Winter Management and Hardiness
Using Finite Element Analysis to model Heat Transfer During and After the Winter Flood

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Introduction

Winter flooding of cranberry beds is a traditional protection technique from dangerously low winter air temperatures. Cold hardiness data gathered in previous years via laboratory research has determined that even dormant uprights possess a critical temperature at which the cells become damaged, thus effecting the next year's growth and yield. Temperature under the ice within the airspace has been measured and determined to be at or just below freezing. But the temperatures within the ice, where the uprights and buds are encased are not well documented. Various weather conditions and ice cover also play an important role in determining the temperature in this critical zone. By developing a model using a process called *Finite Element Analysis,* we produced a rudimentary model that can determine the effects of various environmental conditions on the uprights encased in ice.

Finite Element Analysis

Finite Element Analysis is a tool that may be used to model complex systems or systems in which a large variety of small factors play a role in determining the outcome of that system. By dividing the system into small or finite pieces, the tool may calculate each tiny piece and its related stimuli, obtain a result, and recombine the pieces into the whole. The researcher may then visualize this complex system and make alterations of the stimuli to witness the variable outcome. The tool used in this experiment is called *FEHT,* or Finite Element Heat Transfer. Developed at the University of Wisconsin Solar Energy Lab, FEHT allows the user to enter specific physical properties of the materials being studied, the conditions under which the materials are observed, and the time frame in which the materials should be constrained.

Materials, Conditions, and Time

This study used a cranberry bed, viewed in cross section with varying soil types under saturation or field capacity as well as differing temperature regimes. Daily air temperature was obtained from a field weather station on or near the typical date of flooding with low air temperatures reaching -13°F. Two sets of models, one containing a bed as the flood goes on and the other after ice has formed and water has been drained away. Two basic soil types (sand and peat) were generated as the primary bed material. Loam was used for dike material in both models. The base temperature data were altered by +10 and +20°F to obtain medium and warm day simulations. Incident solar radiation and wind speed remained constant throughout the three temperature regimes.

Soil Properties

Three physical properties govern the activity of soil under the pre-determined environmental conditions. Density determines how much of a mass of a given substance is packed into a given volume. Specific heat is a measure of the energy required to raise 1 gram of a material 1°celcius, and thermal conductivity is a measure of the amount of energy transmittable through a material via molecular bonds. However, the situations we wished to model required calculation and or slight alterations to the materials utilized. Different coefficients were required for saturated versus field capacity conditions.

Environmental Factors

In order to construct accurate models the interaction of the environment upon the model must be taken into account. It also must be understood that no environment may be modeled exactly, resulting in minor adjustments and assumptions. For our situation, we simulated full winter sun at a low angle of incidence. Wind data was retrieved from weather stations in the vicinity of cranberry marshes and extrapolated to the appropriate height. As stated earlier, air temperature data was collected from the same weather station and all components were linked together via a computer program that allowed the conditions to be looped in 24 hour segments, simulating daily fluctuations in temperature, wind and light levels.

With all models, some assumptions must be made, for a fragment of the data needed to construct a complete model may not be easily accessible or have not been collected. We made assumptions, based on material properties of cellulose wood fiber, percent water in the uprights during dormancy and relative proportion of the upright encased in ice and determined that the plant mass would contribute little if any to the heat flow from the ice to the soil. In fact, the plant mass may offer insulating value, but this remains to be tested.

Results

Two ice scenarios and two soil scenarios as well as the initial flooding event were computed by FEHT. The data from these models appear below. The initial flood model described the freezing activity of the flood when applied to a frozen bed, and air temperature at -4 F (-20°C). The first Ice scenario models the effects of diurnal environmental fluctuations on the temperature of the air space under the ice, soil temperature, and temperature within the ice in a range approximating the location of encased uprights with a thin protection (8 inches) of ice. The second model observes the same conditions except with thick ice (16 inches). Both ice models were calculated under cold (- 13 F), medium (5 F), and high (23 F) temperatures.

Temperature thin ice and high temperature regime

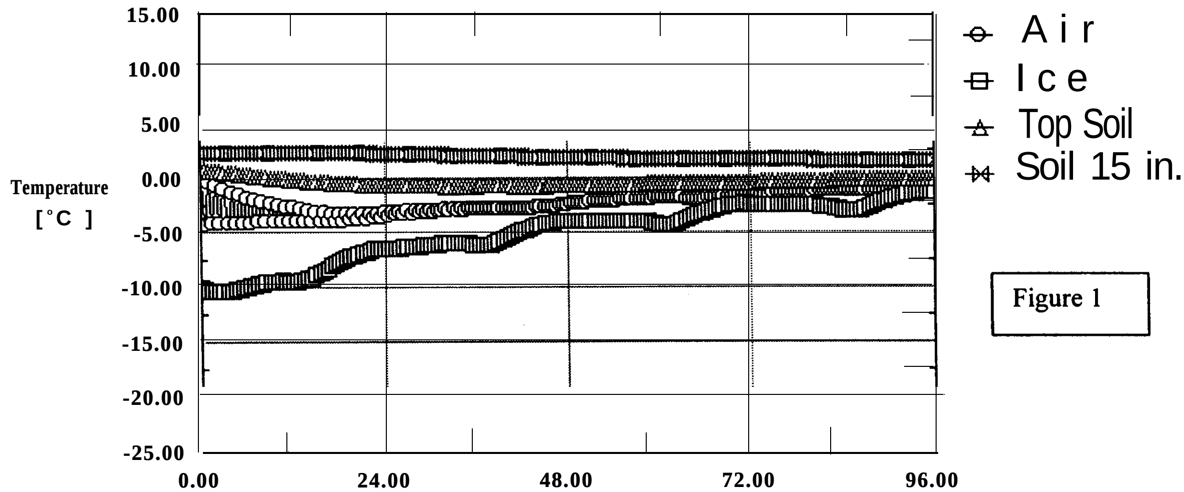

Figure 1

Figure one shows temperature fluctuations of the inter-nodal ice, air gap, soil surface and 15 cm beneath soil surface under thin ice and high temperature regime. Outside air temperature of 23 F (-5 C) is relatively warm a winter scenario but not unheard of. The chart shows fluctuation over a 96-hour (four-day) period. The fluctuation of air gap temperature is contributed to by equilibration of the air and heat flux emanating from the soil and the heat sink of the ice layer. However, after 96 hours the soil temperature only drops to 27 F (-3 C), which is consistent with data gathered in the field under an ice sheet as seen in figure 3.

Thick Ice and Low Temperature Regime

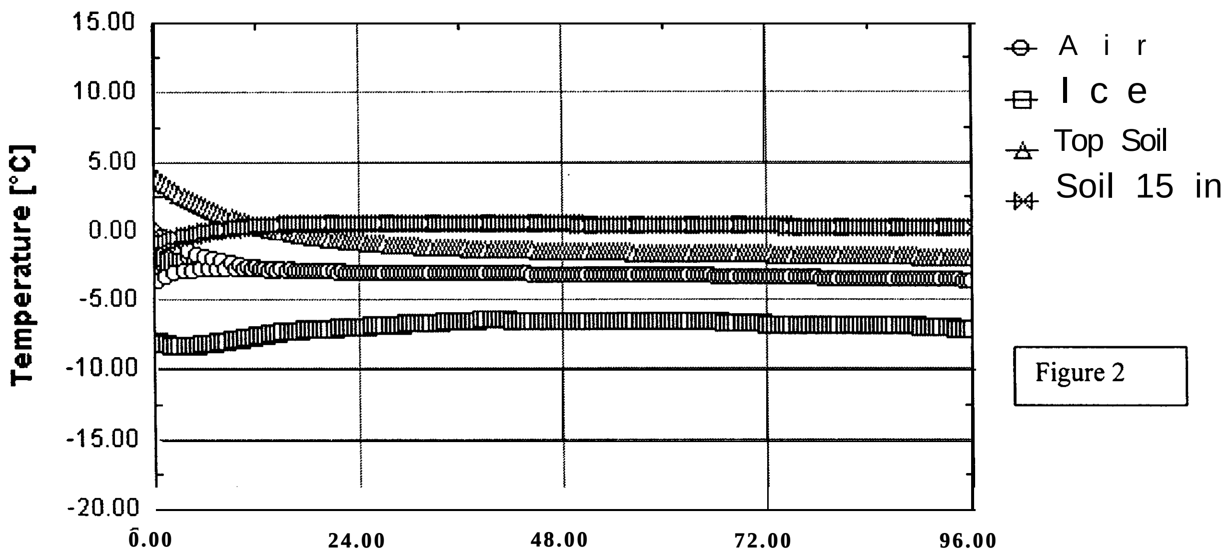

Figure 2

Figure 2 depicts the activity of a thick ice scenario (16 inches) under low temperature (-13 F or -25 C) condition. Once again, the gap air temperature shows a large fluctuation until it equilibrates with the soil and ice temperatures. But the gap air temperature, even with the coldest regime and largest ice insulation, remains within the tolerance of field data in figure 3.

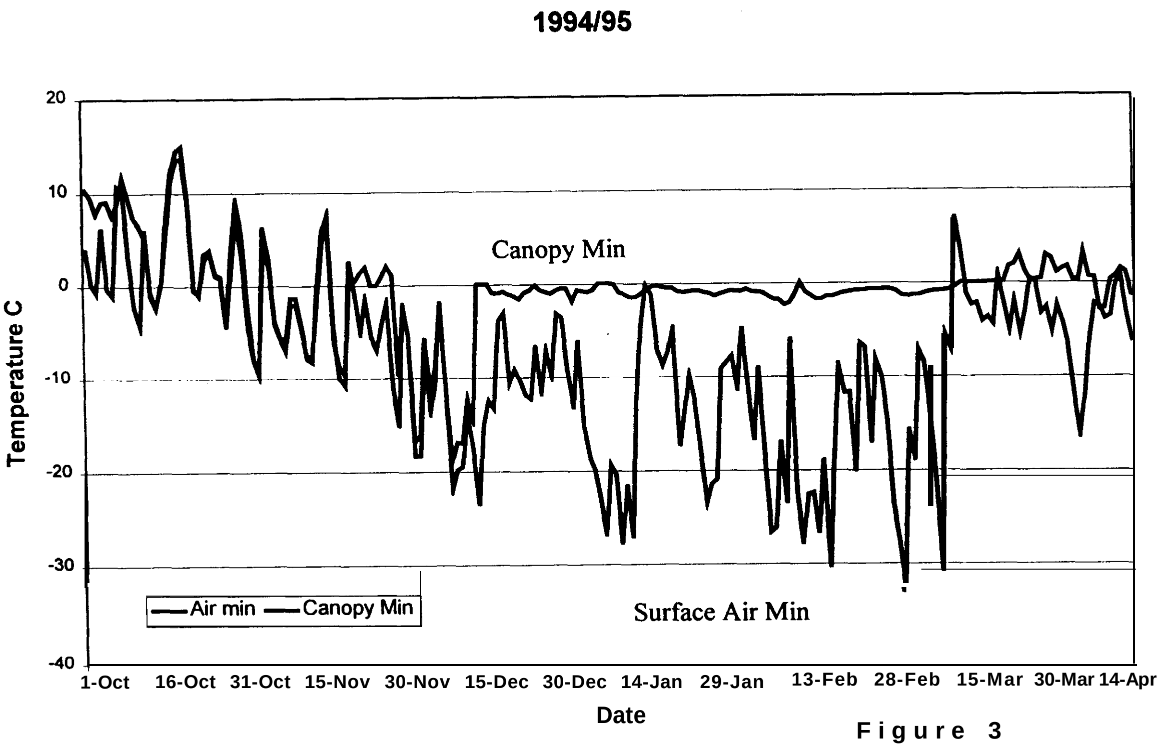

Figure 3

The following chart describes the temperature expected under the ice in the air gap as modeled by FEHT.

	Low	Medium	High
Thin Ice	23 F	25 F	30 F
Thick Ice	25 F	27 F	28 F

Chart 1

Chart 2 describes the temperature regime experience by cranberry uprights as they are encased in ice during winter freeze determined by FEHT.

	Low	Medium	High
Thin	1OF	19 F	30 F
Thick	19F	21 F	23 F

Chart 2

Chart 3 describes the mid-winter survival temperature of leaves and buds as determined by laboratory experiments.

	3/97	2/98
Leaves	14	-4
Buds	-4	-8

Chart 3

It is evident that the ice offers more insulation as it becomes thicker. Also, the temperature within the bud-ice zone is well above the lowest survival temperature as determined in the laboratory, even under the thin ice scenario.

Conclusion

Finite Element Heat Transfer has proven that is may be a useful tool in modeling the activity of a freezing cranberry bed during and after the winter flood. By entering parameters specific to each material to be modeled, and including interactive effects of environmental conditions a researcher is able to accurately predict temperatures in the air gap, at and below the soil surface and within the critical zone where the uprights and buds are encased in ice. This information with data gathered concerning bud hardiness, we have shown that varying thickness of ice sheets in conjunction with cold and warm winter air temperatures is a distinct modeling possibility, offering insight to various management practices. Future models include the addition of snow cover, sand cover, possible inclusion of plant material, and field data pertaining to soil temperatures at specific depths.