Frost protection of any crop can prove expensive. Use of frost hardiness data to limit the use of that protection can prove to provide a large savings for the nurseryman. The browning technique for determining frost hardiness is very simple and straightforward and should be readily adapted to most woody plants.

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FOAMS FOR FREEZE DAMAGE CONTROL IN CONTAINER NURSERIES

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Nurserymen across the Southeastern United States have suffered extensive losses from cold temperatures during the past two winters. The minimum temperatures have been considerably below what is expected for the climatic zones. The worst events were associated with fast moving fronts. The fronts brought high winds as the temperature dropped, then clear cold weather for several days.

Killing weather fronts reach our nurseries only a few times each winter even though they are predicted five to ten times. Much more frequent are freezes associated with clear, cold nights. These events have minimums in the mid-twenties

(0 to -5°C). The following day there is sufficient radiant heating to rewarm the plants well above freezing.

Two Weyerhaeuser Nursery Products Division nurseries, Wight Nurseries, Inc. and Hines Wholesale Nursery, are located in the heart of the problem areas. Although each had a well-managed freeze damage control program, they suffered large losses in 1984 and lesser, but significant, losses in 1985. The primary damage control technique is to "jam" all plants can-tight, wrap the north edge of the beds with paper or poly, and cover sensitive crops with a polyethylene and shadecloth cover. Although effective, the solid poly cover is labor intensive to apply and remove many times each winter.

The Weyerhaeuser Research Development organization was asked to identify and test more appropriate ways to keep container plants from suffering winter kill.

PROBLEM ANALYSIS

It appears that container-grown nursery stock can be killed from either the top down or from the roots up by freezing temperatures. A plant can take a severe beating of the above ground parts and come back to a marketable form as long as it has a vigorous root system. There are a number of cultural techniques available to enhance dormancy in plant tops. However, the cultural management must start early in the fall to be effective. There is no quick dormancy induction treatment. The roots never do go dormant. Root growth and other root activities are slowed by cold temperatures (5). Once the lethal temperature is achieved for the species, the roots die and take the top with them. Even at temperatures above the lethal point, if the soil is frozen, the plant may die from desiccation. This is particularly prevalent on clear days just after a freeze. The air temperature and light levels are causing the plant to transpire but the roots are still encased in a block of soil and ice.

A freeze damage control program must address these three sources of injury:

1. Maintain soil temperature in the cans above the lethal root temperature for the species.
2. Minimize desiccation of the tops when the air warms but the soil is still frozen.
3. Minimize dieback and splitting of the above-ground parts of the plants.

In nursery operations like ours, the possible methods to control freeze damage must be evaluated for practicality when applied on a large scale. While covering an acre or two with poly is practical, covering our hundreds of acres with poly is impractical to do in just a few hours. The key tests of practicality are:

1. Can be applied prior to the winter season at leisure and left in place until spring.
2. Can be applied to large areas in a few hours and be removed before the heat buildup is too much.

It can be expected that a mix of solutions are applicable to different crops and locations within a nursery. The problem for the development team became one of finding or developing a set of solutions which are cost effective on various nursery crops. A search of methods in use and previously developed methods uncovered waterbased foams. A preliminary screening suggested that the foams should offer adequate protection and be applicable to large nurseries.

PREVIOUS WORK

The application of long-lasting foams for freeze protection was proposed in the 1950's for many agricultural crops (1). Many universities and manufacturers studied materials and application methods. Ironically, the flurry of activity was caused by the same type of weather we experienced these past two winters. When the farmers and nurserymen had a few mild winters beginning in 1970, the demand for new frost protection methods dwindled.

A literature search on frost control foams surfaced a number of researchers and manufacturers who were active during the early 1970's (1-4). Dr. Harry Braud at Louisiana State University was one of the principal researchers. A phone call was made to Braud to obtain his current views of the art. He told us that he thought the technology of using foams for frost protection was workable and that he had gotten good results. He was most successful with a protein-based surfactant. When the cost of the protein went way up, the economic benefit for his target crops was lost and he stopped his development work.

Waukesha Foundry, Ibex was active as an equipment manufacturer. They are no longer in the business and told us they had sold the product line to Cellufoam. Cellufoam has limited their efforts to supplying foam chemicals to the foamed concrete industry.

The other equipment developer, DeTer Company, Inc., was our last hope. Upon contact, they told us that they had worked on foams for frost protection as late as 1978. Their current focus is foam and equipment for dust supression, but they still have interest in foam for frost control.

The apparently most successful surfactant in the past had been a product called Agrifoam. Agrifoam was developed for frost protection on plants and had been approved by the Canadian Department of Agriculture for use on plants. The manufacturer, Wormald, Ltd., told us that the product was not in production but they would get us a sample to test.

The information each of our contacts sent us and the personal conversations supported our earlier view that foams may have a place in a multiple approach freeze damage control program. Foams should meet our objective of being able to be applied in most any weather. We should be able to cover large areas quickly with reasonable labor. The key issues appeared to be the effectiveness of available surfactants in various container nursery plant types and the stability of the foams in windy conditions.

EVALUATION TESTS

Since foam generators for frost control were not available, we leased a DeTer dust supression foam generator to use in our tests. DeTer and Wormald were to supply surfactant for the test. If the tests were successful and the economics looked good we would address the equipment design issue. It was agreed with our Nursery Products Division to conduct the evaluation at the Hines Wholesale Nursery in Houston, Texas.

First Field Test. The first field test was held at Hines Nursery on February 21 and 22, 1985. Three plants were selected by site staff for the test. *Buxus microphylla* var. *japonica* liners were located in a protected area between greenhouses. *Photinia* × *fraseri* and *Lagerstroemia* in No. 1 cans were located in large beds out in the open nursery.

Although the Agrifoam sample had not arrived from Canada, we decided to proceed with the test. The weather system did us no favor as the overnight low was not expected to go below freezing. At 10:00 p.m. the temperature finally dropped to 40°F (4.4°C), our target application temperature, and we began to apply the recommended DeTer material. Winds were calm. In each plant type three plots approximately six feet (2 meters) square were covered with 1.5 to 2.0 in. (35 to 50 mm) of foam. In addition, foam was placed against the upwind edge of the bed of plants. An hour later, at 11:00 p.m., the temperature had warmed to 44°F (6.6°C). The covering over the *Buxus* liner bed was still intact and coverage was good. The other two test areas looked intact also. Before sunrise, at 5:30 a.m. the next morning, the test areas were revisited. The *Buxus* liner bed was still well covered both in the center of each plot and on the edges. The *Photinia* had fair coverage in the plots, but the edges were about dissipated. The *Lagerstroemia* was poorly covered. An investigation of why the liner bed area was so good ensued. The foam had developed a frozen crust even though the air temperature was well above freezing. It must have been caused by a combination of radiation heat loss from the surface and below freezing dew point. The protected location prevented much air movement. The low dew point would contribute to the mostly water foam evaporation and lowering the surface temperature to freezing.

This odd twist may be of benefit. If the foam does develop a crust, it will be much more resistant to wind destruction and should reduce the rate of sublimation.

At 6:00 a.m. we again foamed the three locations so we could see what happens to the foam when the sun comes up and shines on it. When the sun came up the foam dissipated in less than an hour. Only a slight residue film was left on the test plants.

We were still encouraged enough to keep the DeTer equipment and wait to test more surfactants. Hopefully the test could be conducted on a colder night. The Hines staff was trained to operate the foam generator so they could be more opportunistic in scheduling the test than we could from Tacoma, Washington.

Results. The night that the foam was tested, the low temperature was 33°F (0.5°C). In the *Buxus* liners, the foam provided 5.5°F (3°C) protection on edge liners and 1°F (0.5°C) in center liners (See Figure 1). The temperature problems were measuring soil temperatures in the liners and one gallon pots. The protection that the foam afforded in the *Photinia* was 1°F warmer with foam than the black poly shielded control pot. We did not quantify the protection that foam gave on center pots in *Photinia* because the probe got accidentally pulled out of the pot during the night when the foam was applied. The probe was sitting in the foam just above the soil in the pot and showed again the phenomenon of the foam freezing although the air temperature was well above freezing. Degree of protection is not really meaningful in this test since the ambient never dropped below freezing. If the ambient had been well below freezing we would expect better protection.

Second Field Test. When the new surfactant samples arrived in Houston from Wormald and DeTer, the foam equipment was set up and the second field test was conducted. Again several different plant types were foamed.

These tests were conducted during the second week in March when the temperature was in the low 60's°F (16 to 17°C). There were five surfactants tested. Millifoam and Millifoam 130 made by Onyx, DeTer 4027 and DeTer 1010 (foam

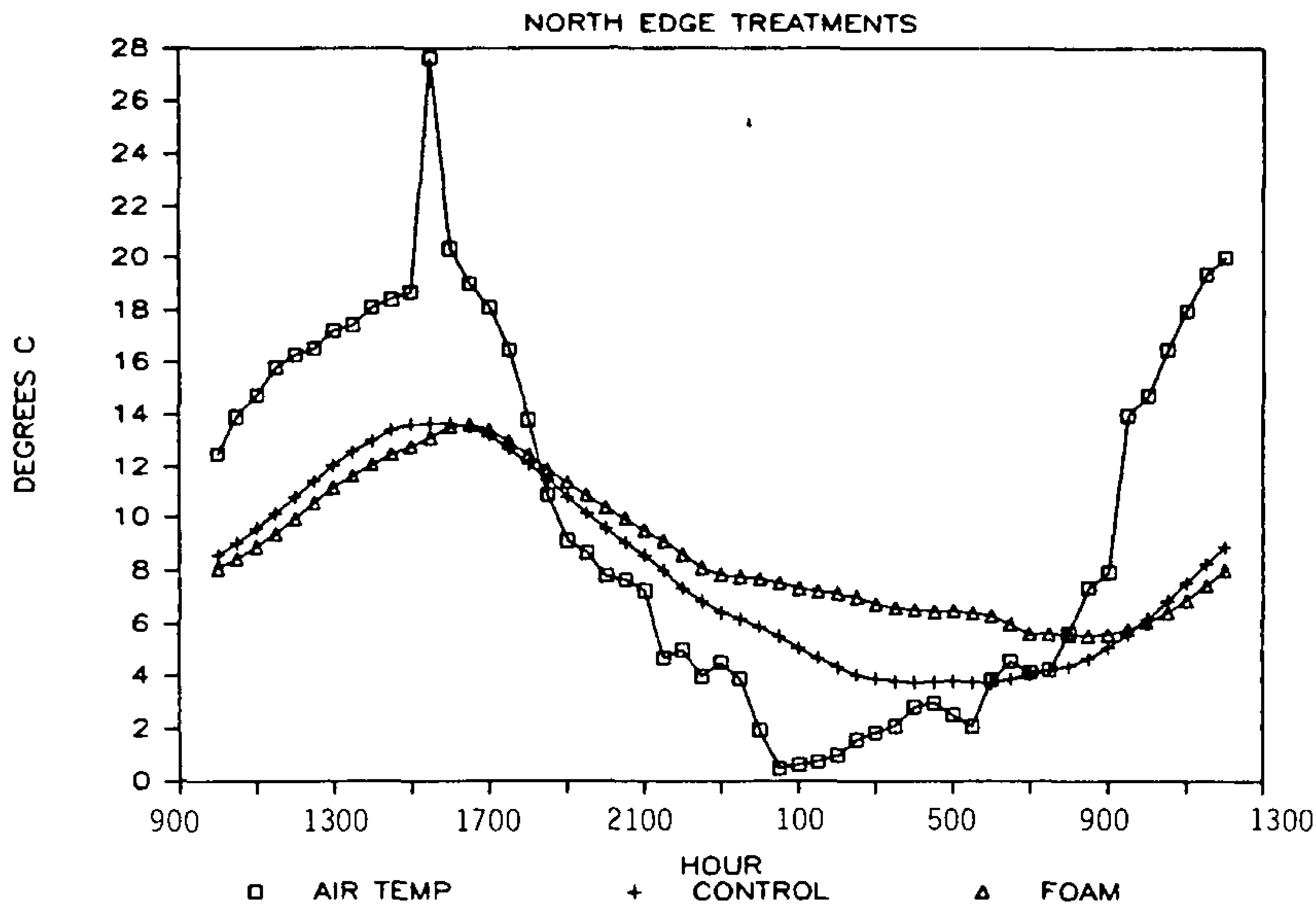

Figure 1. Temperature curves from first field test of foam applied to *Buxus microphylla* var. *japonica* liners.

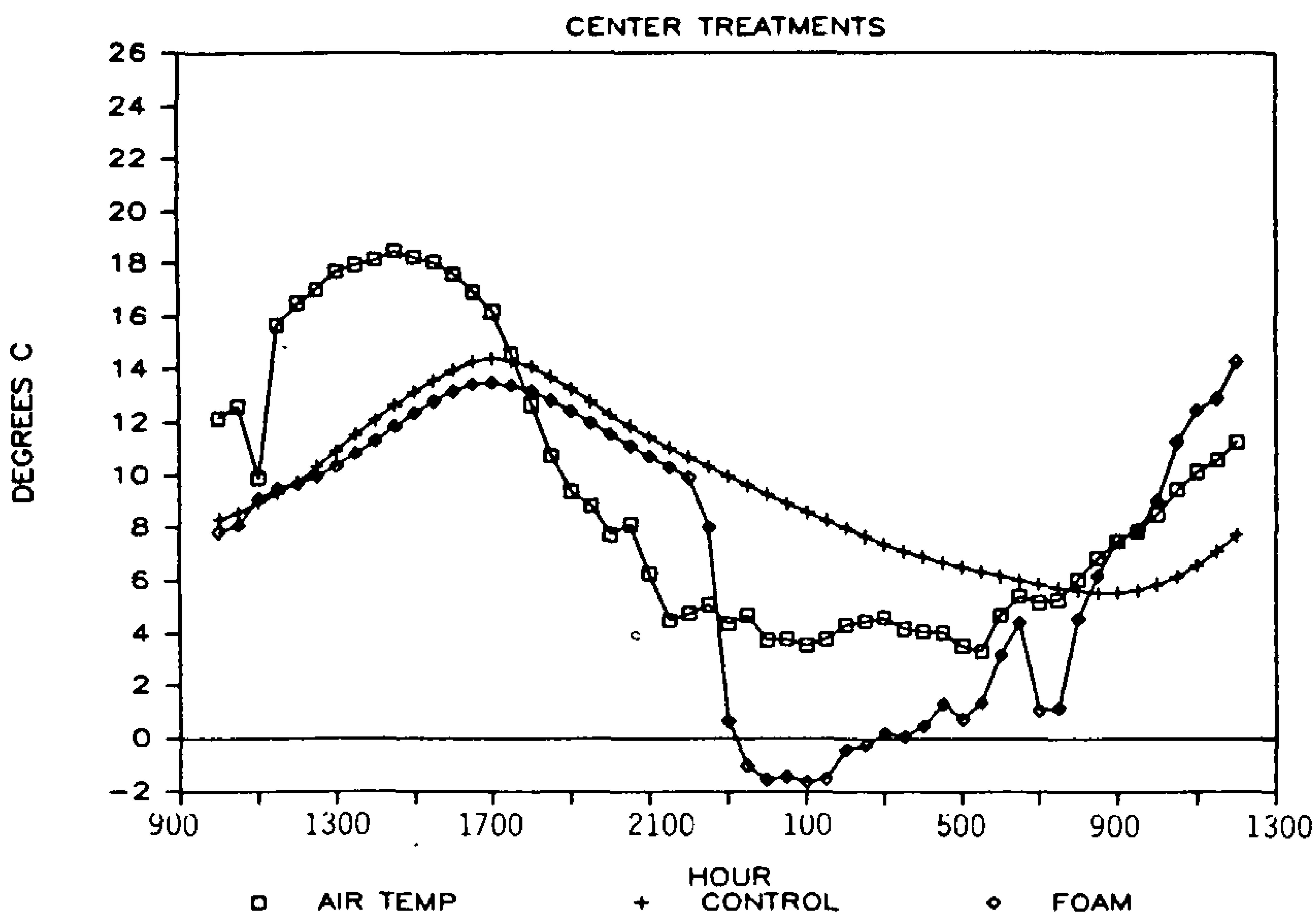

Figure 2. Temperature curves from first field test of foam applied to #1 *Photinia* × *fraseri*. Notice foam temperature drop below freezing even though air temperature was +3°C.

used in February tests), and Agrifoam. Each foam was applied to five different plants; *Buxus microphylla* var. *japonica*, *Lagerstroemia*, *Ligustrum*, *Lonicera*, and *Nandina domestica* 'Nana.' After application, the *Lonicera* showed some leaf drop and the *Lagerstroemia* showed some tip burn with both Millifoam samples and the DeTer 1010 material. No plants were killed. The DeTer 4027 and the Agrifoam caused no ill effects. The DeTer 4027 and 1010 and both Millifoam samples all are short lived foams. During the March test they all dissipated in less than an hour. The Agrifoam was much more stable and had noticeably more body to it. Even in the warm temperatures, the Agrifoam was stable for most of the day. Also, a sample of each foam was collected and frozen in a freezer. All foams, except Agrifoam, reduced in volume and left a thin frozen layer. The Agrifoam froze as a solid mass without any noticeable reduction in volume. Overall, Agrifoam exhibited the best physical characteristics for protecting plants of all the foams tested.

Cost of Foam for Frost Protection. Based on the surfactant used during our field trial, the cost of the foam itself is not great. With a material cost of 0.01-0.02 cents per cubic foot of foam, it would cost $1.60 per inch of thickness per 1000 square feet. That equals about $140 per acre for a two-in. foam blanket. These costs represent only the cost of the surfactant. They assume that water is available and very inexpensive. There are no labor costs or equipment costs included.

CONCLUSIONS

At the conclusion of our field testing and after reviewing our results, we were convinced of the practicality of a foam frost control system to protect plants in one of our nurseries. The cost does not appear prohibitive when compared with the cost of covering and uncovering a nursery bed with poly several times per year. The stumbling block may be the development of equipment to apply the foam over a large area in a short time.

Although foam systems are exciting, we refocused our attention and resources to evaluate non-woven materials as structureless bed covers. Such covers, if effective, could be left in place for long period of time. Compared to applying foam at each freezing event, non-woven bed covers may be as economical, especially when we include the necessary cost to develop foam application equipment.

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KEEPING PLANTS WARM WITH COVERS

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For the past five years we have used a practical and inexpensive system for protecting container nursery stock during the most severe periods of winter, i.e. late December to late February. The procedure involves laying white 4 mil. plastic directly on top of the plants.

The Development. Our standard practice is to overwinter plants in unheated plastic houses; however, to overcome the high construction cost involved, we began to investigate structureless systems such as Gouin's Microfoam (1). This effective practice was discarded because Microfoam is available only in narrow widths and the material is costly. In addition, I could not see my way clear to lay several hundred thousand plants on their side and then have the monumental task of setting everything back up again the following spring.

I constantly asked myself, "What purpose does the poly-house provide that can't be done by poly alone"? I realize that there are many complex factors that are involved but the one function I kept coming up with is that the poly-house provides a means of holding the plastic cover in place.

The System. Before covering, to help reduce the possibility of a fungus problem, we apply a shotgun fungicide mixture of Benlate, Manzate 200, and Daconil. A thorough watering just prior to covering is necessary because you will not be able to get to the plants for the next several months.

In our area late December through mid-February is the time of our most severe freezes and is our period of covering. To expedite the covering process we constructed a 3-point tractor mounted pipe boom that extends half way across our standard 17 ft. wide bed. A 20 ft. roll of 4 mil. white plastic is put over the pipe and the tractor travels down a roadway adjacent to the bed unrolling the poly directly over the plants.