ARTIFICIAL FROST APPARATUS

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This paper reports two attempts to simulate natural frost in a temporary insulated enclosure out-of-doors, one using, around the plant, a refrigerating coil through which was passed carbon dioxide gas newly vaporized from its original liquid state in a pressure cylinder, the other using solid carbon dioxide (dry ice) on a steel disc above the plant. The frosting was done at the University of Minnesota Cedar Creek Natural History Area in northern Anoka County, Minnesota, on May 25, 1960, and on May 29, 1962. An artificial frost apparatus had been devised earlier, by Studhalter (1942) for injuring cambium tissue of individual tree branches; the effects have
been reported by Glock (1951) and Glock and Agerter (1963).

**Apparatus Using CO₂ Gas Refrigerant**

**Description of apparatus**

A commercial-type steel cylinder was procured containing 50 lbs of CO₂ under pressure of 840 lbs/sq in. and having a total weight of 125 lbs. The cylinder was of the siphon type, so that liquid CO₂ was forced up to the valve outlet when used in an upright position. Change from liquid to gas at the valve exit produced refrigeration beyond that point through latent heat exchange.

The valve opening of the tank as received was threaded for ½-in. pipe coupling which was used with a galvanized nipple and a pipe-garden hose adapter. A 3-ft section of rubber hose extended from there through the wall of the frost chamber to the upper end of a 50-ft helical coil of §₄ in. O.D. soft copper refrigeration tubing to which it was firmly attached by a stainless steel hose clamp. The valve and portion of hose outside the frost chamber were wrapped with fiberglass insulation. The coil having an inside diameter of 18 inches was placed around the test plant without touching it. The bottom and top were tied to four dowels inserted into the ground (Fig. 1). A 1-ft length of garden hose conducted the waste CO₂ from the lower end of the coil beneath the chamber wall to escape outside.

**Fig. 1.** Refrigeration coil being set up around oak sapling. May 25, 1960.

Four corrugated boxes 23 by 30/₄ in. and 2 in. thick, filled with crumpled newspaper, formed the walls, which were held together with rope. The completed chamber enclosed approximately 7 cu ft. Gummed paper tape sealed the corner cracks. Two wool blankets over the open top were supported by two welding rods inserted horizontally through opposite top corners of the chamber. The blankets allowed periodic observation within the chamber. Packed soil closed the space between chamber walls and soil (Fig. 2).

Thirteen mercury laboratory thermometers were inserted from the outside, the lowest below the chamber wall into the surface soil, the other 12 through the double wall of the chamber with the entire immersion length extending inside the chamber. They were inserted in holes drilled near one corner in the north wall of the chamber at the following levels above the base of the chamber: 2, 5, 7, 10, 15, 20, 25, 30, 40, 50, 61, and 76 cms. Another laboratory thermometer was inserted in the outlet of the waste CO₂ hose. Readings were made at approximately 10-min intervals, beginning 18 min after slightly opening the CO₂ valve. Two max-min thermometers were installed horizontally, one on the soil surface, the other at the 76-cm level.

**Behavior of apparatus**

The test began at 2:00 PM when the air temperature was 17.7°C. In the absence of previous experience, procedure depended on trial and error. The chamber air temperature dropped so rapidly at first that a strong inversion developed and the temperatures at all levels fell much lower than planned. Eighteen minutes after injection of the CO₂ into the coil, air temperature at all levels had dropped below the freezing point. The lowest temperature of the first reading was −18°C which occurred at the 5-cm level. The temperature profile is not presented here but is available in tabular form from the authors.

The valve required periodic adjustment because of occlusion by CO₂ ice. The rate of cooling was adjusted according to the temperature of the CO₂ emerging from the outlet hose and the temperatures indicated by the thermometers protruding from the chamber wall.

The flow of CO₂ was stopped at the end of 1½ hrs and natural warming of the system proceeded until 6:30 PM (3½ hrs after closing valve) when the apparatus was dismantled. The max-min thermometers showed minima of −16°C on the soil surface and −6.6°C at the 76-cm level. The temperature within the surface soil did not fall below +12°C.

**Behavior of the test plant**

A seedling sprout of *Quercus ellipsoidalis* E. J. Hill, about 76 cm tall and in its natural undisturbed position, was used as the test plant. Spring growth was well under way. Leaves were one-third to one-half expanded. New shoots averaged 7.6 cm long and were unliagnified.

Examination midway through the treatment revealed that the new shoots were solidly frozen. Upon removal of the chamber the leaves were flaccid (Fig. 3) and their color had changed from bright green to olive drab. The
outer tissue of the entire stem was a dark grayish-green. It was found later that the entire shoot had died back to the soil surface.

Regrowth of the oak sapling

Observation on Nov. 5, 1960, revealed that three vigorous sprouts had developed from dormant or adventitious buds at the root crown beneath the soil surface where the temperature had not fallen below +12°C. The three sprouts seen from left to right in Fig. 4 were 46 cm, 14.7 cm, and 43.5 cm tall. The scale at right is 50 cm tall. The stems which died from the experimental frost of May 25 extend above the new leafy shoots.

Winter dieback, natural frost, and regrowth of 1961

During the following winter, all except the tallest shoot at the left (Fig. 4) died back below the soil surface and did not regrow from the base. Observation on July 21, 1961, showed that the left shoot had died back to 4.5 cm above the soil surface and then had regrown from that level to form two new shoots 15.3 and 21.5 cm long. Another shoot from a bud 2.5 cm above the soil surface had grown 6.3 cm tall by May 22 when a shallow temperature inversion developed during a clear night following a strong cold front. Sub-freezing temperature occurred and oak shoots were frosted generally from near the soil surface to a height of 2 meters. The delicate, partly expanded shoot died back 3.8 cm and then regrown from a young bud 2.5 cm above the soil surface to form a new shoot 12 cm long.

Thus experimental and natural frosts in late May of 1960 and 1961, respectively, produced similar results in the same oak sapling growing in a natural woodland of central Minnesota, although development in 1961 was retarded because of the lateness of the season. Unfortunately a detailed temperature profile is not available for the natural frost of 1961 for comparison with the artificial one of 1960.

Apparatus Using Solid CO₂ Refrigerant

On May 29, 1962, another attempt was made by Lawrence and Jon Sanger to artificially frost the same oak sapling with a greatly simplified apparatus (Fig. 5) consisting of a commercial fiber drum 31/2 in. high, 21/2 in. inside diameter, with walls 3/16 in. thick, and with a removable steel head. The cardboard bottom of the drum was removed and discarded, the lower 11/2 in. of the wall was removed by a circular cut and this cylindrical portion was attached to the top of the drum above the steel head using a strip of canvas and waterproof glue to bind the two walls sections together. The upper compartment, now having a steel floor, formed the container for the solid refrigerant, the lower one, 20 in. high and enclosing 4.4 cu ft, constituted the frost chamber. Flexible corrugated cardboard sheet was applied to form an insulating layer 1/2 in. thick on the outside walls; it was held in place by masking tape. Holes were drilled through the insulated wall of the frost chamber to admit the bulb and lower stem of a series of mercury laboratory thermometers.

The cylinder was then placed over the test oak sapling and sheets of dry ice 3 in. thick, previously cut from a 50 lb block (10 by 10 in.), were laid flatwise on the steel drum head to simulate a cold night sky; the refrigerant compartment was then covered with an insulating blanket. The air temperature within the frost chamber fell gradually over a period of about 30 min, the heat being absorbed by the chilled steel ceiling, until the lowest reading was a few degrees below 0°F, when the dry ice was removed from the refrigerant compartment and the temperature was allowed to rise slowly. When the apparatus was removed from the sapling it was found that the effects rather faithfully reproduced those of radiation frosts which occur on spring and autumn nights when sky is clear and atmosphere is dry. The uppermost leaves were frosted more severely than the lower. Leaves and parts of leaves that were sheltered from radiant heat loss toward the cold drum head by intervening leaves were not frosted.

The total cost of this experiment, exclusive of thermometers, was $5.00 for materials, about one-fifth the cost of the earlier one; also the expenditure in time and effort was greatly reduced. The only tools used were a carpenter’s saw and a drill. We are grateful to Wilna Monserud for preparing the figures from Kodachromes.

Literature Cited