Here's how frost damages seedlings

BY J. W. CARY

HOW MANY TIMES have you stepped out in your field or garden after a cold night and seen a row of beans or tomatoes with wilted, black, and dead seedlings intermingled with plants that show no sign of frost damage? Do freezing temperatures really vary that much in the row, or are some seedlings more frost resistant; and if so, why don't agronomists select these plants and develop new varieties? Direct answers to questions like these are not simple, but we are beginning to understand why frost affects tender seedlings in a variety of different ways.

Strangely enough, the dewpoint of the nighttime air is a key factor in the type of freeze damage mentioned above. When the air is very dry, so that dew does not form on the leaves, water in the seedlings may supercool (the temperature drops below the freezing point but ice does not form) and the plant tissue can survive the cold. In other plants the supercooled water may become unstable and turn to ice, killing the plants even though frost did not develop on the leaves.

When night air is moist and dew forms on the leaves, frost crystals develop on the leaves as soon as the temperature falls to 32 degrees (F). These crystals in turn cause ice to form inside the leaf instead of allowing the water to supercool. Ice spreads through the tender tissue causing death or severe injury. When dew does not form on the plant it is possible for the water inside the plant leaf to remain below the freezing point for several hours without forming ice.

Top, two seedlings in the same field; one killed by a freeze and one survived. The difference was the formation of ice crystals within the plant. The leaf below was only partially damaged, and shows how frost injury spreads outward from the veins. If the freezing temperature had continued the injury would have spread inward until the entire plant was killed.

The drawing shows that the lethal temperature for sugarbeet seedlings varies with the stage of growth. Below, chilling injury to bean seedling leaves. The trifoliate in the lower left is normal, the other three show varying degrees of curled, thickened growth caused by several hours of exposure to a 28-degree temperature without ice formation.

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Whether or not supercooled water turns to ice depends on various things inside the plant we know little about. Some of these include the duration of the freeze, the energy of the water in the seedlings, and the weather and soil conditions during germination and emergence. There may also be some genetic differences involved.

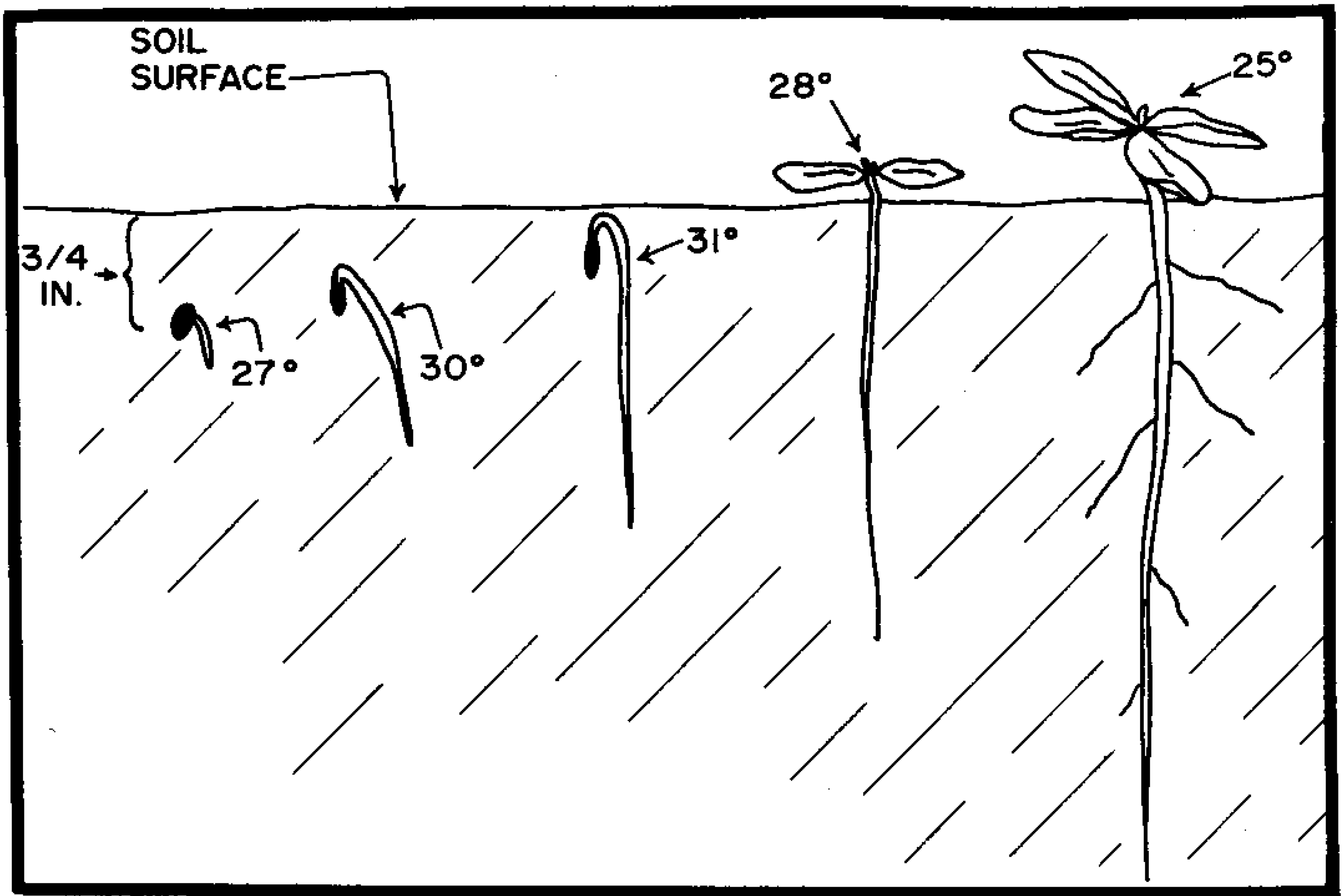
If the temperature of a bean seedling stays near 31 degrees, a little ice may form without causing any apparent injury. In general, however, when ice forms there will be at least some cell death. If the temperature falls even 2 degrees below freezing in the seedlings for more than 10 minutes after ice starts to form, death will follow due to ruptured cell membranes in the leaves and stem.

When the temperature falls below freezing but ice does not form in the plant tissue, bean seedlings will at first appear to have escaped damage. However, some of the new trifoliates that later emerge from the chilled growing tips may be malformed. These injured leaves are curled and wrinkled. This type of injury evidently results from changes in plant growth chemistry caused by cold temperatures per se rather than from the cell rupture and dehydration that occurs when ice forms in tender tissue.

Sugarbeets

Sugarbeet seedlings are another interesting frost-sensitive plant because they possess more ability to cold-harden than beans. Sugarbeets are often injured by cold just as the seedlings are ready to emerge from the soil. The stem is particularly susceptible to ice damage at this time, and a soil temperature of 31 degrees at the ½-inch depth may be lethal. On the other hand, a sugarbeet seedling with 4 to 6 true leaves may survive freezing at 24 degrees if it has been hardened by cool temperatures. The change in susceptibility of sugarbeet seedlings to cold temperatures as they grow in the field has been known for many years, but only recently have some of the reasons been understood. Ice crystal injury in seedlings is similar to ice damage in an automobile radiator. If there is not enough antifreeze in the water, a slushly solution forms. The solution has many ice crystals, but does not rupture the radiator. As ice crystals begin to freeze out in an antifreeze solution, the remaining liquid becomes more and more concentrated. Consequently the temperature must fall lower and lower to continue to freeze water out of the remaining solution and enlarge the ice crystals. If the ice crystals get large enough, the radiator will burst.

The same thing happens in sugarbeet seedlings, except naturally occurring salts, sugars, and other organic compounds assume the role of antifreeze. As a seedling begins to germinate, it contains only a small amount of water, and large ice crystals do not form because of the relatively high concentration of dissolved materials. As the stem and root elongate


SOIL
SURFACE
3/4
IN.
27°
30°
31°
28°
25°

in the soil, the seedling absorbs more water and its "antifreeze" solution becomes weaker. This situation becomes progressively worse until the cotyledons reach the sunlight and begin to manufacture sugar and other organic compounds. The concentration of dissolved materials in the plant then rises and frost protection increases.

Sugarbeet seedlings can be frozen nearly solid at all stages of development without damage so long as the temperature does not fall below a critical minimum point, just as slush can form in a car radiator without damage so long as it does not get too cold and form massive pieces of ice. This critical minimum temperature is determined jointly by the amount of ice a seedling can tolerate before cell damage occurs, and by the concentration of dissolved materials in its sap. A small increase in the concentration of dissolved materials provides a large amount of cold protection for seedlings such as sugarbeets, that can tolerate 50 percent of their internal water in the form of ice. Increasing the dissolved material in seedlings such as beans, which may tolerate only 10 or 20 percent of their water as ice, has an insignificant effect on cold survival. This is one reason sugarbeet seedlings become more frost-resistant after their leaves reach light, while bean seedlings do not harden appreciably after emergence.

Because a sugarbeet seedling can tolerate about 50 percent of its internal water in the form of ice, the placement of fertilizer may influence its cold survival. Increasing the concentration of certain soluble salts around the growing roots increases the concentration of these salts in the plant tissue, and reduces the amount of ice that will form in the seedling at any given temperature during a freeze. For example, it has been shown in the laboratory that increasing the level of salts in the solution around a sugarbeet seedling root during germination can lower its lethal temperature from 31 to 28 degrees. This may mean the difference between death and survival during many spring frosts, because even when air temperatures fall well below 32 degrees, the soil around the emerging seedlings may stay near 30 degrees for several hours as heat is released from freezing soil moisture.

Potassium nitrate is one of the salts that increases cold survival under laboratory conditions. Ammonium, urea, phosphates, and sulfates are not effective because they are toxic at high concentrations or are not absorbed by the seedlings in great enough quantities. More research may lead to practical guides for increasing seedling freeze survival by fertilizer placement. Currently, though, the best recommendation for frost protection of seedlings is a firm, moist soil surface on cold nights, combined with sprinkling and artificial covers where practical.

Can we help?

Increasing the amount of ice a seedling can tolerate without death may have more practical potential than artificially manipulating the level of salts in the sap. Little is known about this at the present time, but there is some indication that ice tolerance is linked to the permeability of cell membranes, and a number of chemical compounds are being studied in this regard. We do know exposing sugarbeet seedlings to cool temperatures during germination increases the tissue's tolerance for ice.

Sugarbeets, like beans, may not grow normally after chilling. Seedlings that have 4 to 6 true leaves and are frozen at temperatures in the low 20's often retain live crowns in spite of severe leaf damage. As new leaves grow from the crowns, a few may be malformed, with thickening and curling evident. Little is known about the cause of such malformed growth other than it appears to be a biochemical disturbance triggered by cold temperatures and, like the beans, may resemble herbicide damage.

Chill injury may be more prevalent in crop production than is commonly realized. We have known for many years that tropical and warm-season plants can be damaged by cool temperatures well above the freezing point. It is possible that moderate damage also occurs in cool-season plants, but is not recognized because no visible symptoms appear. Some scientists are attempting to unravel the biochemical changes that can occur in plant cells during chilling, and others are searching for genetic factors that make seedlings germinate and grow better under cool conditions. All of these varied avenues of research will be merging to provide some practical solutions to frost problems with tender plants. □

J. W. CARY *is a soil scientist at the U.S. Department of Agriculture's Snake River Conservation Research Center.*