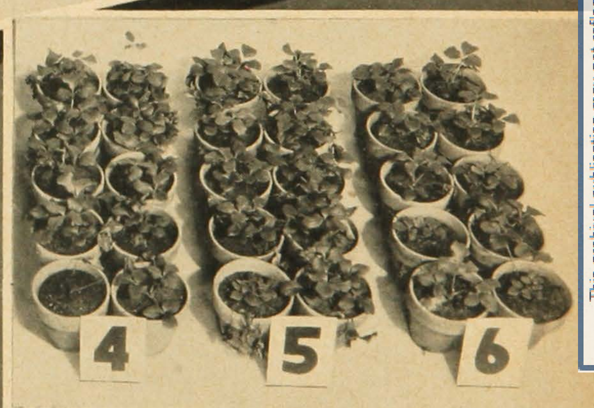
Winter Behavior of Strawberry Plants

Bulletin 375
March 1944

by
W. G. Brierley
and
R. H. Landon



Plants mulched before being hardened by frosty nights are easily injured. These six lots were mulched at weekly intervals from October 7 to November 11, frozen 24 hours at 21° F., thawed, and tested in the greenhouse for growth response.

This archival publication may not reflect current scientific knowledge or recommendations.
Current information available from Minnesota Agricultural Experiment Station: http://www.maes.umn.edu

Agricultural Experiment Station
UNIVERSITY OF MINNESOTA

HIGHLIGHTS: *Behavior of . . . . .*

● Frosty nights prepare strawberry plants for winter by checking growth and developing hardiness. Because weather conditions are variable, plants are not likely to harden to the same extent or at the same time each fall.

● During the winter the internal activity of dormant plants is low, and because of this, dormant strawberry plants do not smother easily. They are able to survive if only a little oxygen is available. It is likely, therefore, that losses of plants in the field commonly attributed to "ice smothering" are the result of other causes.

● Ice alone apparently causes no serious injury to dormant strawberry plants, and the mulch commonly becomes filled with ice during winter in northern localities.

● Beneath a layer of ice, or if the mulch becomes filled with ice, the temperature at times may fall low enough to kill strawberry plants. Ice and low temperatures, ice and excess water as the plants thaw, or a rise in crown temperatures while the plants are covered with ice or otherwise closely confined, have been associated with injury or killing. Injury under some of these conditions also may be the result of diseases.

● The "danger-point" for well-matured, well-hardened plants lies close to 21°, and the actual killing point lies close to 10°.

● The locally important June-bearing varieties usually are hardy under Minnesota conditions. Beaver, Dunlap, and Premier appear to be dependably hardy at 21°. The new variety Burgundy is somewhat hardier, and the Catskill is slightly less hardy.

- Fall-bearing varieties as a group are less hardy than June-bearers. The seedlings Minn. No. 1166 and Minn. No. 1167 usually are not injured at 21°. Gem is somewhat less hardy, and Wayzata has shown severe injury at 21°.

- In the average winter, a good mulch provides adequate protection against too-low temperatures, and an additional covering of snow makes protection more certain.

- Mulching at the right time is more important than the exact degree of cold resistance in well-hardened plants. "Late" mulching, or to delay until the temperature falls below 20°, may result in severe injury or killing, even of well-hardened plants.

- The best time to mulch usually may be determined by watching fall weather conditions closely and noting particularly the temperature at the ground level beneath the leaves. A series of light frosts will harden the plants, and mulching before severe freezing occurs usually will avoid serious injury.

- Plants mulched too early may continue to grow slowly. Leaves produced beneath the mulch are bleached and the plants do not harden. Such plants may be severely injured or killed at temperatures only a few degrees below freezing. They are less hardy than plants in the early stages of growth in sunlight in the spring.

CONTENTS

Accepted for publication August 23, 1943

6M—3-44

WINTER BEHAVIOR OF STRAWBERRY PLANTS[1,2]

W. G. BRIERLEY[3] and R. H. LANDON[4]

WHILE IT HAS long been known to strawberry growers in northern regions that plantings protected by a mulch spread over the fields in the fall usually escape serious winter injury, all too frequently there have been losses of plants even when mulched according to accepted practices. The possible causes of such losses have long remained in doubt because of difficulties that may easily be recognized. The strawberry is an herbaceous perennial and the small size of individual plants makes them, in some ways, more difficult to study during the winter than are woody plants from which samples for experimental purposes may be obtained readily at any time.

During the winter in northern regions, strawberry plants in the field are held fast in frozen soil and often are completely covered with mulch, snow, and ice. When attempts are made to remove the covering of snow, ice, and mulch and to dig the plants from the frozen soil the resulting mechanical injuries greatly hamper studies of other types of injury. Even under such handicaps studies have been carried on that have added materially to our knowledge of the behavior of strawberry plants in winter.

In recent studies, more general use has been made of potted plants to determine the ability of strawberry plants to endure low temperatures, exposure to ice, or other winter conditions. Potted plants can be kept under conditions comparable to those in the field and may be handled with little or no disturbance at any time during the winter. For many of the studies reported in this bulletin, strong well-developed plants with 10 to 12 leaves have been selected in the field. These plants usually have been dug in September, potted in 5-inch pots, and plunged in peat in open frames to mature and harden. They have been watered only when necessary to avoid drying. After exposure to several light frosts they have been mulched to avoid injury from low temperatures.

As the potted plants handled in this manner have escaped the handicaps of crowding or drouth towards the close

[1] The studies reported herein are related portions of a general study of the hardiness of strawberry plants that has been in progress at the Minnesota Agricultural Experiment Station during the past 11 years. A part of the work relating to hardening and cold resistance was carried on by Ernest Angelo. The study of soil temperatures beneath mulches in winter was conducted by V. E. Iverson. Others who assisted at various times were R. E. Nylund, H. E. Andrews, O. C. Turnquist, and Violet Lundgren.

[2] Assistance on this project was given by workers supplied on official project No. 165-1-71-124, Minnesota Work Projects Administration. Sponsor: University of Minnesota.

[3] Division of Horticulture.

[4] Section of Plant Physiology and Agricultural Botany, Division of Plant Pathology and Botany.

of the growing season, they may have been matured and hardened as well as or even better than plants in the field. This possibility is indicated by the condition of surplus stock held into the spring of 1941. Of 257 potted plants of several June-bearing varieties, 251 or 98 per cent grew vigorously. As survival in the same season under generally comparable conditions in the field averaged 90 per cent for the same varieties, although weaker plants were included, it is evident that the potted plants were at least equal to the plants in the field in their ability to survive winter conditions. The results obtained with potted plants are believed to measure fairly accurately responses of strawberry plants to winter conditions.

In some studies for which potted plants were not adapted, winter-stored plants were used. These were dug in late fall, soil shaken from the roots, and selected for uniformity in size. They then were tied in bunches and stored where they could be protected both from drying and from severe cold. So long as these plants were kept a few degrees below freezing they remained in good condition until spring and could be used at any time without injury.

FROST TOUGHENS PLANTS

★

Strawberry Plants Are Matured and Hardened by Frosty Nights

Strawberry plants usually continue to grow while temperatures are relatively high and moisture supply is ample. Production of new runner plants and development of those already formed are retarded by colder weather in the fall. Similarly, internal activity of the plants, particularly respiration, is slowed down by colder weather. These activities appear to rise and fall with fluctuating temperatures, but the first frosty nights tend to check all activity and begin the development of hardiness.

Active growth is not always resumed in warm weather following early frosts, but any hardiness gained appears to be lost and more frosts are needed to develop hardiness again. In a series of frosty nights and mild days, more hardiness seems to be gained from each frost than is lost during the day. This process results in a net gain in resistance to cold until the maximum hardiness is reached. In the southern half of Minnesota this stage appears to be reached by the end of October or early November. In the northern part of the state frosts occur somewhat earlier. At times, severe freezes may come suddenly and cause much injury to plants, particularly to everbearers that have not had an opportunity to harden.

While the plants are growing and maturing, the amount of stored foods usually increases. Accumulation of stored foods in vigorous runner plants apparently is related to the development of hardiness. This behavior accounts for the fact that strong runner plants develop more resistance to cold than weak, late-formed plants, and also are hardier than the more or less exhausted "mother" plants used in planting the field.

Dry spells in early fall also appear to affect hardiness, probably by interfering with the accumulation of stored foods and resulting in a somewhat lessened ability to harden. Drouths occurring after an ample supply of food has been formed may aid in the development of resistance to cold by checking growth.

The time when the full development of maturity and of resistance to cold is reached is obviously related to weather behavior of the particular season. This point should be kept in mind in determining the proper time to apply the winter mulch.

WINTER ACTIVITY IS LOW

★

Respiration in Dormant Plants Continues at Greatly Reduced Rate

During the winter in northern localities, strawberry plants usually remain completely dormant. Generally they are held fast in the frozen soil and often are embedded in ice that forms in the mulch. Some activity must continue within the dormant plants, however, if they are to survive and function in the following growing season. As the degree of activity might possibly be related in some way to survival, or might furnish information relative to the question of "smothering," the internal activity of dormant plants was studied. Activity was expressed by rate of production of carbon dioxide.

Although the behavior of the plants was somewhat erratic and their activity low, apparently there was a downward trend in internal activity from October to the end of March, as shown in table 1. The apparent increase in activity as shown in this table for December 15 and January 15 may be attributed to the known effect of a rise in temperature upon the output of carbon dioxide by dormant plants. The plants were stored in a deep cold frame where the temperature during December and January fell gradually to 27°. As all determinations of the production of carbon dioxide were made at 32° the rate of activity following this rise of 5° probably was somewhat high for the plants at that time of year.

Table 1. Activity of Strawberry Plants During the Dormant Season and in the Early Stages of Growth, 1936-1937

(Activity expressed by rate of production of CO_2)

Date of test	Temperature during test	CO_2 output, mg. per 100 grams of plants per hour
PLANTS DORMANT		
October 23	32°	5.8
November 6	32°	6.3
November 16	32°	5.0
December 3	32°	3.8
December 15	32°	5.5
January 15	32°	6.3
March 4	32°	4.1
March 19	32°	2.0
March 25	32°	1.9
April 1	32°	1.9
PLANTS IN EARLY STAGES OF GROWTH		
April 8	32°	4.8
April 16	32°	5.1
April 23	41°	7.2
April 30	48°	8.2
May 7	58°	9.0
May 14	58°	11.7

The study was continued beyond the first of April to note the behavior of the plants at the end of dormancy. Although the temperature in the storage frame remained at 32° on April 8 and 16, and although the determinations of the output of carbon dioxide were made at the same temperature, an increase in internal activity was noted. The plants showed no indications of growth at this temperature, but their increased activity indicated that they were no longer completely dormant. The determinations of activity on April 23 and on the three succeeding dates were made at the temperatures observed in the storage frame on each date. At these higher temperatures, when the plants were beginning to grow, the activity of the plants increased rapidly.

This study indicated no abrupt changes in the activity of dormant strawberry plants during the winter. As long as the plants were completely dormant their activity was low. The downward trend in the output of carbon dioxide may be only an indication that some stored foods are being slowly consumed during the winter. Activity was found to rise before growth began and increased rapidly with rising temperatures during the early stages of growth.

DANGER POINT IS 21° F.

★

Dormant Strawberry Plants Are Likely To Be Injured at Temperatures Below 21° and Usually Are Killed at 10°

Strawberry plants do not develop exactly the same degree of cold resistance each year. Weather conditions in the fall vary so much that the development of maturity and of resistance to cold probably are somewhat different each year. Conditions of the plants also will vary in different localities, on different soils, and with varying rainfall. In addition, the plants themselves are not alike. Runner plants that form early and become well established by fall are known to be hardier than either late-formed poorly developed plants or "mother" plants. In addition to injury from cold, serious losses may be caused by drying of the plants during an "open" winter.

The relation between resistance to cold and mulching practice should be kept in mind. Information relating to cold resistance probably is most useful in determining the best time for mulching. A mulch spread over a field at the proper time, plus the added protection from snow, usually can be depended upon to protect the plants from temperatures low enough to cause injury.

Numerous tests carried on over several years with potted plants have shown that well-matured and hardened plants of the June-bearing varieties studied have been able to withstand exposure for 24 hours to a temperature of 21° F. with little injury. However, considerable injury has occurred at this temperature among plants that were not well-matured and hardened.

Freezing tests at 16° with similar plants have shown injury varying from slight to severe. Plants that were fully matured and hardened withstood this temperature better than weak plants, just as at 21°. Injury was more severe among plants from crowded rows or if final development in the field was hindered by drouth.

Tests carried on for 24 hours at 10° showed that not many plants were able to survive this exposure. Only a few plants grown and hardened under the most favorable conditions were able to survive; all of them were injured.

No evidence was obtained in these studies to indicate that strawberry plants become hardier during the winter. Survival among potted plants commonly was not as good in late winter or very early spring. Although the poorer survival in late winter may have resulted in part either from drying or from disturbance of plants and mulch as samples were withdrawn, the records show that in no test conducted later in the winter or very early spring was survival better than in early winter tests.

The results obtained in these studies are in general agreement with those obtained in other northern states. It is apparent that the "danger point" for dormant strawberry plants lies somewhere close to 21°. Injury is likely to be more and more severe at successively lower temperatures until the "killing point" is reached at about 10°.

BURGUNDY IS HARDIEST

★

June-bearers as a Group Are More Hardy than the Fall-bearers

Although the temperatures that are likely to injury or kill strawberry plants have been fairly well determined, it was considered desirable to know if any of the locally grown varieties or seedlings were hardier than others. Accordingly, for several seasons, comparisons were made of the relative hardiness of the common or promising

Table 2. Relative Hardiness of Varieties Grown Locally

Varieties	Relative hardiness
JUNE-BEARERS	
Burgundy (Minn. No. 1192)	Hardiest. Very little injury at 16°
Beaver, Dunlap, Premier	Dependably hardy at 21°
Catskill	Somewhat less hardy. Injured at 21°
FALL-BEARERS	
Minn. No. 1166, Minn. No. 1167	Usually hardy at 21°
Gem	Somewhat less hardy
Wayzata	Severely injured at 21°

varieties of both June-bearing and fall-bearing types. Varieties included in the study were Beaver, Catskill, Dunlap, Premier, and Burgundy (Minn. No. 1192) of the June-bearing type, and Gem, Wayzata, Minn. No. 1166, and Minn. No. 1167 of the fall-bearing type. Uniform plants of these varieties were dug in the field in September and handled as already described.

These observations, covering a period of eight years and based on the performance of several thousand plants, have led to the general rating of the varieties tested, as shown in table 2. Of the varieties tested, the new variety Burgundy has proved hardiest. This variety has rarely shown injury at 21° and usually withstood exposure for 24 hours at 16° with very little injury. Even at 10° some plants have survived, but severe browning of the crowns showed that they were greatly weakened at this temperature.

No clearly marked differences in hardiness were found between the varieties Beaver, Dunlap, and Premier. Differences noted in one season usually were not repeated in other seasons. All three varieties were dependably hardy at 21°, usually showed considerable injury at 16°, and were severely injured or killed at 10°.

The Catskill variety, although showing good survival at times, generally was more injured at all temperatures than any of the other June-bearers.

Of the fall-bearing type, the seedlings Minn. No. 1166 and Minn. No. 1167 showed the best survival, but they were not quite equal in hardiness to the Beaver, Dunlap, and Premier. Gem showed more injury at 21° than the seedling varieties, and Wayzata usually showed severe injury at 21°.

As a group, the fall-bearers are less hardy than the June-bearers. Survival and injury of all varieties at the different temperatures are shown in table 3. The fall-bearers showed poorer survival and a higher percentage of dead plants at all temperatures.

That the fall-bearers are less hardy probably is due to fall blossoming and fruiting. This behavior probably lessens the amount of food substances stored in the crowns and tends to delay maturity. That Wayzata showed more injury than Gem may be an effect

Table 3. Relative Cold Resistance of June-bearing and Fall-bearing Varieties

Temperature treatment, degrees F.	Growth response: Vigorous		Weak		Dead	
	June-bearers*	Fall-bearers†	June-bearers*	Fall-bearers†	June-bearers*	Fall-bearers†
	Per cent					
27°	91	63	6	33	3	4
21°	84	71	13	17	3	12
16°	56	37	29	28	15	35
10°	12	1	30	19	58	80

* June-bearing varieties included Burgundy, Beaver, Dunlop, Premier, Catskill.
† Fall-bearing varieties included Minn. No. 1166, Minn. No. 1167, Gem, Wayzata.

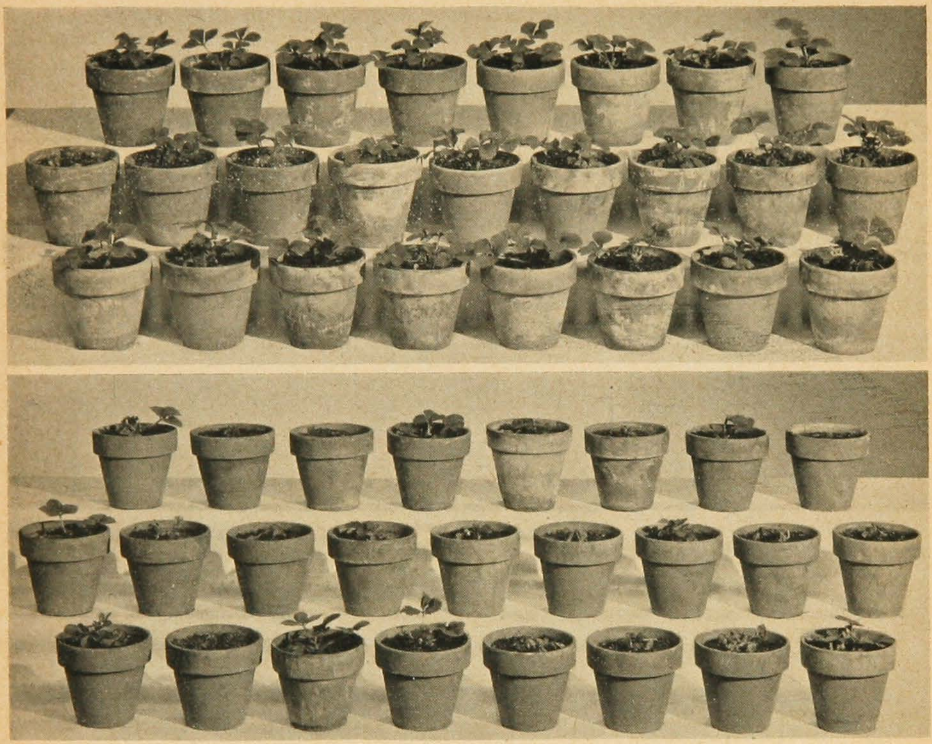


FIG. 1. Experimental smothering of dormant strawberry plants

Growth response of plants after 4 weeks in the greenhouse—no oxygen added

(Above) Plants from Jar 5, sealed for 4 weeks. Carbon dioxide 31 per cent; oxygen 0.6 per cent.
(Below) Plants from Jar 9, sealed for 6 weeks. Carbon dioxide 42.5 per cent; oxygen 0.3 per cent.

of difference in time of fruiting. As Gem fruits most heavily in August, the plants have a somewhat longer time to mature than Wayzata plants that fruit heavily during September.

PLANTS HARD TO SMOTHER

★

Dormant Strawberry Plants Survive Many Weeks in Airtight Jars

Although it has been the common belief that strawberry plants are "smothered" beneath a covering of ice, it will be shown that dormant plants can survive such exposure for 10 to 14 weeks with little injury. As the belief in smothering has been so widespread, an experiment was carried on to determine if plants actually could be smothered.

Dormant plants from winter storage were packed tightly in 2-quart jars. Glass tubing was inserted through the stoppers to allow for withdrawal of samples of the confined air for analysis. After the jars were sealed they were stored in a cellar at 27°.

In the first test, carried on for two weeks, oxygen in the jars was reduced to less than one half of 1 per cent and carbon dioxide rose to 20 per cent. When the plants were potted they grew normally and showed no signs of injury.

As no injury occurred in the first test, a second test was carried on for seven weeks. The results obtained are shown in table 4. Analyses of the air in the jars were made each week. When the samples were withdrawn, an equal volume of fresh air entered the jars. This small volume of fresh air increased the concentration of oxygen each week to about 2 per cent. Only slight injury occurred at this low oxygen level during the seven-week period, as shown in table 4. Most of the additional supply of oxygen was used by the plants during the weekly intervals. Apparently, dormant strawberry plants are able to survive for many weeks when the oxygen supply is very low.

As no smothering or serious injury appeared in these tests, a third experiment was conducted in which the air confined within the jars was analyzed only as they were opened to remove the plants for potting. The results of this test are also shown in table 4. In this case, when no oxygen was added to the air confined within the jars, the plants remained in good condition and only a few weak plants appeared in the first four weeks. During this time the oxygen supply fell to less than 1 per cent and the concentration of carbon dioxide rose to 27.6 per cent.

During the fifth week under these severe conditions injury began to appear as indicated by 24 per cent of weakened plants. After six weeks, none of the plants were vigorous and 34 per cent were dead. After seven weeks, all were dead. No injury appeared in any of the check lots taken directly from winter storage.

It is not known whether the very low oxygen supply or the high concentrations of carbon dioxide caused injury, but it was obvious that dormant plants could be "smothered" under unusually severe conditions in the laboratory. No smothering occurred in the earlier tests when the plants received a very limited supply of oxygen each week. In the third test only nominal injury appeared during

Table 4. Behavior of Dormant Strawberry Plants Sealed in Glass Jars

Sealed in jars, weeks	Analysis* of confined air, average of 2 samples		Growth behavior in greenhouse, average of 2 samples		
	CO_2 Per cent	O_2 Per cent	Vigorous Per cent	Weak Per cent	Dead Per cent
		2 PER CENT OXYGEN ADDED EACH WEEK			
2†	19.1	0.0	96	4	0
3	24.2	0.1	92	4	4
4	26.5	1.2	86	8	6
5	24.8	0.6	94	2	4
6	19.5	0.6	98	0	2
7	21.6	0.9	98	2	0
Check	....	.....	100	0	0
		NO OXYGEN ADDED			
2	20.1	1.0	96	4	0
3	21.6	0.3	98	2	0
4	27.6	0.5	94	6	0
5†	27.2	1.4	76	24	0
6	36.1	0.6	0	66	34
7	42.5	0.5	0	0	100
Check	....	.....	100	0	0

* Analysis made at time samples were withdrawn for growth tests.
† One sample only.

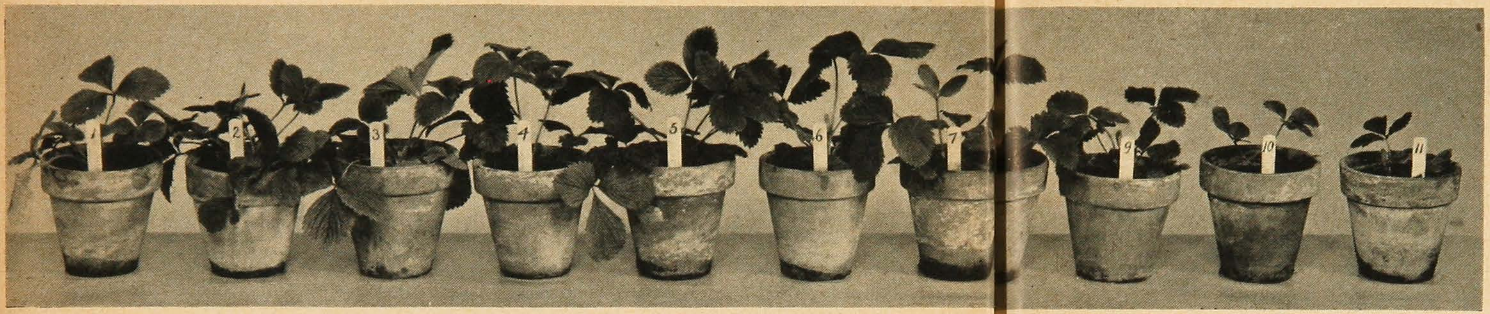


FIG. 2. Effect of ice upon the survival of dormant strawb—1938

Representative plants from lots sealed in ice for 1 to 10 weeks (left to right) and check (last on right) nowth of Lots 1, 2, 3 checked by red spider. Lots 9, 10, and check are smaller because of shorter period

the first four weeks with the oxygen supply very limited and with carbon dioxide at relatively high concentrations. Although injury increased during the fifth and sixth weeks, exposure to these severe conditions for seven weeks was necessary in order to kill all the plants. As very little injury had been found to occur beneath a covering of ice maintained for 10 weeks or longer it does not appear likely that conditions in the field are so severe as in the tightly sealed jars. Ice in the field usually is granular, porous, cracked, and more or less filled with straw, leaves, or weed stems so that channels probably are provided for the movement of oxygen and carbon dioxide. Because of such conditions, it may be that plants under ice in the field are able to obtain the small amounts of oxygen they require, and that carbon dioxide escapes so that high concentrations are avoided. Until further evidence is available it would seem that losses of plants in the field are not so likely to be due to "smothering" beneath a covering of ice as to other factors. Low temperature probably is the principal cause of injury under an ice sheet, but losses also may be caused by increased activity of the crowns in sunlight before the ice melts, to excess water as the plants thaw, or to diseases.

ICE ALONE NOT HARMFUL

★

Marked Injury May Result from Ice Accompanied by Extreme Cold or Other Adverse Conditions

Most strawberry growers in northern localities believe that "smothering" occurs in their fields when the plants are covered with ice. This idea is current despite the fact that in many seasons the mulch becomes filled with ice. This ice may remain in the mulch for a considerable length of time in the winter and often does not melt completely until early spring. When other conditions are favorable this covering of ice seems to be associated with only nominal injury to the plants. Although the formation of an ice covering may in some way be related to injury, apparently it is not correct to attribute such injury to "ice smothering" in all cases.

Dormant strawberry plants may be severely injured at temperatures below 20°, and a covering of ice affords very little protection against cold. During extremely cold weather the temperature beneath a layer of ice may fall below 20° and has been found to fall as low as −1° (table 8). Such evidence indicates that low temperatures may be the cause of the greater part of the injury generally attributed to ice.

As there was some doubt that ice was the immediate cause of injury, a study was made of the effects of ice upon the survival of strawberry plants. Small areas of rows in the field were surrounded by board frames and flooded in December with water at a temperature close to freezing. After 3 or 4 inches of ice had been formed, the flooded areas were covered with boards. Snow added to the covering and protected the plants against severe low temperatures. The board covering was removed in the spring when the ice began to thaw.

In this way ice was maintained over the small areas for a period varying in different seasons from 12 to 14 weeks. As conditions could not be controlled in the field, difficulties were encountered that affected survival of the plants. In one season the field was not mulched until after injury had occurred at temperatures below 20°. Injury another year probably followed flooding when the temperature ranged between −16° and −20°. Poor drainage caused injury at another time. Injury from ice and other causes varied in extent. Survival in different years varied from 45 to 85 per cent compared with an average survival of 90 per cent in the remainder of the fields.

It was evident that factors such as early cold and low temperatures during flooding probably had increased the extent of injury, but the poorest survival of 45 per cent occurred on a poorly drained site. However, in no case was there a total loss of plants covered with ice for 12 to 14 weeks.

As conditions could not be controlled in the field, the study was continued in the fall of 1937 with plants matured and hardened in pots. These were placed in a cellar where they were protected against temperatures below 21°. The plants were sealed in ice by flooding with water at a temperature close to freezing. After all the plants had been sealed for a week, 10-pot lots were withdrawn at weekly intervals, thawed slowly, and brought into growth in a cool greenhouse to note the extent of injury. Little difference in survival was found between the several lots (table 5). Only slight injury occurred in any of the lots. There

Table 5. Survival of Dormant Strawberry Plants Sealed in Ice for 1 to 10 Weeks
(10 pots per lot, variety Beaver, 1937-38)

Lot No.	Weeks under ice	Subsequent growth: Vigorous	Weak	Dead
		Number of plants		
1*	1	9	0	1
2	2	10	0	0
3	3	9	0	1
4	4	8	2	0
5	5	10	0	0
6	6	9	0	1
7	7	9	0	1
8	8	8	1	1
9	9	10	0	0
10	10	8	1	1
21†	10	8	2	0
22	10	7	1	2
23	10	9	0	1
Total		114	7	9
Per cent		87.7	5.4	6.9
Check, not iced, number of plants		8	0	2

* Lots 1 to 10 held at 21°-31°.

† Lots 21, 22, and 23, after 10 weeks under ice, were thawed, placed under higher temperatures until growth had started, and then frozen again for 24 hours at 28°, 23°, and 19°, respectively.

Table 6. Survival of Dormant Strawberry Plants Sealed in Ice for 1 to 10 Weeks
(10 pots per lot, variety Beaver, 1938-39)

Sealed in ice in cold cellar				Checks mulched in cold frame				Checks mulched in cold cellar			
Weeks under ice	Subsequent growth			Weeks in frame	Subsequent growth			Weeks in cellar	Subsequent growth		
	Vigorous	Weak	Dead		Vigorous	Weak	Dead		Vigorous	Weak	Dead
	Number of plants				Number of plants				Number of plants		
1	8	0	2	1	7	1	2				
2	6	1	3	2	8	0	2	2	10	0	0
3	5	2	3	3	10	0	0				
4	10	0	0	4	9	0	1				
5	8	2	0	5	7	1	2	5	7	3	0
6	10	0	0	6	9	1	0				
7	10	0	0	7	10	0	0				
8	10	0	0	8	10	0	0	8	5	2	3
9	9	1	0	9	3	0	7				
10	10	0	0	10	2	2	6				
Totals	86	6	8		75	5	20		22	5	3
Per cent	86	6	8		75	5	20		73	17	10

also was relatively little injury in three lots that were held under ice for 10 weeks, brought into the early stages of growth, and then frozen again, as shown in the table.

Similar results were obtained when the study was repeated the following year (table 6). The plants were handled in the same manner and check lots protected by mulch were kept in a cold frame or in the cold cellar. In this test when injury was observed it did not appear to be related to the length of time the plants were sealed in ice, as only nominal injury occurred in the lots held longer than three weeks under ice. Injury in the check lots appeared to be caused by drying. These results indicate that an ice seal maintained for as long as 10 weeks was not in itself a cause of serious injury to strawberry plants held at temperatures above 21°.

To obtain further evidence relative to the effects of ice, plants from winter storage were tied around screen-wire cylinders and then covered with cheese cloth. About half an inch of ice was built up on the cloth by spraying with ice water. After one to three weeks in storage at a temperature slightly below freezing, the ice was thawed at a temperature a few degrees above freezing. While thawing progressed, the plants were water-soaked and none survived. Other lots of plants were prepared so that the ice layer was not in contact with the plants. When this ice was cracked away, so that the plants were not water-soaked as they thawed, practically all survived and grew vigorously.

In all the foregoing experiments injury had been observed at temperatures only a few degrees above freezing whenever plants were more or less closely confined either in winter storage, beneath a layer of ice, in glass jars, or beneath a soggy mulch in the field. That injury may be caused by temperatures a few degrees above freezing while plants are closely confined is shown in table 7. The plants used in these tests were taken from winter storage, sealed in glass jars, and kept at a few degrees above freezing. This table shows that, in the first test, the total percentage of injured and killed plants in the jars was five times greater at six days than at three days as shown by growth for six weeks in the greenhouse. In the second test, observations of growth after three weeks in the greenhouse showed no plants were killed, but injury increased

FIG. 3. Effect of ice upon the survival of dormant strawberry plants—1939

Representative plants from lots sealed in ice for 2 weeks (upper left) to 10 weeks (lower right). Lot 1 (1 week) not shown on account of injury by red spider. Lots 8, 9, and 10 are smaller because of shorter period of growth.

markedly with the length of time the plants were sealed.

As injury was observed at temperatures a little above freezing while the plants were confined, a study was made of the effect of sunlight on the temperature of strawberry crowns sealed in ice. So long as these plants were held in a cold dark cellar, crown temperatures were the same as air temperatures. However, when the plants were placed in sunlight, crown temperatures rose above freezing in a few minutes. Usually within half an hour, and before the ice covering had melted enough to free the plants, crown temperatures rose to points varying from 35° to 39°. When thawing was rapid, the crowns seemed to become flooded with water from the melting ice and the temperatures dropped to about 34°. These plants, and check lots not injured by wires inserted to record temperatures, were thawed and their growth behavior observed. Higher percentages of injury and killing were found in both treated plants and checks than had been observed previously with iced plants kept in the dark. It is recognized that conditions in the field are likely to be different from those prevailing in this experiment. When plants in the field are covered with ice, light intensity probably is reduced

Table 7. Injury and Killing of Dormant Strawberry Plants When Closely Confined at Temperatures a Few Degrees Above Freezing

Test No.	Days sealed	Weeks in greenhouse	Growth response		
			Injured	Killed	Total injury
			Per cent		
1	3	6	4.2	7.5	11.7
	6	6	43.3	15.8	59.1
2	3	3	17.5	0	17.5
	6	3	27.5	0	27.5
	9	3	27.5	0	27.5
	12	3	37.5	0	37.5
	15	3	75.0	0	75.0
	18	3	70.0	0	70.0

considerably beneath the mulch, but the fluctuations in crown temperatures may occur over a period of many days. The occurrence of mud on the soil surface indicates that temperatures do rise above freezing beneath the ice-filled mulch. Such evidence makes it appear probable that temperatures beneath a covering of ice may rise to a point at which injury occurs.

In all these studies no serious injury to dormant strawberry plants has been observed that can be attributed to ice alone. Ice has caused little or no injury at temperatures slightly below freezing. But marked injury or killing has occurred when plants have been exposed to ice and low temperatures, ice and excess water at the time of thawing, or temperatures slightly above freezing beneath an ice layer.

3-INCH MULCH IS ADEQUATE

★

In an Ordinary Winter 3 Inches of Mulch Will Protect Against Injury from Low Temperatures

In studying the ability of a strawberry plant to survive winter conditions, not only is it necessary to know its reaction to low temperatures, but it is desirable also to know what temperatures are likely to occur in the winter environment of the plant. A record of the coldest air temperatures above a strawberry field gives very little information relative to the temperatures to which the plants are subjected beneath the mulch, snow, and ice in the fields in winter. Although information was available relative to soil temperatures during the winter months, information was needed in regard to the effects of various types and depths of mulches upon the temperatures occurring beneath such protective coverings. In order that information of this nature might be obtained, a study was carried on during the winters of 1934-35 and 1935-36.

Suitable plots were located in an open field in the fall. One of these was kept bare and the others covered with various types and depths of mulches. The several treatments used during the two seasons and their effects upon the temperatures beneath are shown in table 8. Throughout both seasons all additional snowfall was removed from the plots in order to maintain the several treatments as nearly as possible in their original condition. The temperatures shown in the table are the lowest recorded in each season at the soil surface beneath the mulches, a location that corresponds to the position of the crowns of strawberry plants.

This table shows that in 1934-35, a season which can be regarded as fairly typical for the locality, all the mulches afforded satisfactory protection against injuriously low temperatures. That the temperature fell slightly lower beneath 6 inches of straw than under 3 inches of straw apparently was due to the formation of a layer of ice in the 6-

Table 8. Minimum Temperatures at the Soil Surface Under Various Mulch Treatments During the Winters of 1934-35 and 1935-36

(All figures in degrees Fahrenheit)

Season	Type and depth of mulch treatments									
	Bare ground surface	3 inches straw	3 inches marsh hay	3 inches peat	3 inches leaves	3 inches snow	3 inches ice	6 inches straw	6 inches leaves	6 inches snow
1934-35	−7	22	......	22	......	......	......	19	......	21
1935-36	−7	9	15	−2	16	7	−1	25	18	17

inch mulch following a rain, whereas little ice formed in the 3-inch mulch.

The season of 1935-36 was of unusual severity, with a prolonged period of sub-zero temperatures. Although, under such conditions, the mulches were not as effective as in the previous year, the figures obtained are of interest.

Under 3 inches of ice the lowest temperature for the season was −1°, and beneath 3 inches of ice-filled peat it was −2°. These temperatures were only a little higher than the minimum of −7° recorded at the surface of bare ground, and they were considerably below the temperatures at which injury or killing of strawberry plants can be expected. The table shows that somewhat better protection was afforded by 3 inches of snow, and by 3 inches of straw. As the latter is representative of the common mulching practice it is of particular interest to note that in this instance the minimum temperature of 9° was below the usual "killing point" of strawberry plants. Beneath 3 inches of marsh hay, a material of finer texture than straw, the lowest temperature recorded was 15°, and under 3 inches of mixed leaves it was 16°. As shown previously, only plants that are well matured and thoroughly hardened are likely to survive after exposure to these temperatures. Under 6 inches of snow and 6 inches of mixed leaves, the lowest temperatures were 17° and 18°, respectively. Under 6 inches of straw the minimum for this exceptionally severe winter was 25°, well above the "danger point" for strawberry plants.

It is of particular interest to note the temperature of −1° beneath 3 inches of ice. It is a common belief that strawberry plants smother when covered with ice. This low temperature shows that ice affords little protection against cold, and indicates the possibility that a considerable portion of plant losses occurring under ice may be due to cold alone.

A study of the temperatures shown in table 8 indicates that no advantage is likely to be gained in an ordinary winter from a mulch of 6 inches in comparison with 3 inches of straw. In any locality or season, when a covering of snow adds further protection against low temperatures at the soil surface, the use of more than 3 inches of mulch probably would be neither necessary nor economical. The marked improvement afforded by 6 inches of straw during the severe winter of 1935-36, however, suggests the possibility that supplemental mulching may sometimes be desirable. When snow covering is lacking, or if winter temperatures are unusually low, or if frequent thaws have filled the mulch with ice, it may be desirable to provide further protection to strawberry plants by applying additional mulch material if this work can be done conveniently. A heavy mulch, however, may cause heating in the spring before it is removed.

These results indicate that in an average winter a grower need not be greatly concerned about the hardiness of his strawberry plants if they were well matured and hardened in the fall and protected at the proper time by a good mulch. Generally the temperature beneath mulch and snow is not likely to fall below the "danger point" for strawberry plants.

SUCCESS DEPENDS ON TIMING

★

Strawberry Fields Should Be Mulched After Several Light Frosts but Before the Temperature Falls Below 20°

It was formerly the practice to delay mulching strawberry fields until the ground had frozen hard enough to support a wagon. Mulching this late was not satisfactory as winter injury was not always avoided. As soon as it became known that injury to strawberry plants could be expected at temperatures below 20° F. it was evident that a considerable part of the injury observed on late-mulched plants occurred in the late fall before the plants were protected. When earlier mulching was recommended, many growers began to mulch too early and in some cases experienced more severe losses than with late mulching. As "early" and "late," because of variable weather, are not definite indications of the best mulching time, the relation of time of mulching to hardiness was studied.

Potted plants of the Beaver variety were used in 1939. These plants were dug in early September and handled as previously noted. Enough were potted to provide for six lots of at least 100 plants each. Mulching with 3 inches of straw was begun October 7 and one lot mulched each week until November 11. During the latter part of September and throughout the mulching period daily minimum temperatures were recorded at the soil level beneath the leaves. This location was selected because temperatures under the leaves are likely to be a few degrees higher than in the air above the plants, and a more accurate record was obtained of the temperatures to which the crowns were exposed. Minimum temperatures at or below freezing during this period are given in table 9.

Table 9. Occurrence of Frosts Beneath Strawberry Leaves in the Fall of 1939

Periods*	Occurrence of frost
Before Oct. 7	Sept. 25, 29°; Sept. 30, 26°
Oct. 7-14	Oct. 14, 25°
Oct. 15-21	Oct. 16, 23°; Oct. 17, 24°
Oct. 22-28	Oct. 27, 29°; Oct. 28, 20°
Oct. 29-Nov. 4	Oct. 30, 26°; Nov. 2, 23°; Nov. 3, 20°; Nov. 4, 24°
Nov. 5-11	Nov. 5, 30°; Nov. 6, 27°; Nov. 8, 26°; Nov. 10, 18°; Nov. 11, 18°

* One lot of potted plants was mulched on the last date of each period.

Frosts occurred on the mornings of September 25 and September 30 as shown. Warm days without frost from October 1 to 12 probably caused the loss of any hardening developed by the earlier frosts. Moreover, new growth appeared among the plants mulched October 7 and 14. Beginning on October 27, frosts occurred frequently. November 10 and 11, previous to the final mulching, the minimum temperature beneath the leaves was 18°, a temperature at which injury is likely to occur.

Plants in the six mulched lots were examined before the freezing treatments were begun. All the plants mulched October 7 had developed one or two new yellow leaves and most of the old leaves were moldy. Those mulched October 14 also had developed some new leaves. These were not so completely bleached as in the previous lot but were far from normal color. The old leaves were not moldy. The lot mulched October 21 showed a slight development of the crowns but no bleaching had occurred and the old leaves were in good condition. No evidence of growth was observed in the lots mulched on later dates.

Ten days after the last lot was mulched, 10 pot samples were taken from each of the six lots for freezing treatments. One group of samples was frozen for 24 hours at 27°, a second group at 21°, and a third at 16°. All lots were thawed slowly and brought into growth gradually in a cool greenhouse.

The growth response of these plants is shown in table 10. This table shows that all of the plants mulched October 7, which had developed bleached leaves under the mulch, were killed at 27°. It is apparent that any hardening from the frosts of September 25 and 30 was lost by these plants during the week of warm weather before they were mulched. Also, the fact that all plants were killed at 27° indicates that

Table 10. Growth Response after Exposure to Freezing Treatments for 24 Hours of Beaver Strawberry Plants Mulched at Weekly Intervals, 1939

(Potted plants, 10 pots per lot)

Date of mulching	Freezing temperatures in laboratory								
	27°			21°			16°		
	Vigorous	Weak	Dead	Vigorous	Weak	Dead	Vigorous	Weak	Dead
	Number of plants								
October 7	0	0	10	0	0	10	0	0	10
October 14	5	2	3	4	4	2	0	2	8
October 21	10	0	0	9	0	1	0	5	5
October 28	10	0	0	9	0	1	2	6	2
November 4	9	1	0	9	1	0	9	0	1
November 11	7	3	0	8	2	0	6	3	1

they did not harden beneath the mulch. These plants were unable to withstand exposure to 27° for 24 hours, whereas plants of the same variety in the early stages of growth in sunlight in spring have been found to endure a similar exposure with no evidence of injury (see table 13).

The plants mulched October 14 had an opportunity to harden only on the night before they were covered, and they had produced a few bleached leaves beneath the mulch before the freezing tests. These plants were more resistant to cold than the lot mulched a week earlier but they still were not far advanced in hardening as is indicated by the number of weak and dead plants.

Hardiness increased in the lots mulched on later dates as shown by better survival following exposure to 16°. It is of interest to note the increase in hardiness of the lot mulched October 28 immediately following two frosts, and the marked increase in hardiness of the plants mulched November 4 following several frosts. Although a short exposure to frost hardened some of these lots it is clear that the maximum hardiness was developed in the plants mulched November 4 by a series of frosts at 20° or above.

The plants mulched November 11 showed somewhat less satisfactory survival although they were more hardy at 16° than any lot mulched previous to November 4. This last lot was exposed to a temperature of 18° on two nights just before they were mulched. Increase in the number of weak plants in this lot probably was due to these hard freezes adding to the injury by the controlled freezing treatments. This result indicates that when mulching is too long delayed the plants may be injured by hard freezes before they are protected by mulch.

Severe drouth in September, 1940, presented a repetition of this study with potted plants as attempts to dig plants in the hard dry soil caused extensive damage to the roots. The study, therefore, was carried on in the field. Mulching was delayed until after a light rain so that the plants might recover somewhat from the effects of drouth.

As in the previous season, records were kept of the temperatures close to or below freezing that occurred beneath the covering of leaves. The temperatures observed are shown in table 11. The temperature did not fall below 34° in October and maximum air temperatures were above 50° throughout the month. The first freezing beneath the leaves was November 6. No records were made after November 11 as all plots were covered with snow continuously from that time until March 10.

Table 11. Occurrence of Frosts Beneath Strawberry Leaves in the Fall of 1940

Periods*	Occurrence of frost
Before Oct. 14	None
Oct. 14-21	None
Oct. 22-28	None
Oct. 28-Nov. 4	None
Nov. 5-11	Nov. 6, 29°; Nov. 7, 27°; Nov. 8, 25°; Nov. 9, 33°

* One plot was mulched on the last date of each period.

Mulching was begun October 14 and the remaining plots were mulched at successive weekly intervals. The blizzard of November 11 interfered with the regular mulching program. After that date the mulch was put on over the snow.

November 6 the plots were examined for evidence of growth or yellowing. Plot 1, mulched October 14, showed a general development of new leaves, all of which were yellow. Plot 2, mulched October 21, showed less growth and the newly developed leaves showed somewhat less yellowing. Plot 3, mulched October 28, showed some slight development of the crowns but there was no apparent yellowing. Plot 4, mulched November 4, and all later lots showed no evidence of growth or yellowing, and all appeared to be fully matured and dormant. The heavy covering of snow over all the plots after November 11 afforded ample protection from low temperatures during the following week when minimum air temperatures were only a few degrees above zero. No evidence of frozen soil was found until December 2 when the mulch was spread on Plot 7 over 7 inches of new snow. Some formation of ice at the plant level was noted at this time in the first four plots. Periods of mild weather, and heavy rains on January 1 and February 12, 1941, led to the formation of a layer of ice over the plants extending upward into the mulch over the plots mulched before November 11. Although ice covered the plants in the plots mulched later than November 11, none formed in the mulch as it was separated from the plants by a layer of snow.

On March 20 nearly all snow had melted but the mulch was filled with granular ice and the soil beneath was frozen to a depth of 6 to 8 inches. Soil temperatures were not recorded in the plots, but as low temperatures are known to occur beneath a layer of ice during cold weather, it is likely that when air temperatures fell to zero or below on March 16, 17, and 18, the temperature at the surface of the soil beneath the ice-filled mulch fell low enough to cause injury at this time to the plants that had made some growth beneath the mulch in the fall.

Records of the condition of the plants in the several plots made April 25 are shown in table 12. A representative number of plants was examined in each plot and their condition expressed in per cent. This table shows high percentages of weakened and dead plants in Plot 1 in which the plants produced many yellow leaves beneath the mulch. Weakening and killing in Plots 2 and 3 were directly related to the extent of growth and yellowing observed in the fall. Loss of 9 per cent of the plants in Plot 4 mulched November 4 probably can be accounted for by the fact that the plants, although well matured, had not been fully hardened by frosts before they were mulched. Only nominal losses occurred in Plots 5, 6, and 7 that

Table 12. Survival of Beaver Strawberry Plants in Plots Mulched at Weekly Intervals in 1940

Plot No.	Date mulched	Number plants examined	Condition of plants: Vigorous	Weak	Dead
			Per cent		
1	Oct. 14	314	9	28	63
2	Oct. 21	366	16	39	45
3	Oct. 28	341	57	32	11
4	Nov. 4	324	83	8	9
5	Nov. 18	351	92	3	5
6	Nov. 25	309	91	3	6
7	Dec. 2	322	89	6	5

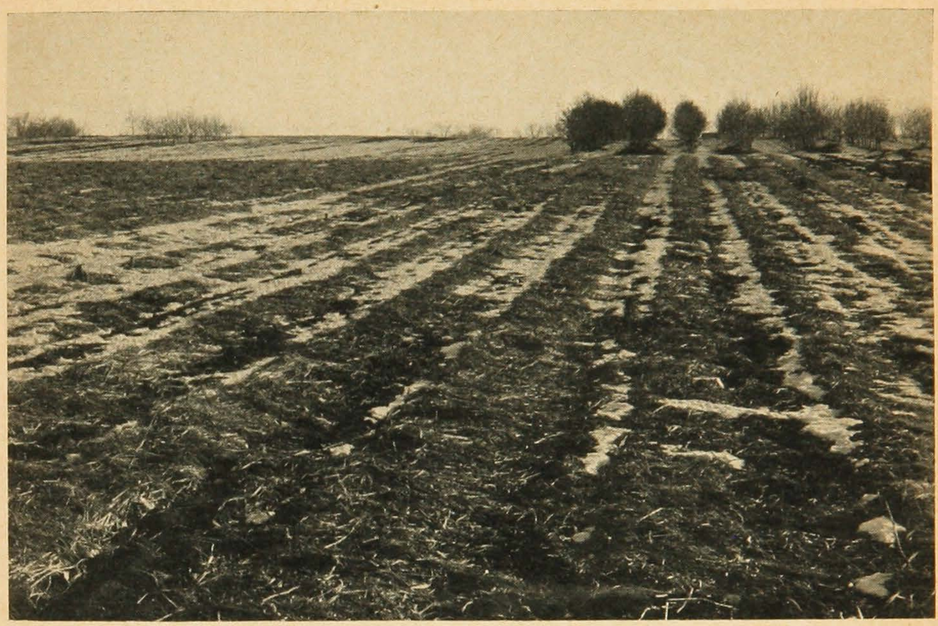


FIG. 4. In an open winter strawberry plants need good mulch protection, as shown in this field at the University of Minnesota Fruit Breeding Farm

had been exposed to frosts before being covered by snow and mulch. Most of the plants in these plots that were weakened or killed were either mother plants or late-formed runners.

These results show that mulching too early is likely to lead to severe injury. When the mulch was applied too early the plants tended to develop yellow leaves, apparently did not harden to any great extent, and were injured or killed at temperatures only a few degrees below freezing. A series of light frosts seems to be necessary to develop maximum hardiness in strawberry plants. The best time to mulch apparently is immediately after a series of light frosts. Generally it will not be safe to mulch before such frosts occur. Also, it will not be safe to delay mulching until the temperature beneath the leaves falls below 20°, or to wait until the ground freezes hard. Weather reports should be watched carefully and temperatures observed in early morning close to the crowns of the plants by means of a thermometer placed beneath the leaves. In this way the best time to mulch should be easily determined.

In central and southern Minnesota, where severe freezing usually does not occur until late in October and where the soil is not likely to freeze until sometime during the first half of November, it is not likely that conditions in the average season will make it desirable to mulch before late October. However, mulching usually should be done before mid-November.

In northern Minnesota, where severe freezing may occur suddenly and earlier in the fall, a somewhat different procedure may be needed, particularly for the fall-bearing varieties that are less hardy. As the crowns and roots are most in need of protection, it is suggested that an early, light application of finely divided mulch material be spread over the plants and allowed to sift down below the leaves. Such a light mulch applied before mid-September should serve to protect the crowns and roots against injury from early hard freezes and at the same time afford the leaves some opportunity to function in maturing and hardening. The usual heavier mulch can be spread later when the frequency and severity of hard frosts indicate the need for such protection. In the average season it is likely that in northern Minnesota it will be desirable to apply the full depth of winter mulch at least by mid-October.

PLANTS RESIST SPRING FREEZES

★

Plants Reharden Against Frosts Occurring during Early Stages of Growth in Spring

Observations at University Farm of the behavior of established strawberry plants at the beginning of growth in the spring have shown that such plants often escape serious injury when exposed to rather severe freezes. In the early spring of 1938, plants of the Beaver and Dunlap varieties that had not been mulched during the winter had begun to grow in late March and showed several fairly well unfolded new leaves per plant. On the night of March 31 a sudden drop in temperature exposed these plants to a minimum air temperature of 19° F. In the open fields and beneath these unprotected plants the ground was frozen hard although its temperature probably was somewhat higher than that of the air. These plants continued their growth with the return of warmer weather and showed little injury.

A similar but more severe test occurred in the spring of 1939. Plants of the same varieties, not protected by mulch, had started to unfold their new leaves in early April, although they were not quite so far advanced as those observed during the previous spring. Frosts of varying severity occurred on nearly every night from April 1 to 18. The plants were partially protected by light snow on April 7, 8, 11, 17, and 18, but there was no such protection on April 6 and 12 when the minimum air temperatures were 20° and 16°, respectively. The temperature of the crowns at the soil surface probably was somewhat above these figures. Survival, with subsequent production of good yields, under these severe conditions at the beginning of growth was 90 per cent for Dunlap and 95 per cent for Beaver.

The resistance of these growing plants to fairly low temperatures indicated that either the cold resistance acquired in the fall had been retained or that if hardiness had been lost the plants were able to regain it rapidly enough to escape serious injury. In order to obtain further information relative to the cold resistance of strawberry plants in the early stages of growth under controlled conditions, a study was carried on with eight varieties during early April in 1941. The varieties used were those listed in table 13. All the plants had been potted and plunged in peat in the fall, matured, hardened, and mulched before the onset of severe cold weather. The mulch was removed April 1. During the two weeks preceding the freezing test there was no frost and conditions were favorable for growth. During the first week the minimum air temperatures generally were between 35° and 45° and the maximum temperatures ranged between 42° and 65°. During the second week warmer weather prevailed. The lowest temperature recorded during this week was 40° on the morning of April 9 and on April 12, 13, and 14 the maximum temperatures were 79°, 76°, and 75°, respectively. Under such conditions the plants grew rapidly and all had two or three fully unfolded new leaves when the freezing test was begun.

On April 15, samples of 10 pots each from each of the eight varieties were exposed for 24 hours to a temperature of 27°. On April 16, 17, and 18, similar samples of the growing plants were exposed directly to temperatures of 21°, 16°, and 10°, respectively, for 24 hours. All samples were thawed slowly and then returned to the open frames to observe their growth response.

Table 13 shows the results obtained following the exposures to 27° and 21°. As all plants in all varieties were killed at 16° and 10° these results are not shown in the table. In all eight varieties no plants were killed at 27° and only a few were injured and weakened. Growth following exposure to 21° was very erratic in the eight varieties but it is of interest to note that 18 of the 80 plants, or 22.5 per cent, were able to survive and grow vigorously after this sudden and severe treatment. As there was severe injury to the Beaver, Dunlap, and Burgundy (Minn. No. 1192) plants at 21°, it does not appear that these varieties, generally rated as the hardiest among local varieties, had retained the degree of hardiness usually found in dormant plants. As hardened dormant plants of these varieties generally have escaped serious injury at 21° and often have survived fairly well at 16°, it is apparent that in the early stages of growth these plants were much less hardy. It is of interest to note, however, that the plants beginning growth were hardier than those that grew and bleached beneath a mulch applied too early in the fall (see table 10).

The observed ability of unprotected plants in the field to withstand freezing temperatures during the early stages of growth, and the survival following exposure to controlled temperatures at 27° and 21° as shown in table 13 is believed to be an indication of the ability of strawberry plants to reharden rapidly to a limited degree at this stage of growth rather than that any considerable degree of hardiness has been retained.

PRINCIPAL CONCLUSIONS

★

Findings of These Studies Point the Way to More Satisfactory Mulching Practices

These related studies show that strawberry plants are hardened by several light frosts in the fall. Mulching should be delayed until the plants

Table 13. Cold Resistance of Strawberry Varieties in the Early Stages of Growth
(10 pots per lot)

Variety	Temperature treatment*					
	27°–Growth response			21°–Growth response		
	Vigorous	Weak	Dead	Vigorous	Weak	Dead
	Number of plants					
Beaver	10	0	0	0	3	7
Catskill	9	1	0	0	1	9
Dunlap	10	0	0	1	3	6
Premier	10	0	0	4	4	2
Burgundy	10	0	0	1	3	6
Gem	9	1	0	0	0	10
Wayzata	8	2	0	5	5	0
Minn. No. 1167	8	2	0	7	2	1

* Comparable lots of all these varieties were killed by exposure for 24 hours to temperatures of 16° and 10°.

are hardened but the plants should be covered before the temperature at the crowns falls below 20°. Considerable injury may result if fields are mulched either too early or too late. Fully matured and hardened plants usually can endure temperatures as low as 21°. This is close to the "danger point," however, and there is likely to be increased injury down to the "killing point" which lies close to 10°. No evidence was obtained to indicate that the plants become hardier during the winter. When growth begins in spring, the plants appear to be able to harden quickly to escape injury from frosts, but they are less hardy then than in late fall and winter.

Varieties of the June-bearing type are somewhat hardier than those of the fall-bearing type. The common practice of covering the fields with 3 inches of straw mulch usually will provide ample protection against temperatures low enough to cause injury. Snow over the mulch provides additional protection. Internal activity of the plants is low in winter and they require very little oxygen at that time. This low activity possibly explains their survival for many weeks beneath a covering of ice. Dormant plants have been "smothered" experimentally only when tightly sealed in jars for seven weeks. In the field it is likely that there are channels in the ice for the movement of oxygen in the small amounts needed for survival.