many of the points mentioned before, supervision is almost synonymous with quality in finding out quickly, and at the right time, what has to be done, and how it has to be done.

12. *Timing*: If timing is going to play a large part in the production of quality in container stock—as it really does—it is also the big key to larger profits. If what has to be done in the production of container-grown nursery stock is not timed properly, you can be assured that quality will be reduced as well as profits. On the contrary, if everything can be done at the proper time— whether it is planting, watering, feeding, spraying or dusting, pinching, spacing, weeding, and winter protection, you can be certain to harvest both quality and profits.

MODERATOR MAIRE: Our next speaker comes to us from Washington State University at Pullman. He has been there for a couple of years in research and teaching and has been doing considerable work in the ornamental field. He has been in the nursery business all his life, most of the time in Minnesota. He is going to talk to us this morning on soil temperature in container-growing. Dr. Charles Pfeiffer:

SOIL TEMPERATURE CONDITIONS IN CONTAINER-GROWN PLANTS[1]

CHARLES PFEIFFER AND ALAN PETTIBONE
Department of Horticulture and Department of Agricultural Engineering, Washington State University, Pullman, Washington

INTRODUCTION

Injury of container-grown ornamental plants often occurs during severe winters. Commercial nurserymen have long sought to prevent this loss by over-winter storage in protected areas, use of various mulches, or covering containers with polyethylene tents. Over-wintering problems have often limited the utilization of container-growing in northern climates.

Winter injury or death has been attributed to intercellular or intracellular freezing within the plant, tissue desiccation due to transpiration exceeding water absorption, a combination of these (5, 11), and the result of rapid temperature fluctuation of the tissue (9). Maximov (7) proposed that the question of temperature influence on the root needed further investigation. He postulated that plants from different ecological groups would respond differently. Later Doring (4) found woody plants with early spring leaf development and flowering were not influenced as much by soil temperature as plants with the late spring development.

---

[1] Scientific Paper No 3063, Washington Agricultural Experiment Station, Pullman, Washington, Project No 1289

The assistance of Mr Marlin Edwards for maintaining the temperature recording equipment used during this work is gratefully acknowledged

Support of this work by Mr Bruce Briggs, Briggs Nursery, Olympia, Washington, is gratefully acknowledged

This paper defines prevailing soil temperature conditions of container-grown plants in Western Washington.

MATERIALS AND METHODS

The experiment was established at Briggs Nursery, Olympia, Washington, on September 20 1966. The original design (Figure 1) consisted of 2 plots of 100 containers of 1-year-old *Juniperus sabina* 'Tamariscifolia' grown in metal nursery cans situated pot to pot. The growing medium used in the container was a mixture of shredded hemlock bark (80%) and spent hops (20%). Two multipoint strip chart recorders, each equipped with 16 copper-constantan thermocouples (TC), were employed to record soil temperature data. Thermocouples were distributed within each plot (Figure 1) with point

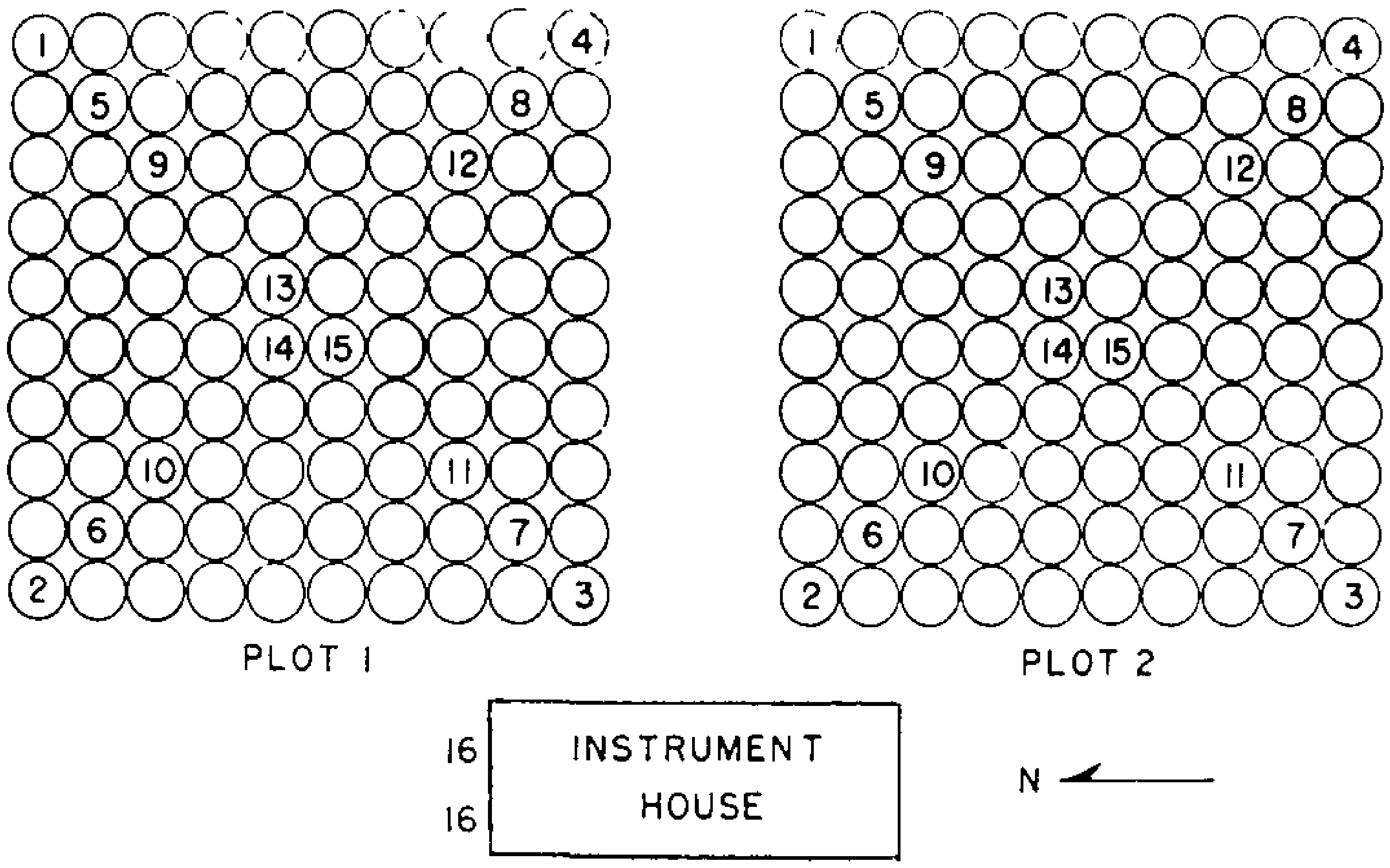

Figure 1 Plot layout and thermocouple locations

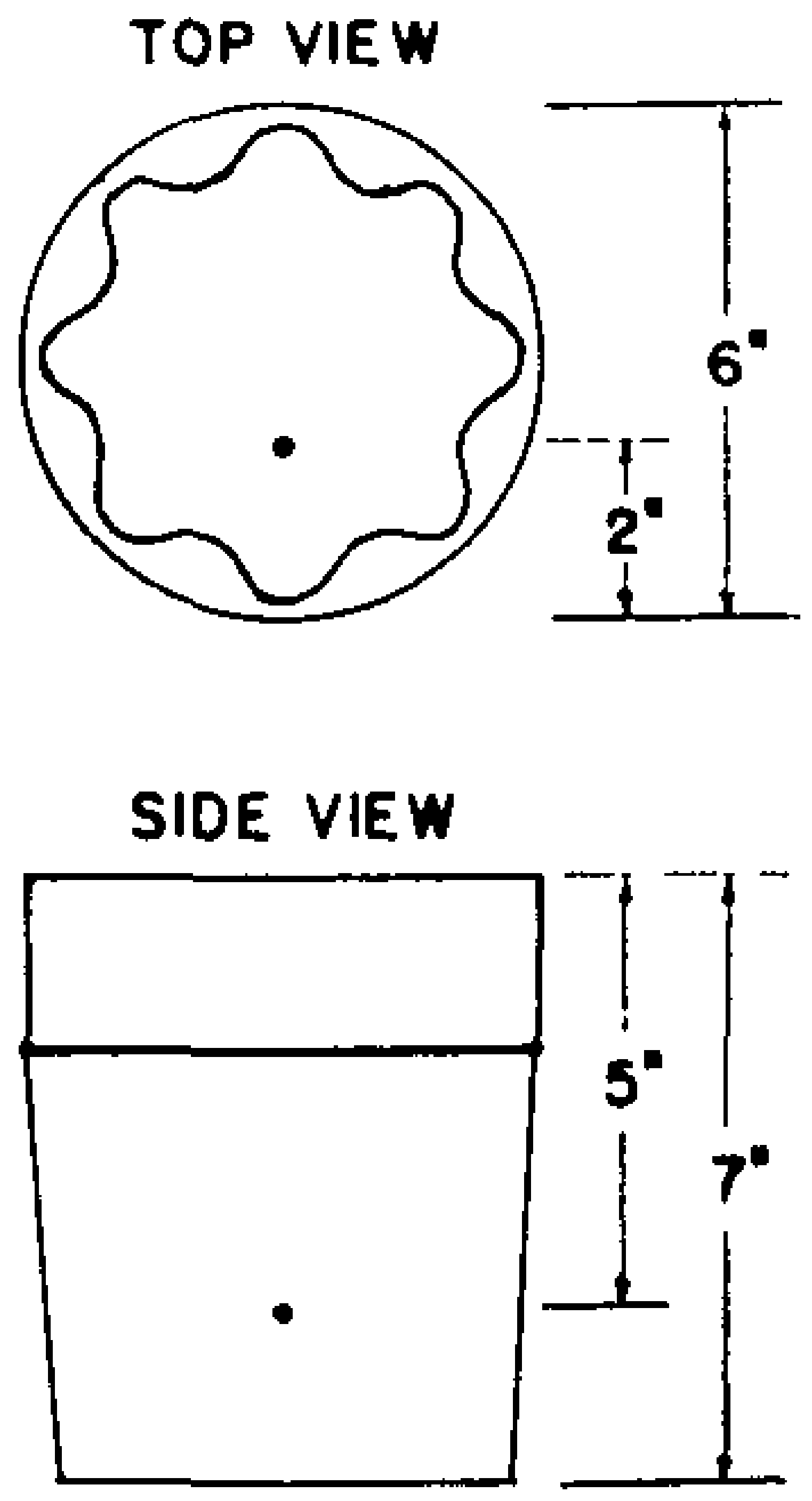

Figure 2. Thermocouple position in container.

16 recording air temperature at 16 inches above ground. Thermocouples were placed in each monitored container two inches in from the south side and five inches below the top edge of the container (Figure 2). Temperatures were recorded hourly. Plot 1 was covered with a polyethylene cover during the winter season to obtain the information regarding the variation of soil temperature between covered and uncovered plots of cans.

The first two-weeks data indicated the need for one additional plot which was established on October 13, 1966. This plot was established as the others with the exception that a single layer of reflective foil (asphalt coated Kraft paper covered on both sides with aluminum foil), the height of the cans, was wrapped around the periphery of this group of cans.

Thus a total of three plots were established. Plot 1 was covered with polyethylene, Plot 2 was left as an uncovered control and Plot 3 was left uncovered but had a foil barrier around the periphery.

RESULTS

Temperature data for thermocouples (TC) located in the middle of each plot (TC 13, 14, and 15) were no different than that recorded for the third row of cans (TC 9, 10, 11, and 12) in each respective plot. This observation held true throughout the investigation. Therefore, these data can be obtained by referring to plot temperatures recorded for the third row of containers.

The data for November 2, 1966 (Figure 3), a typical sunny fall day, illustrates the influence of solar radiation on soil temperature in the containers. The greatest temperature fluctuations occurred in the outer row of containers which had a southern exposure (Figure 3 Control TC 3, 4, 7, 8, 11, and 12). The magnitude of the temperature fluctuation was greatest in the outer row of cans but also carried over to the second row.

Early observation of this fact lead to the introduction of a third treatment with protective barrier around the periphery of Plot 3. The data (Figure 3 Barrier) illustrates how effectively this barrier reduced the magnitude of the temperature fluctuation on November 2. It also tended to stabilize the temperature throughout the plot. As a consequence, all the containers had a lower soil temperature than the control plot.

This winter was exceptionally mild. Seldom did the temperatures drop below freezing, but four representative days were selected to illustrate soil temperature observations (Figures 4 and 5). Delineation of data for all TC locations was not done since temperature patterns observed were similar to those previously described. Consequently, the remaining data compare container temperatures by rows (TC 4, row 1; TC 8, row 2; TC 12, row 3).

January 14, 1967 and February 17, 1967 (Figure 4) were cool, cloudy days, while February 15, 1967 and March 18, 1967

(Figure 5) were representative of bright, sunny days. As shown in Figure 4, soil temperatures were more uniform throughout the plots during cool, cloudy weather. The control plot was similar to air temperature, but both the covered and barrier plots were somewhat cooler.

Soil temperature measurements showed a different pattern during bright sunny weather. The barrier treatment (Figure 5) was not only effective in reducing diurnal soil temperature fluctuation in the outer rows of cans, but it also resulted in a more uniform temperature across the plot. Tem-

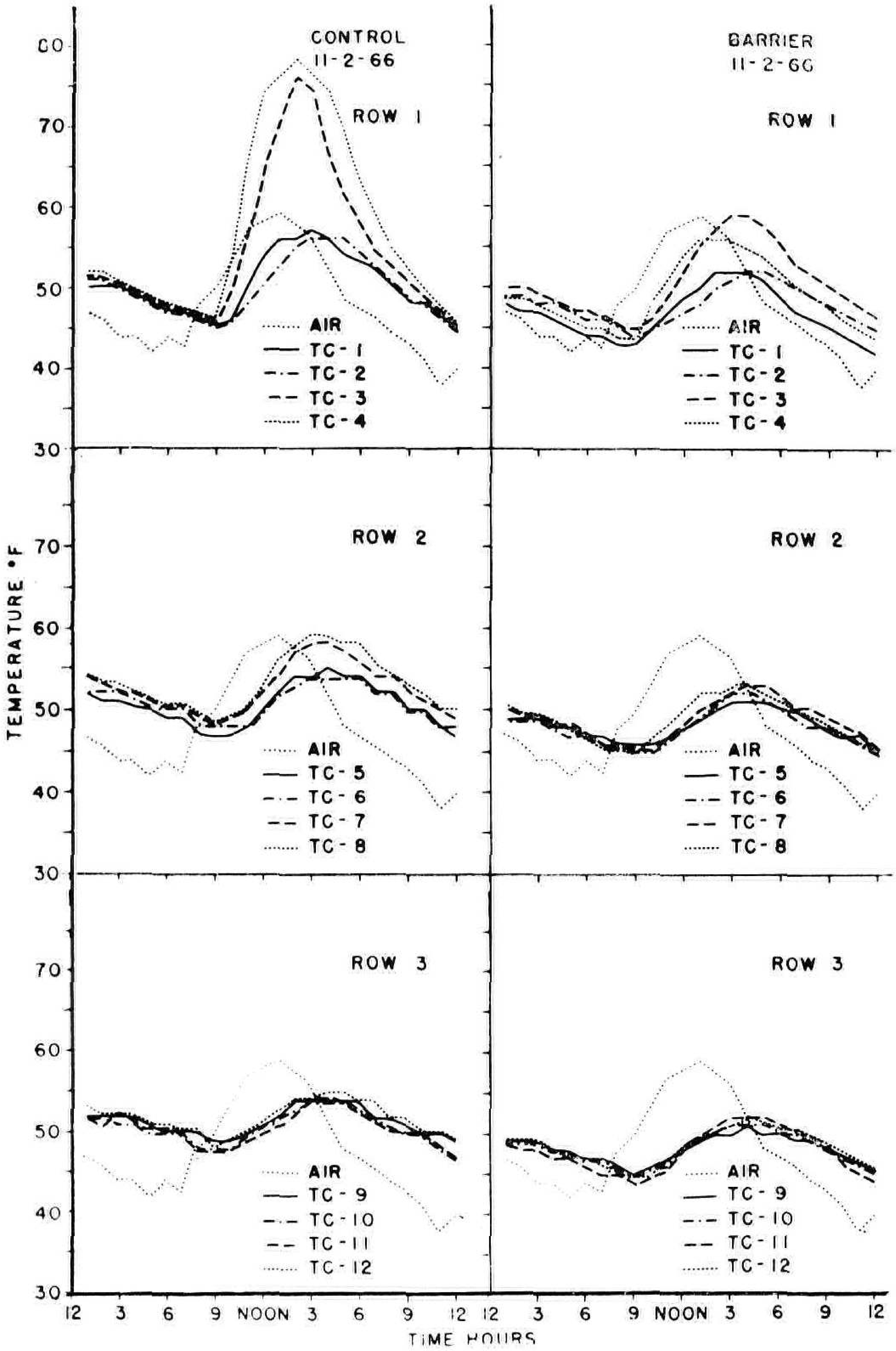

Figure 3. Comparison of temperatures recorded in different locations in an unprotected control plot and a plot protected by foil barrier on November 2, 1966.

peratures tended to be lower than in the other treatments, and the temperature differential within the plot was less.

Temperature fluctuation in the control plot on bright days was most marked in the outer row of containers. Although

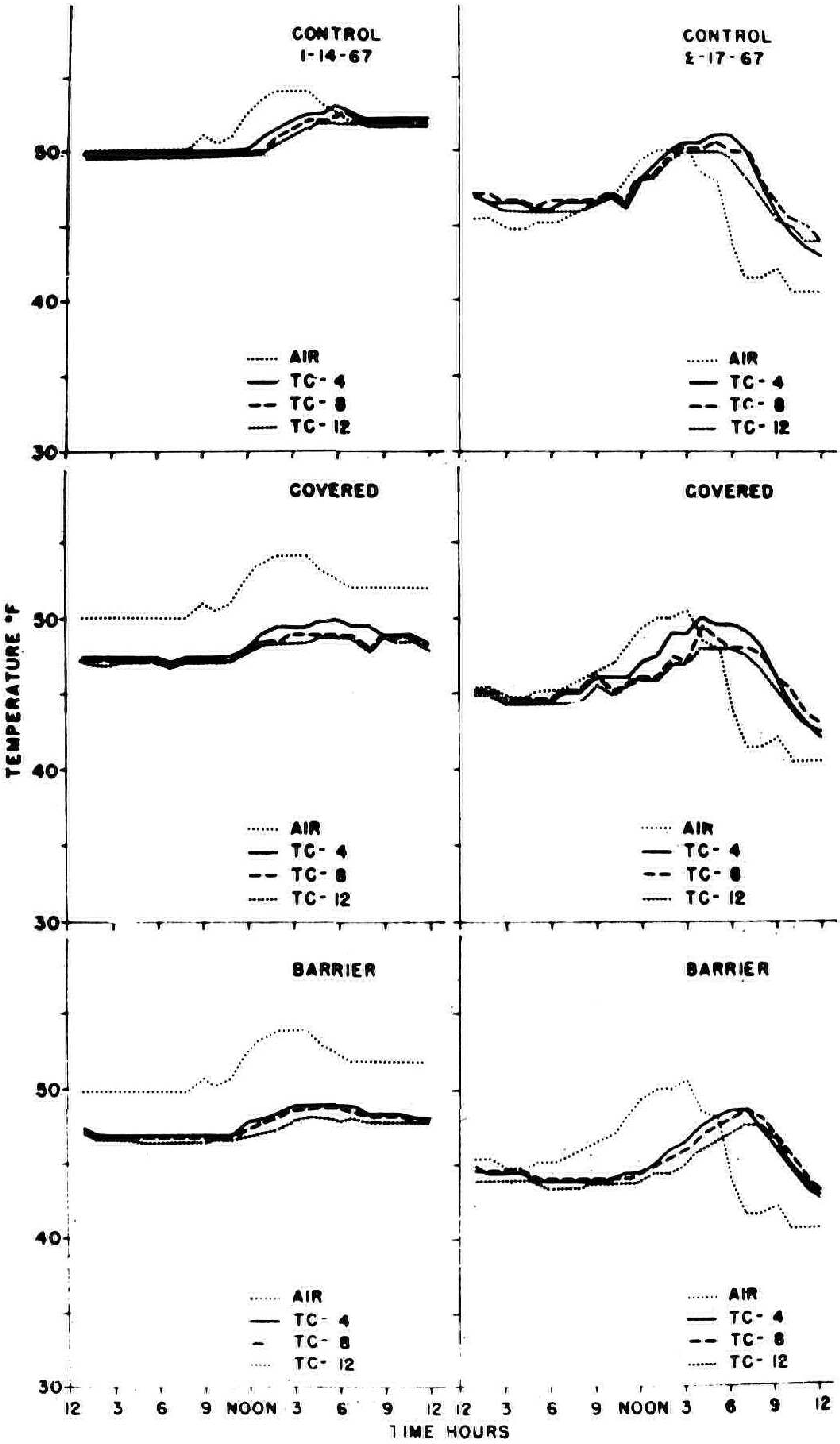

Figure 4. Diurnal temperature fluctuations recorded by rows for representative cool, cloudy days. January 14, 1966, and February 17, 1967. (row 1, TC 4; row 2, TC 8; row 3, TC 12).

the containers in the inner row were somewhat warmer than those of the barrier treatment, the differences were not great (3-5° F.).

Unlike the control treatment, the containers in the cover-

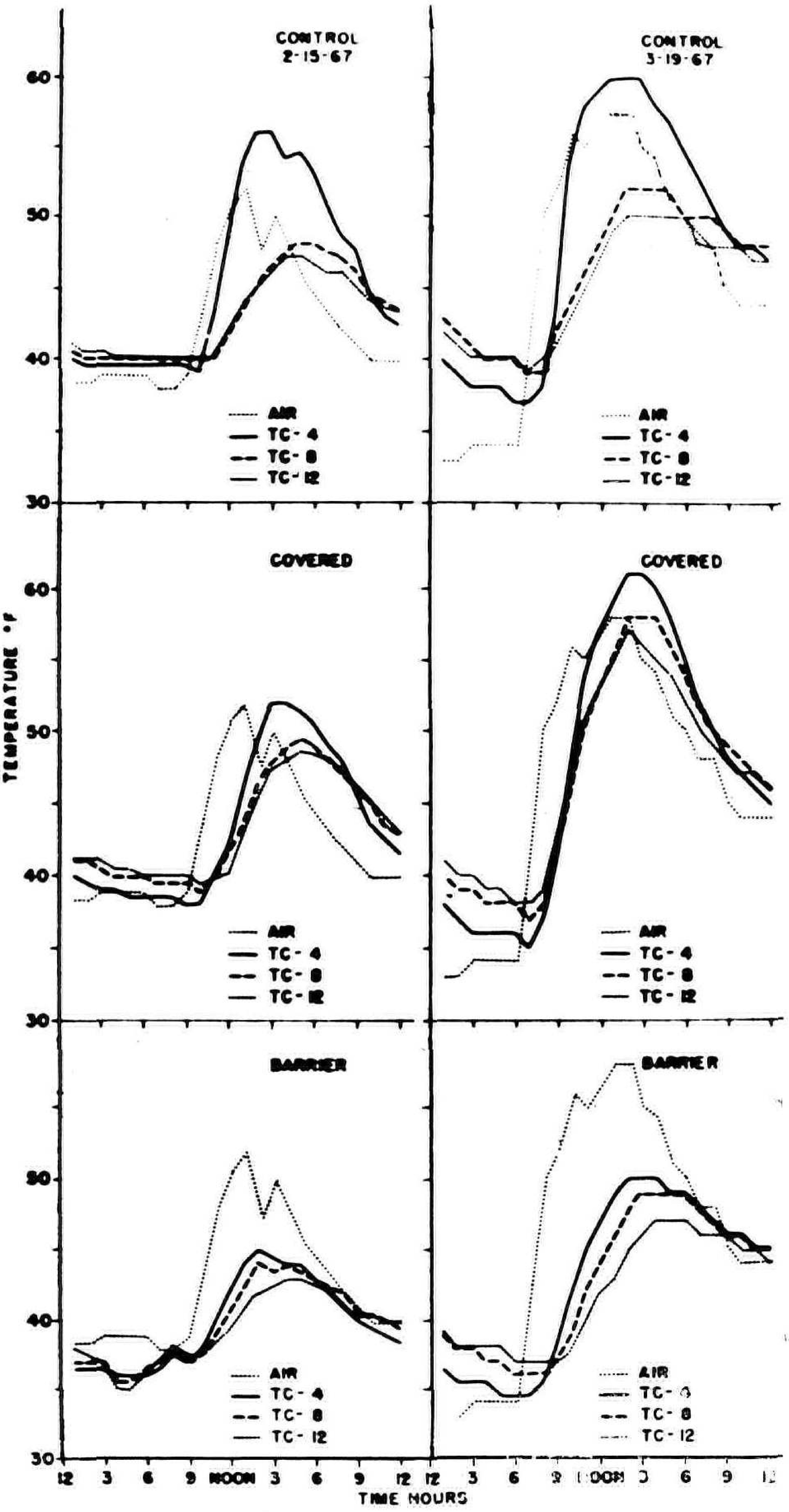

Figure 5. Diurnal temperature fluctuations recorded by rows for representative warm, sunny, days. February 15, 1967, and March 19, 1967. Row 1, TC 4, Row 2, TC 8, Row 3, TC 12.

ed treatment exhibited a more uniform temperature across the plot (Figure 5). The heat trapping effect of the polyethylene may have caused the greater temperature fluctuations which were observed across the entire treatment. Although diurnal temperature fluctuations were great, there was less variation due to position of cans in the plot. The rate of temperature rise was somewhat slower in the covered plot compared to the control plot (Figure 5), but the rate of rise and fall were similar. Thus both the barrier and the covering tended to even out temperatures across the plot.

DISCUSSION

Plants have the capacity to withstand very low temperatures when properly hardened (3, 5, and 6). However, it has also been shown that hardiness can be lost by even brief exposure to mild or high temperatures (8). One of the most critical effects of low temperature on plants is the rate of temperature fall (10). Rapid changes in temperature can cause more injury than slower rates (1, 2, 3, 5, 6, 9, and 11). As a result, temperature fluctuations may be a more critical factor in plant survival than the frequency or degree of low temperature.

Roots (5, 11) are more subject to injury from low temperature than either stems (1, 5) or leaves (5, 9). They are also more subject to injury from rapid changes in temperature (2,5). This suggests that injury to container-grown stock from temperature fluctuations may be greater to the root than to the rest of the plant. In this study, fluctuations in soil temperature were as great as, or greater, than air temperature, particularly in the outside rows.

The greatest diurnal fluctuation in temperature occurred in the outermost rows, particularly in those on the south side, when the containers were exposed to direct sunlight. This is also where the greatest amount of winter injury or loss of plants occurs. When containers are protected with a plastic cover, loss is found to be negligible.

It is of interest to note that the foil barrier resulted in as uniform a temperature throughout the plot as a plastic cover. If temperature fluctuation was the primary cause of injury and plant loss, then less injury would be expected from a barrier than a plastic cover. Results of this study showed that the differences in temperature between containers at any given hour was reduced by a plastic cover even though diurnal fluctuations were greater than either the unprotected control plot or the plot protected by the foil-barrier.

These results as well as the results from other studies on hardiness and injury (2, 5, 6, 8, 9, and 11) question the practice of covering plants with plastic to reduce injury. While a plastic cover may have other effects than those noted here, such as influencing evapo-transpiration rates and/or recovery from low temperature injury, an exterior foil-barrier such as used in this study appears to be superior at reducing temperature fluctuations.

SUMMARY

Soil temperature conditions occurring during the critical period for winter injury were studied. It was found that diurnal soil temperatures in the outer row of containers fluctuated greatly which would agree with injury observed to container-grown plants. While soil temperatures under polyethylene protection were as uniform as those with a foil barrier, the diurnal fluctuation was as great as the control plot.

A foil barrier showed less temperature variation within the plot and between plots than did other treatments. Therefore, if fluctuation of temperature is a critical factor, plants protected by a foil barrier should show less injury.

LITERATURE CITED

1 Brierley, W G 1942 A note on an unusual case of cold injury to the Haralson apple *Proc Amer Soc Hort Sci* 40·236

2 Carric, D B 1920 *Resistance of the roots of some fruit species to low* temperature *Cornell University Memoir* 36 613-661

3 Chandler, W H 1954 Cold resistance in horticultural plants A review *Proc Amer Soc Hort Sci* 64 552-572

4 Doring, B 1934 Die temperature — Abhangigkeit der wasseraufnahme and ihre okologische bedeutung *Zeitschr F Bot* 28: 305-446

5. Levitt, J 1956 The hardiness of plants Academic Press, Inc New York, N Y

6 ------------------------------ 1951 Frost, drought, and heat resistance. *An. Rev Plant Physiol* 2 245-268

7 Maximov, N A 1929 The Plant in Relation to Water (English edition). George Allen and Unwin Ltd, London, 451 p

8 Proebsting, E L, Jr 1959 Cold hardiness of Elberta peach fruit buds during four winters *Proc Amer Soc Hort Sci* 74 144-153

9 White, W C and C J Weiser 1964 The relation of tissue desiccation, extreme cold and rapid temperature fluctuations to winter injury of American Arborvitae *Proc Amer Soc Hort Sci* 85 554-563

10 Winkler, A 1913 Uber den einfluss der aussenbedingungen auf die kalteresistenz ausdauernder gewachse *Jahrb Wiss Bot* 52 467-506

11 Zehnder, L R and F O Lanphear 1966 The influence of temperature and light on the cold hardiness of *Taxus cuspidata* *Proc Amer Soc Hort Sci* 89 706-713

MODERATOR MAIRE: I don't think I really need to introduce our next speaker. Everybody here knows him. He is in the nursery business right outside Vancouver, B. C., and has been for a long time. So, Walter, come up here and tell us about liner production. Walter Van Vloten: