5]}$$

Monteith (7) states that, if the state of the surface is given by T_c, critical leaf temperature, and e_c, vapor pressure at leaf surface, and the state of the air by T_a, air temperature, and e_a, vapor pressure of air, the latent heat loss, LE, from the leaf is:

$$LE = [(2\rho C_p)/\gamma]\,[e_c - e_a)/r_v] \quad \text{[Eq. 6]}$$

(γ = psychrometer constant = .646 mbar C^{-1} at 0^oC (7) and r_v = diffusion resistance for water vapor (7).)

Two important parameters involved in determining the off time are the wet bulb temperature and the wind speed. Wind speed is involved in the determination of A through the heat loss coefficients. As the humidity increases, i.e. T_{wb} increases, the off time is increased, because less evaporative cooling occurs (Fig. 2). As the wind speed increases, however, the off time decreases, due to increased rate of heat loss (Fig. 3).

Field tests. Sprinkled and unsprinkled apple blossom temperatures were monitored by thermocouples during intermittent sprinkling for frost protection at the Rock Springs Agricultural Research Center located in central Pennsylvania. In addition, application rates and pulsing cycles were recorded (Fig. 4). One half of the 0.7 ha apple orchard is equipped with individual sprinklers (Reed Irrigation Systems, Inc., Browning sprinklers with 07 nozzles) over each tree (set 3 x 5.5 m). The sprinklers were pulsed on and off by electronically controlled solenoid valves connected to an automatic timer.

Results

Fig. 4 depicts the temperature of a sprinkled blossom and corresponding application rates and pulsing cycles during a May 4, 1978 frost. The time period of most interest is between 3:30 and 4:30 AM. To examine this period more closely, a section of Fig. 4 has been expanded (Fig. 5).

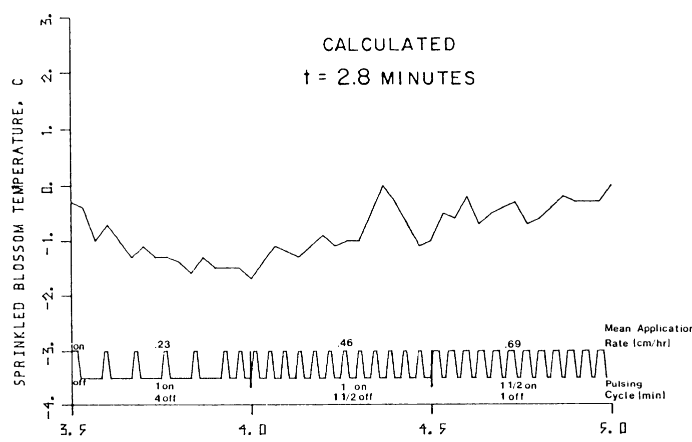

Fig. 5. Expanded period from 3:30-5:00 AM for a sprinkled blossom temperature, mean application rate, and pulsing cycle vs. time during a 1978 frost.

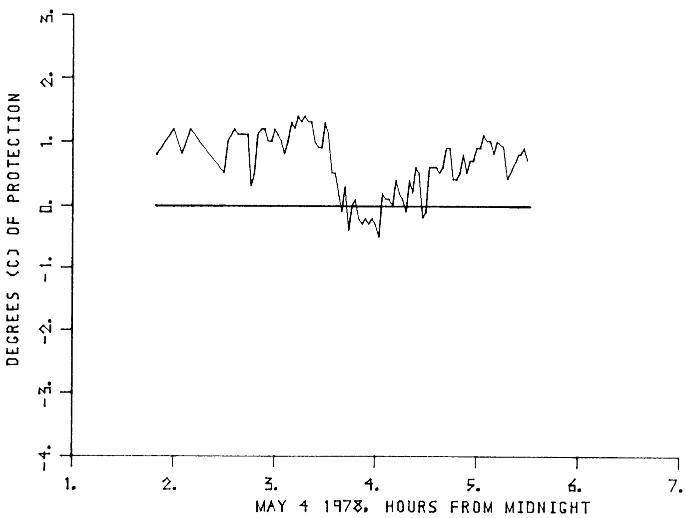

Fig. 6. Average degrees of protection provided by sprinkling during 1978 frost.

During the period between 3:30 and 4:00 (Fig. 5), although the sprinkling rate was adequate, the 4 min off time was too long and allowed the blossom to cool more than it could warm during the on period and subsequent freezing period. Therefore, overall cooling occurred. During the period of 4:00 to 4:30 the off time of 1.5 min did provide protection. Thus one can conclude the optimum off time to be between 1.5 and 4.0 min. Eq. 1 predicts a maximum off time of 2.8 min for the existing conditions. Although this particular off time was not observed, it is within the limits determined from the data. Granting the data does not provide decisive evidence for the predicted 2.8 min off time, even at the lower limit of 1.5 min a 60% reduction in application rate from 1.14 to 0.46 cm/hr is obtained.

Another way to view the effect of sprinkling and pulsing is to consider degrees of protection. Degrees of protection are the degrees a representative sprinkled blossom is above a representative unsprinkled blossom (Fig. 6). Between 3:30 and 4:00, no protection was provided, but between 4:00 and 4:30 the blossom was protected. This demonstrates the importance of the appropriate pulsing cycle, even when the application rate is sufficient.

Pulsing provides a method by which the amount of water required for sprinkling for frost protection may be reduced. However, it is essential to not only determine the appropriate amount of water to be applied, but also the appropriate pulsing cycle to make it work successfully.

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Turbulent Heat Fluxes above a Heated Orchard[1]

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Additional index words. frost protection, orchard microclimatology, turbulent heat fluxes

Abstract. **Spatial and temporal components of the turbulent heat flux above a heated orchard are discussed. Direct measurements of the temporal component of the turbulent flux at 2 locations are reported. Drag anemometry and fine-wire thermocouples provided measurements of u, v, w, and T at 30 Hz. About 10% of the energy provided by heating escaped the crop zone by the temporal flux. Variation in the flux measured at a given location was caused by changes in wind speed and direction, and heater proximity.**

Rising fuel costs and the uncertainty of supply at any price necessitate maximizing the efficiency of orchard heating. The USDA estimates over 6 million barrels of oil are burned annually to protect fruit crops from cold (E. E. Garett, personal communication). Ways of conserving some of this oil should result from study of current orchard heating techniques. Martsolf and Panofsky (3) developed a complete energy budget for a hypothetical box of dimensions dxdydz containing a heated orchard. Transport of energy through the facets of the box was via 3 fluxes: radiation divergence, mean flow, and turbulent mixing. The turbulent heat transport at the top of the box was written (3):

$$Q = -\rho c_p \iint \overline{w'T'}\, dxdy \qquad \text{[Eq. 1]}$$

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