STUDIES IN THE
WINTERKILLING OF CEREALS

by

Harlan Randolph Sumner, B. S. A.

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INTRODUCTION

Nearly 70% of the wheat (89), 7% of the oats (89), and 1% of the barley (29) grown in the United States is sown in the fall. The winter wheats are more desirable than the spring wheats: they are earlier maturing and consequently escape hail, hot winds, diseases, etc.; they give larger yields under favorable conditions; are more drought resistant; and permit a more efficient distribution of labor (64). Warburton (83) recommends growing winter oats in the Southern states wherever possible. Winter oats yield more than spring oats; mature earlier; allow a better distribution of labor; furnish a pasture and cover crop as well as prevent washing; and they may be grown on soils of less fertility (83). According to Derr (11), winter barley in the Southern states yields more; matures earlier, and thus escapes drought, and hot winds; provides a cover and pasture crop; and permits a more economic distribution of labor than spring barley.

Temperature is the chief limiting factor in the yield and quality of cereals. The maps on page 2 show the relation of the distribution of spring and fall sown grains to temperature. The isotherms of 10°, 20°, and 30° connect all points of equal mean temperature for January and February. Figure I shows how markedly the regions of spring and fall sown grain follow the temperature curves. The shaded area on Figure II shows the area in which Warburton (83) has stated that winter oats could be grown with profit were it not for the occasional winter of

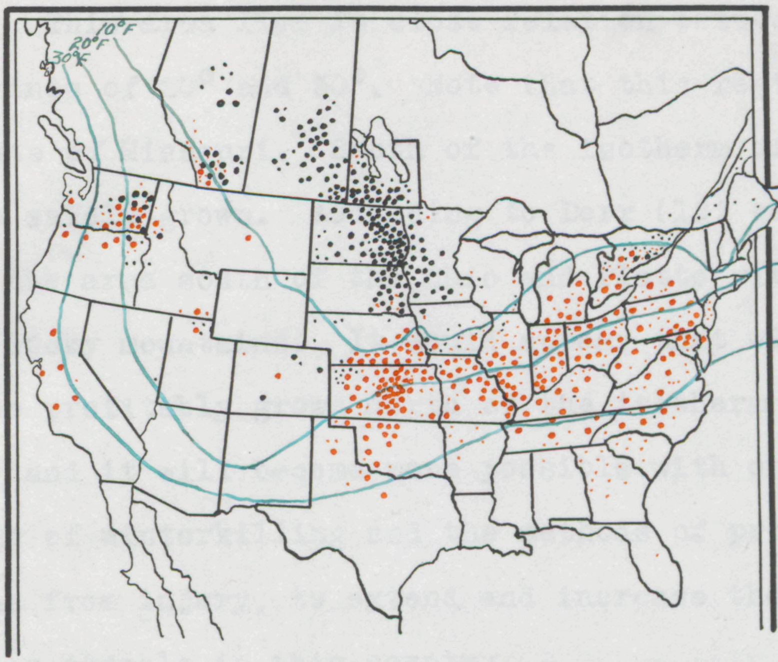


Fig 1:- Distribution of winter and spring wheat. Black dots represent spring and red dots winter wheat. Large dots represent 100,000 acres each, small dots 5,000. Isothermal lines connect points of equal mean daily minimum temperature for Jan. and Feb.

After Salmon.

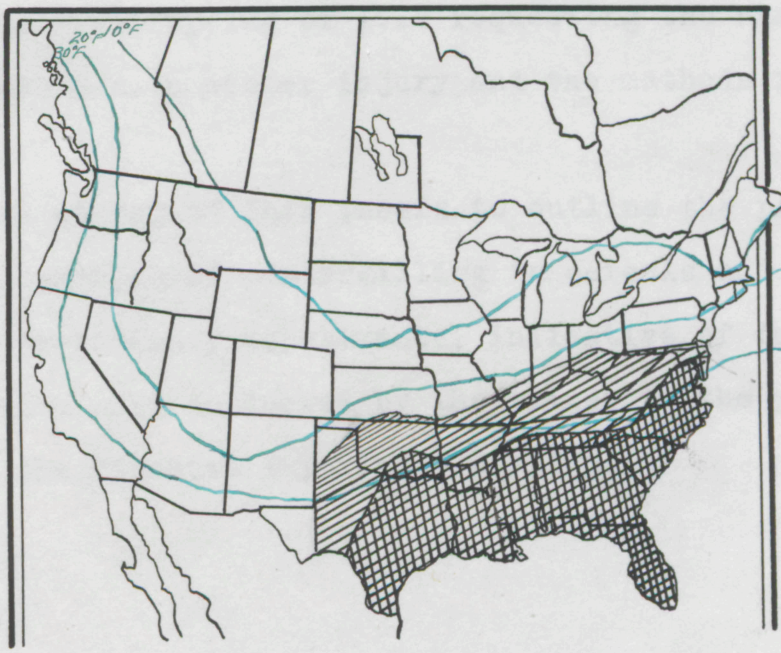


Fig. 2:- Distribution of winter oats in the South. In heavily shaded portion they may be safely grown, in light shaded portion there is danger of winterkilling. Isothermal lines connect points of equal mean daily minimum temperatures for Jan and Feb.

After Warburton.

severe cold. This area lies in close relation between the isothermal lines of 20° and 30°. Note that this region extends into the State of Missouri. South of the isotherm of 30° winter oats are safely grown. According to Derr (12) barley is confined to the area south of the Ohio and Platte rivers and west of the Rocky mountains. It would appear that winter barley cannot be profitably grown north of the isotherm of 20°. It is possible, and it will become more possible with our increasing knowledge of winterkilling and the methods of protecting winter grains from injury, to extend and increase the production of winter cereals in this country.

The farmer is demanding that attention be paid to the problem of winterkilling. As a result of the severe winter of 1916-17 the Missouri Experiment Station received many letters in the early spring of 1917 requesting the names of varieties resistant to winter injury and the methods for protecting them.

It is the object of this thesis to outline the present status of the problem of winterkilling in cereals and to report certain preliminary experiments, indicative of future development, which were conducted by the writer in the winter of 1916-1917 at the Missouri Experiment Station.

REVIEW OF THE LITERATURE ON WINTERKILLING.

The causes of winterkilling as determined by various investigators may be classified as follows: (1) heaving; (2) physiological drought; (3) smothering; and (4) freezing of the plant tissues.

HEAVING.

Heaving is one of the most common sources of injury. It generally occurs in the late winter or early spring when the soil is well supplied with moisture from the winter snows. The expansion and contraction caused by alternate freezing and thawing of the soil moisture causes the plants to be lifted out of the soil. The plants with their deep roots torn and broken, suffer from drought and ultimately die or at least are badly injured.

Land that is poorly drained is subject to greater danger from heaving than is a well drained soil. Good drainage as a protection against heaving was advised as early as 1847 by a farm correspondent in the Genesse Farmer. (26) He advised, as a safeguard against winter injury, the planting of wheat only on well drained soil. Carleton (9) has noted that winter grains are more easily winterkilled on low, wet lands because under such conditions heaving is more apt to occur.

The plants should be firmly rooted in the soil to withstand heaving. In this respect the date of planting influences the amount of heaving which the plant is able to resist since the root development is dependent largely upon the stage of growth. Koglovski (33) noted that the vigorous growth and degree of stooling that a plant acquires in the fall is proportional to the amount of winter injury. In the Genesse Farmer (26) for 1847 a correspondent advised planting fall wheat early and deep to protect the plants from heaving. It was found by Buhlert (7) that the more hardy sorts were less developed than those with less resistance. The total dry matter of the parts above ground averaged 0.0164 grams per plant; that of the hardy sorts averaged 0.0150 grams. The same fact was found to be true in comparing the dry weight of the roots. He also found the less hardy sorts to have a greater total root length than the hardy varieties. This is shown in the following table.

Variety	Degree of Resistance	Dry Weights			Root Length mm.
		Above ground	Roots	Ratio	
Wheat					
Preussen	more	0.0150	0.0192	1:128	873
Eckendorf	less	0.0164	0.0216	1:32	927
Rye					
Zeeland	----	0.0221	0.0177	1:0.8	873
Johannis	----	0.0176	0.0134	1:0.76	628

Derr (12) has stated that the late seeding of barley is liable to result in winterkilling. Carleton (9) has observed that a winter hardy variety produces a large number of strong roots, but grows little above ground before winter. He also states that winter grain should be seeded early enough to form a strong root system before winter.

It is an accepted fact that sowing with a grain drill is superior to sowing broadcast. Among the points in its favor the fact that drilling causes a less amount of winterkilling has been noted by several investigators.

In 1889 Latta (35) stated in a comparison of drilled and broadcasted plots: "The broadcasted plots have invariably been damaged most in winter. The superiority of the drill after four years of testing is plainly manifested." Hays (31) in a two years test found that drilled plots yielded 9.05 bushels per acre compared to 6.25 bushels on the broadcasted plots. He further noted that the drilled wheats were more deeply and strongly rooted and withstood heaving better than those plants on the broadcasted plots. Falke (17) found that seeding with a press drill caused wheat, rye, and barley to be more resistant to winterkilling than when otherwise sown. Warburton (83) stated that oats when broadcasted are more apt to winterkill than when drilled. He obtained a yield of 24.3 bushels per acre on plots which were sown broadcast and 26.7 bushels yield upon plots which were drilled. Barley was found by Derr (11,12) to root deeper and to withstand cold better when drilled than when sown broadcast. Similar results are reported by Livingston (37). McClelland (44) has advised shallow drilling of oats in preference to broadcasting. Carleton (9) also commended the practise of drilling winter grains. Schmitz (67) reported that drilled wheat will stand the winter better than broadcasted wheat.

The practice of seeding winter grains in open furrows to protect the plants from heaving is recommended by different authorities. The action of the frost and winter rains causes the soil to crumble and wash down from the ridges, thus filling around the plants that have been partly lifted from the soil. This method has been recommended as a protection from heaving by Redding (58); Warburton (83); Remy (59); Duggar (14, 15); McClelland (44); Ricks (60); Salmon (65); and Schinitz (67). The method of sowing in the open furrows will be taken up in detail later in this thesis.

Rolling winter grains in the early spring or immediately after heaving gives excellent results. By this means the plants are pressed back into the soil and the surface and sub-soils are reunited. Montgomery (46) at the Nebraska Station in a four year test, obtained an average yield of 43.3 bushels per acre on drilled plots that were rolled and only 38.2 bushels per acre on drilled plots that were not rolled. He stated: "Early spring rolling of winter grains, pressing the earth as it does about the plant roots that have been partly heaved out by the frost, produces good results." Warburton has advised rolling winter oats immediately after heaving. Derr (12) wrote: "Where the crop (barley) has suffered from heaving, excellent results follow from the judicious use of a light roller in order to bring the exposed plants into closer contact with the soil." Duggar (14) also has recommended rolling as a method of decreasing the number of plants injured by heaving.

Heaving is a common type of winterkilling. It will be found beneficial to plant the crop moderately deep with a grain drill and roll the field with a light roller in the early spring to press the plants back in the soil. The practise of planting the crop in open furrows will also be found to be helpful where heaving occurs. Well drained soils are not apt to heave and any practise that will aid in the formation of a sturdy root system may be advised.

PHYSIOLOGICAL DROUGHT

Winterkilling due to physiological drought, or in other words, to the freezing of the soil moisture so as to cause the plant to suffer from lack of moisture, is rarely found.

Pfeffer (55) believed that in certain instances the plants may be killed because the soil becomes so deeply frozen that no moisture is available to the plants. Schimper (70) stated that a frozen soil is quite dry to all plants. Sacks and Müller-Thurgau (10) observed wilting was due to the inability of the roots to take up moisture which had evaporated from the leaves. Molisch (10) claimed that plants exposed continually to a temperature too low for normal metabolism, but above the freezing point, will die. Under these conditions the plants turn yellow or dark colored spots appear upon the leaves.

SMOTHERING

The smothering of plants due to the formation of an ice sheet over a field is a rare but possible cause of winter injury. After a heavy snow which melts and does not drain off, a sudden lowering of temperature may form an ice sheet over the field and the plants are smothered. This type of winterkilling was mentioned by Wright (88).

FREEZING OF THE PLANT TISSUE.

The most destructive as well as the most common type of winterkilling is the freezing of the plant tissues, which is directly due to low temperature. Although this is an important phenomenon, suprisingly little is known of the underlying causes of this mode of injury. Contradictory, confusing, statements are prevalent even today and the correct solution remains yet open to debate.

Death Due to the Mechanical Action of the Ice.

The early Greek writers (10) with their limited knowledge concerning cell structure believed that the death of the plant was due to the mashing and rupturing of the plant organs by the ice. In 1737 Du Hamel and Buffon (10) offered the theory, based upon a slight knowledge of plant structure, that death, after an exposure to a low temperature, was the result of cell wall injury due to the expansion accompanying ice formation. Du Hamel and Senebier (55) thought that death was due to the bursting and crushing of the cells by ice. The same theory has been supported by Hales, Miller, Shomer, Sennebier, Thonin, Sprengel, and Schubler. (86)

These erroneous theories regarding the mechanical action of ice have since been conclusively disproven. One of the most severe blows this theory has received is the fact that ice is rarely, if ever, formed within the cell, but instead it occupies the intercellular spaces.

Goeppert (86) in 1830 showed that ice was more likely to form in the intercellular spaces than within the cell itself. Then in 1860 Sachs found that the ice rarely formed within the cells and he even went further to claim that if it did form within the cell, the freezing of all the water within the cell would not be sufficient to rupture it. In this last claim he was supported by Nageli. (86) Müller-Thurgau and Molisch (10) with the aid of a microscope found that ice is very seldom formed within the cell but that the ice crystals occur in the intercellular spaces. Sebastiano Cavallero (1), Goeppert (86), Prillieux '86), Kunisch (86), and Lugger (38), have all supported and offered proof to this fact.

At this place it is perhaps fitting to speak of the manner in which the ice forms in the plant.

Formation of Ice in the Plant.

Sachs (86) in 1868 observed the formation of ice within the plant tissues. This was also observed by Prillieux (55) who concluded that the large ice clumps which formed in the intercellular spaces force the cells apart. Prillieux and Müller-Thurgau (86) both noted that these ice clumps are composed of two layers of prismatic crystals. The thickness of these layers depends upon the supply of moisture which they have to draw from. As these prisms grow the cells collapse. The growth of the ice crystals was thought to be due to the addition of water molecules to the end of the prism. Weigand (86) has made an excellent report of his studies on the formation of these ice crusts in Spirogyra and Nitella. Sachs (86) reported that there is no relation between the formation of the palisaded ice prisms, which often incrust the surface of plants, and the structure of the cell wall or the nature of the cell sap.

In most fleshy structures the ice masses which are lenticular in form lie irregularly or parallel to the surface. In leaves, Wiegand found, that the ice crystals first line the spaces of the spongy parenchyma while in twigs the ice layer completely separates the inner and outer layers. The ice crystals are composed of pure water.

Thus from the facts which have been discovered concerning the formation of ice in plants one would conclude that death is not due to mechanical injury. Müller-Thurgau and Voigtlander were able to cool tissue below the death point and if no ice formed the plants were not killed. Thus they proved that ice formation is necessary for death. Mez (10) has found that if ice formation begins as soon as the freezing point is reached the injury is not so great as if supercooling is practiced. Following the discoveries of intercellular ice formation, by Göeppert, Sachs and others, another theory for the cause of death was offered.

Death Due to the Rate of Thawing.

Sachs (10) after immersing frozen plants in cold water to determine the effect of slow and rapid thawing, concluded that death was caused by the rate of thawing. Detmer (1) in 1888 agreed with Sachs but he claimed further, that some parts of the plants die in consequence of freezing alone. This theory at once provoked the severe criticism of many investigators, notably Müller-Thurgau and Molisch.

Both Müller-Thurgau and Molisch (10) after thawing a great number of plants at various rates were positive in their statement that the rate of thawing has little influence upon the death of plants. However, with the fruit of the apple and pear they found that the rate of thawing influenced the amount of injury. Vines (81) mentioned the fact in 1886 that if a plant is thawed slowly it will live, because the cell will have time to absorb the water again. Pfeffer (55) has concluded that since a non-resistant plant cannot be saved by the most careful thawing and a resistant plant survives even after a most rapid thawing, death is caused by low temperature and not by the rate of thawing of the ice within the plant. Wright (88) found that if plants are thawed out slowly they are not so badly injured as if rapid thawing had taken place. Abbe (1) in 1895 discussed the rate of thawing and its influence on death. He claimed that it is not the injury due to rapid thawing but the accompanying evaporation that eventually results in the death of the plants. Chandler (10) found that the rate of thawing has little or no influence upon the amount of injury.

At the time Müller-Thurgau and Molisch condemned the theory of death as a result of rapid thawing they presented the theory that death is caused by the withdrawal of the moisture from the plant cells.

Death Due to Desiccation.

The ice crystals as found in the intercellular spaces are pure water that has been withdrawn from the cells. There is much argument as to the manner in which the water is withdrawn from the cells. Wiegand (88) has clearly reviewed this point.

There are two theories offered to explain the manner in which the water passes from the cell into the intercellular spaces: (1) the expulsion, and (2) the attraction theory.

The adherents of the expulsion theory claim that the cell gives up water at low temperatures before freezing commences. But, Keiner, Molisch, Kuhne, and Greeley have only found a few instances in which the cells exude their moisture at low temperatures and, too, the ice is not formed until the intercellular spaces are several degrees below freezing. The third objection is found in the fact that this ice formation occurs in dead material where the protoplasmic wall ceases to excrete water.

For the attraction theory Wiegand (85) gave this hypothesis which is summarized as follows: The cell is surrounded by a surface film of nearly pure water. In this film, as the temperature lowers, crystals form. The cell wall is then lacking its water of imbibition and consequently the water will move thru the cell wall until this force is equalized. This water is gathered from the inner wall layers and they will be supplied with water by the protoplasm which in turn will receive its water from the cell sap. Thus a readjustment of equilibrium will occur throughout. Or, it may be that the crystal actually draws water towards itself by the adhesive character of the molecular structure of the crystals.

Müller-Thurgau and Molisch (45) both held that death is due to the withdrawal of the water from the cells. Pfeffer (85) has modified this somewhat and concluded that the death of plants, unable to withstand desiccation, is directly due to the withdrawal of water resulting from the formation of ice. Molisch (45) noted that following the extraction of the cytoplasm during the freezing process the protoplasm shrinks up into a shapeless mass with the water occupying the interstices. As the plant thaws the intercellular water escapes from the plant by transpiration, very little going back into the cell. The plant then wilts as a result of this rapid loss of moisture. It is here that the difference may be between immature plants and plants which are more mature. According to Abbe (1) in the case of young plants the exudation of the moisture thru the tender cell walls lies on the outside of the cuticle while with older plants the exudation is merely into the intercellular spaces. So, in the case of the tender plants, the evaporation is more rapid and the plant dies; the exudated water in the more mature plants has time to return within the cell again. As the water is withdrawn from the cell and frozen, the cell sap becomes more concentrated and correspondingly greater becomes the force with which the remaining molecules of water are held. The freezing force must overcome the force of imbibition or molecular capillarity.

Weigand (85) has shown that the largest amount of ice is formed near the freezing point and as the temperature falls more ice is formed. He believed that death is due to desiccation as a result of ice formation. Moll (1) has shown that the wilting of plants is due to the collapse of the cells whose exuded water has frozen in the intercellular spaces. Lugger (38) noted that the withdrawal of the water from the protoplasm of the cell by freezing causes death. Schimper (70) has supported this view. Pfeffer (55) believed that death is not due to desiccation alone. Some plants are capable of withstanding much lower temperatures than others that die before the formation of ice occurs. Pictet (55) has shown that if a plant can withstand desiccation it cannot be killed by cold. This view was practically disproved by De Candolle (55). Maksimov (41) upheld the view of Müller-Thurgau when he found that the formation of ice is necessary to cause injury to the plasma membrane. Chandler (10) found that the amount of water loss necessary to cause death, varies in different plants and their tissues.

The temperature at which all the moisture is frozen in the cells is important in considering the influence of desiccation on death. In 1886 Müller-Thurgau (10) determined the percentage of the plant water that is frozen at different temperatures. He found that at -4.5° 63.8% of the water was frozen in the apple: at -13°, 74.4%; and at -15.2°, 79.2% was frozen. Pfeffer (55) has stated that the water would be completely withdrawn at -30°C. He concluded that usually more than one-half of the water in a plant is frozen at from -3° to -8°C; at -50° to -80°C therefore no water in the cell would remain unfrozen. Müller-Thurgau (55) found the freezing points of herbaceous plants to be between -0.15° and -8° C and in succulent plants between -1° and -2° C. Plants have a lower freezing point than that of their cell sap. It is possible to lower the temperature below freezing before ice crystals are formed. Mez (10) found that at -6° C all solutes will crystalize out. He concludes that this refutes the theory of desiccation as stated by Müller-Thurgau and Molisch, as the plant would not be able to survive this temperature. But Chandler (10) has pointed out the fact that Müller-Thurgau and Voigtlander both supercooled plants below the killing temperature without injury to the plants so that Mez's claim is poorly grounded. Plahn (56) believed that the death point due to cold is generally placed too high.

Therefore while the theory of death due to desiccation is the commonly accepted view, yet it will not bear out under all conditions. Schaffnit (64) nearly outlined the complexity of the question correctly when he said: "For those plants to whose constitution and existence water is an absolutely essential factor, the abstraction of water is the primary cause of death while chemical and physical changes produced by low temperatures may be considered as secondary factors." Although investigators such as Chandler are willing to accept desiccation as a primary factor in winterkilling, yet they are constantly producing evidence pointing to other factors which might cause winterkilling; these theories may be termed physical and chemical.

Other Theories Regarding Low Temperatures and Death.

Pfeffer (55) observed that the great variation in the degree of cold which produces injury or death in plants shows that the death is due to disturbances in the protoplasm; these disturbances may vary greatly.

It was observed in 1880 by Kunisch (81) that the lowering of the temperature is accompanied by chemical changes which, he believed, are the true causes of death. Gorke (10, 3) found that the plants most easily killed by freezing have their proteids precipitated at a relative high temperature. Begonia which is killed at a high temperature had its proteids precipitated at -3° C and pine needles were subjected to a temperature of -40° C before their proteids were precipitated. He claims that this precipitation of the proteids results in the death of the plants. Buhlert (6) found that when the juices of plants were kept at from 5° to -40° C chemical changes took place under the action of low temperature but the juices of different plants underwent different changes. The frozen juice caused a precipitate of albumen with traces of lime and phosphoric acid. He found that spring barley precipitated albumen at a temperature of -7° C, winter barley at -15° C and pine needles at -40° C. Schaffnit (10) claimed that death is caused by the precipitation of proteins which is brought about by low temperature. Ramann (57) has found, however, that the protein and sulphur contents of the leaves remain unchanged upon freezing. He further found that the amount of potassium and phosphoric acid was decreased; that the amount of calcium was increased; and that all these changes occur between the stages of thawing and drying out. Pfeffer (55) disagreed with Pictet who observed that a possible cause for death might be a cession of chemical actions, claiming that it does not afford any explanation of death from cold.

Göeppert (55) in 1830 believed that successive freezing and thawing causes death. Wright (87) in this connection found that the second time the cell sap is frozen it freezes at a higher temperature than it did the first time.

Pfeffer (55) believed that death might take place after either long or short exposures to low temperatures. This view was also held by Vines (76). Butters and Rosendahl (7) found that prolonged solid freezing will injure the plants more severely than freezing of shorter duration. Shreve (72) found, from testing succulent plants native to various altitudes in southern Arizona, that the length of exposure to a freezing temperature determines their death, without regard to the minimum temperature reached. Chandler (10) believes that is partially due to continued exposure. Abbe (1) stated that evaporation is the cause of death. Chandler (10) partly supports this view. He stated that when the conducting tissue is frozen so as to prevent the movement of water to that tissue injury will follow.

Bay (2) noted that when the soil temperature was above zero and the air temperature was below zero the cold caused a contraction of the tissues all over the plant and consequently the turgescence is very much diminished, as well as the permeability of the cell walls to water. Sachs, Müller-Thurgau, and De Vries (2) proved that this coefficient of contraction is different in different tissues and in different plants.

Butters and Rosendahl (7) have noted that the mechanical damage from loss of turgidity and brittleness of the plant is great. This form of injury is also mentioned by Chandler (10) who noted that frozen tissues are easily torn.

Winkler (87) found that if a low temperature is approached gradually the evergreen can endure a much lower temperature than if there is a sudden fall in the temperature. Pfeffer (10) claimed that the rate of freezing did not affect the amount of winterkilling. On the other hand, Winkler (87) found that when winter twigs were cooled rapidly to -22°C they were killed, but if kept for 3 days at -16°C, 2 days at -18°C, 3 days at -20°C, 2 days at -22°C, 3 days at -25°C, and 12 hours at -32°C, they would not all be killed. It has been observed by Chandler (10) that the killing temperature of rapidly frozen buds is 4½°higher than that of the more slowly frozen buds. He also found that a rapid fall in the early part of the freezing period does more harm than a rapid fall later. Mez (3) claimed that the protoplasm is directly susceptible to cold and that each cell has a fatal minimum temperature.

From the foregoing one would conclude that death, due to the freezing of the plant tissue, might be induced by some one or several causes. The formation of ice crystals appears to kill some protoplasm, while other protoplasts are more resistant. In a few cases, the rate of thawing may exercise a special influence. Death is not always due to the withdrawal of water from the cell but a withdrawal of this cell moisture is apt to occasion certain other ill effects which determine whether a plant shall, or shall not, survive. Death may result from long or short exposure and even this may be quickened by a rapid fall of temperature. It does not even seem possible at present to find one specific cause of death as a direct result of low temperature, but there is need of more detailed information concerning the views which are now prevalent.

EXTERNAL APPEARANCE OF FROZEN PLANTS

An excellent description of the appearance of a frozen plant is given by Lugger (38) which is summarized as follows:

The first thing noticed in a frozen plant is its lack of elasticity. When bent, a fold is produced which does not assume its former position when the pressure is removed. When the temperature rises, the leaves are wilted and the former bright translucent green has disappeared. The surface of the leaf is moist and the outer skin can readily be detached from the tissues beneath; soon the wilted leaves shrink, become dry, turn brown or black, and appear scalded. The evaporation from this deadened portion is more rapid than from living tissue.

PLANT RESISTANCE TO FREEZING.

Pfeffer (85) believed that resistance to cold depends to a certain extent upon the present and previous external conditions of temperature. Haberlandt (55) noted that plants grown in a temperature of 18° to 20°C were frozen more readily than plants grown at 8°C. Göeppert (55) also noted similar cases. Chandler (10) has stated that the previous exposure is a factor in winter resistance. Cabbage, lettuce and kale grown out of doors in late fall and early winter were more hardy than those plants which were grown in the greenhouse. Schaffnit (10) found that the proteids of rye grown under low temperature conditions required a lower temperature to precipitate them than the proteids of plants grown under greenhouse conditions. Alpelt, Rein (10) and Fisher (10) all have supported this view.

An increase in the density of the cell sap will cause the plant to become more resistant. It does this because of the ability of the sap solute to hold water unfrozen. Thus, if the sap density, which Chandler (10) has defined as the molecular concentration of the sap, is increased, the amount of water held to protect the protoplasm would be increased. Pfeffer (55) believed that an increase in sap concentration would increase the resistance of the plant to freezing. Buhlert (6) found that the albumen of resistant varieties was not as easily precipitated in the presence of potassium chloride, sodium chloride, zinc chloride, and zinc sulphate as the albumen of plants with little resistance to freezing. Lidforss (10) found that in wintergreen plants the starch is changed into sugar during cold weather and that this starch is again deposited in the cell upon the return of warm weather. He believed this sugar is formed for protection against freezing. By the introduction of 5 and 10% sugar solutions the resistance to freezing was increased. Makismov (41, 42, 43) after freezing sections of plants that had been immersed in various solutions found marked protection exerted by both organic and inorganic compounds. Injury was retarded but not entirely prevented by the addition of glucose or glycerine. He (42) found that the introduction of carbohydrates, alcohols, and acetones into the plant cell increased its resistance to cold - even in the case of tropical plants. This protective effect was not in direct proportion to the osmotic pressure and lowering of the freezing point, but was more rapid than the later change. The different substances varied in their influence on resistance.

The sugars proved the best; glycerine, alcohol, and acetone being resistant in the order named. Upon the removal of this protective content the original resistance is restored. He (43) found that the addition of various inorganic salts and salts from organic acids affects the outer layer of the protoplasm causing it to be resistant to freezing. He believed that this outer layer of protoplasm is injured by freezing, since severe freezing causes a loss of the normal impermeability of the cell followed by its death. Duggar (13) has mentioned the fact that plants well supplied with potash are not apt to be injured by freezing. Dusserre (16) grew grapes with and without applications of potassium salts. Those varieties receiving potassium were less injured by severe frosts than the plots to which no potassium had been applied. He believes the difference to be due to the difference in cell sap concentration.

Ohweiler (53) has explained the fact that the tips and edges of leaves are more severely injured than the inner portions of the leaf. The starch is continually being changed into sugar giving the plant a medium with a lower freezing point. The sugar is gradually removed from the leaves and since it would leave the tips of the leaves first the center of the leaf would be highly concentrated and thereby more resistant. He found from the results of freezing tests that: "Extreme differences in sap density, in general, are accompanied by a corresponding difference in their resistance to freezing. Exceptions to this rule are probably due to differences of cell structure although other causes may enter in. In cases where the cell structure is the same, the densities of the cell sap indicate their relative hardiness. In plants of the same genus, or in varieties of the same species, differences in their sap density correspond to differences in their resistance to freezing."

Chandler (10) grew seedlings of corn, cowpeas, garden peas, tomatoes, squash, cabbage, and lettuce in sand. These were watered with different strengths of potassium chloride, and ammonium chloride, also with magnesium chloride, sodium chloride and sodium nitrate. The check pots were watered with distilled water. Plants were also grown in cultures in which the amount of water applied was held to a minimum, thereby causing an increase in the sap density. One-half of the plants in each set were frozen and the rest were determined, by means of a Beckman apparatus, for osmotic strength which was expressed in the number of degrees below $0^{o}C$ at which, with no supercooling, ice formation began in the cell sap. In all the cases tried, if the density of the cell sap was increased there occured a corresponding lowering of the freezing point. These same plants were pulled, washed and grown in another set of solutions containing sugar and other compounds. The results were the same as were secured in the first part of the test. Glycerine was found to be the most effective in producing cold resistance. Ammonium and zinc sulphate readily precipitate proteids. Plants were placed in these salts and the hardiness was found to be increased.

Thus Chandler proved that the results of Gorke (previously mentioned) who states that the precipitation of proteids is fatal, are incorrect.

Chandler (10) found that shaded plants have a lower freezing point, as a result of greater sap density than plants exposed to the light. Thus low temperatures at night would be more injurious than in the day time. He wrote: "In plants not in a resting condition, a large amount of dissolved material either in the sap within the cell or in a solution surrounding the cell, will protect the cell from injury due to low temperature, to some extent at least."

Russell (61) has found that plants after freezing, although they may show a wilted condition, will not die for perhaps several days. If the thickened secondary tissues are present among thin walled parenchymous cells the former are slow in showing the effects of freezing. He believed that the death of a plant from freezing is rarely immediate; that it is delayed in proportion to the uninjured cells - the destruction proceeding from cell to cell.

Müller-Thurgau (55) believed that an excess or deficiency of water or of food material affects the degree of resistance. Vines (81) stated that the larger the proportion of water in a cell the more liable it is to be injured. Galloway (20) also believes this to be true. Chandler (10) studied the effect of a wilted condition upon the freezing point. He froze plants in various stages of turgidity and found some indications that rapid wilting reduces the injury resulting from freezing. It would seem, however, that wilting would be a means of increasing the sap density which has been discussed previously in this thesis.

Wollny (1) has stated that the plant has greater resistance to frost in proportion to the size of the seed from which it is developed. He also found that the plants from unripe seeds have less resisting power than plants from mature seeds.

The degree of maturity of the plant seems to influence its resistance to frost. Sinz (73) shows that a high dry matter content, which may be interpreted as maturity, is closely related to resistance. Chandler (10) feels that the greatest factor in influencing the resistance of plants to cold is maturity. He cited the work of Selby and Eustace in support of this belief. Chandler determined the influence of maturity on the death of plants by freezing sections of tissue which were taken at different points along the trunks of trees. The tissue near the lower part of the tree and near the juncture of growing limbs was found to be the most hardy. Young plants are usually more tender either because the sap density is less or because they are not mature and prepared for the winter rest. However, Schindler (1) claimed that wheat is less resistant to frost as the length of the growing period increases. Göeppert (10) also found young leaves to be more hardy than older ones. Winkler (87) found the young foliage to be more resistant than that which was more mature. Apelt, Rein, and Shumacher (10) all have given evidence to prove that young tissues are more resistant than old.

Sinz (6) found that the varieties of wheat, which, due to the firm texture of their tissues and to the action of the stomata, prevent rapid transpiration, are highly frost resistant.

Buhlert (6) observed that the most hardy varieties of winter wheat have longer and more narrow leaves and have a more prostrate habit of growth than the less hardy varieties. He found no correlation between resistance and the thickness of leaf. Carleton (9) mentioned that the most hardy varieties have narrow, dark green leaves and are quite prostrate in their early growth. The writer (78), however, after a careful study of over 700 strains and varieties of wheat could find no correlation between the width and length of the leaf and the amount of winter injury.

The characteristics which enable one plant to be more resistant to freezing than another are not very well understood. Pfeffer (85) was correct when he wrote: "We do not know the nature of the peculiarities which determine the different powers of resistance of individual plants, and of the same plant at different stages of development." A number of factors have been studied and an attempt has been made in many cases to correlate them with winterkilling. But the results obtained by different investigators vary widely; and the results obtained with one species or variety may be in direct contradiction to those obtained with other sorts or under different conditions. So far, the density of the cell sap seems to be the chief factor in determining a plant's resistance.

OPEN FURROW CULTURE

If the plants are not able to afford protection themselves by means of their physical or chemical composition, artificial protection may, and must be, resorted to.

The greatest protection the winter grains have is snow. The snow blanket serves as a protection from the freezing winds and at the same time prevents the loss of heat by radiation. Müller-Thurgau (55) suggested, as a means of protecting the plants from frost, covering the ground around the plant with earth or snow mulching. On the other hand Wright (88) advised the avoiding of mulching or having any porous material about the roots of wheat. Georgeson (24) at the Alaska station, reported that unless the wheat is protected by at least 30 inches of snow it winterkills. Rutter (60) has written;"The Ontario farmer desires a winter with plenty of snow and steady cold, for these are the factors leading to success in grain growing." A layer of snow greatly increases the temperature. Bouyoucos (5) has shown from a four year average that a soil at a depth of three inches covered with a layer of snow and vegetation is 25°F warmer than a bare soil.

The snow covering may be increased by employing various methods. In 1847 a farm correspondent to the Genesse Farmer (25) wrote of leaving a rough seed bed for wheat as a protection from cold winds and to catch the snow. Another wrote and advised the rolling of snow on a field so that it will not melt so rapidly.

It is a matter of common observation in a field of wheat that the plants rooting in some dead furrow pass the winter unharmed while the rest of the field may be badly damaged. No investigation was made of this fact until 1889 when Sheldon (71) of the Kansas Station seeded grain in furrows. The furrows were opened by three small double shovels - miniature listing plows - which were fastened to the frame of a Buckeye one-horse drill. The furrows were about 8 - 10 inches deep and 14 inches apart. Unfortunately the winter of 1889 was not severe enough to test this method thoroughly. The work was continued and the following year Georgeson (21) reported the following data:

Listed plot	35.34	bushels per acre
Drilled plot	29.83	" " "
Gain by listing	5.51	" " "

The wheat in the furrows was noted to be four days later in maturing than the drilled wheat. In 1897 it was reported in the Deutsche landwirtschafliche Presse (90) that grains sown on fields having a rough surface afford better protection than lands which had been smoothed down. Redding (58) of the Georgia Station reported that the best results were obtained from seeding in open furrows, the rows being 12 or 18 inches apart. The winter oats were sown in furrows 2 to 3 inches deep. Two acres of the plots were sown with the furrows running east and west, these were badly winterkilled but those which extended north and south were comparatively uninjured. In the open furrow plots every tenth row was leveled and of these "not one in ten survived", the other rows yielded 40 bushels per acre.

Contradictory results are reported by Stebut (77). He found, after a number of years of observation, that an abundance of snow is followed by somewhat lower yields than the average of rye and wheat. He has shown that the eight year average yield of wheat on sheltered fields was less than two-thirds as large as the six year average yield on open fields. The only foundations he has for such statements however are based upon yields, which may have been influenced by other factors. If based upon the percent of winterkilling the results could be considered.

Warburton (83) advised the sowing of winter oats in open furrows. If it is not possible to sow in open furrows then he recommended sowing with a grain drill, making the surface as rough as possible. He further advised running the furrows at right angles to the prevailing winds. He reported results from the Alabama Station which gave a small advantage in yield to the oats sown in open furrows. Thiry (80) found that seedlings survived better when sown in furrows which are protected from the north winds. Duggar and Cauthen (15) found that winter oats killed 20% in broadcasted plots and only 5% when sown in open furrows. Remy and

Kreplin, (59), Duggar (14), McClelland (44), and Carleton (9), all have reported favorably regarding the practice of seeding winter grains in furrows.

Salmon (65) of the Kansas Station has reported some extensive work with seeding winter grain in open furrows. This test was carried on for three years, 1913-16; the first two years the seed was sown with a lister drill and the last year by means of a shoe drill with a disc furrow opener attachment. He reports the following data:

Spring Survival in Percent

Kind of Grain	1914		1915		1916		Average	
	Fur.	Sur.	Fur.	Sur.	Fur.	Sur.	Fur.	Sur.
Winter wheat	96.0	95.3	100.0	100.0	100.0	100.0	98.7	98.4
Winter barley	96.0	92.5	57.6	30.0	87.0	0	80.2	40.8
Winter oats	86.5	7.5	44.9	33.3	3.0	0	44.8	13.6

Yield in Bushels per Acre

Kind of Grain	1914		1915		1916		Average	
	Fur row	Sur face	Fur row	Sur face	Fur row	Sur face	Fur row	Sur face
Winter wheat	37.8	37.9	17.4	18.7	---	---	27.6	28.3
Winter barley	35.0	38.1	10.3	9.2	---	---	22.7	23.7
Winter oats	26.5	12.3	19.2	18.1	---	---	22.9	15.2

This shows that the seeding of the grain in furrows increased the winter survival 0.3% for wheat; 39.4% for barley; and 31.2% for oats. The yields do not show any increase from seeding in the furrow. Every winter except 1915-16, during the cold periods the ground was covered with snow. The results found at the Kansas, Hays Substation, are decidedly in favor of seeding in furrows. Similar results were obtained in the cereal nursery at Manhattan. Salmon considered the protection afforded by snow to be the most important factor in winterkilling.

According to data by Salmon (65) the chief protection that is secured from the open furrow is the low temperature of the soil surrounding the plant roots. This relation is illustrated in the following table, taken from Salmon (65).

Relation of Furrows to Temperature.

Location of Thermometer	1914-15 Mean Min. Temp. Dec.3 to Mar.24	1914-15 Mean Min. Temp. For days 0°C or below	1914-15 Lowest temp.	1915-16 Mean Min. Temp. Dec.3 to Mar.24	1915-16 Mean Min. Temp. For days 0°C or below	1915-16 Lowest temp.
	In degrees Centigrade					
Surface	-0.06	-1.92	-6.8	-2.85	-3.57	-16.08
2 inches	0.20	-1.59	-4.9	-1.86	-2.56	-10.56
4 inches	0.31	-1.22	-4.9	-1.31	-1.95	- 7.44
6 inches	0.59	-0.84	-3.7	-0.93	-1.57	- 6.77

This table shows that there was an average difference of 1.28° C between the average minimum temperatures for the surface and the six inch furrow for two years. There is also a difference of 6.19 degrees between the lowest temperatures, for the two years, of the surface and 6 inch furrow.

Ricks (60) in a comparison of cultural methods, tested the influence of broadcasting, drilling and open furrows upon winterkilling. He reported the following:

Method of Planting	Stand Secured	Approximate per cent winterkilled	Yield in Bu. per Acre
Broadcasting	good	25	19.0
Drilling	good	2	31.0
Open Furrow	good	2	29.0

This shows that the oats which were drilled were 20% less winterkilled and gave a yield of 12 bushels more than the other plots. Similar results were obtained the second year. Ricks concluded that no trouble was experienced from winterkilling if the oats were planted with a grain drill.

The depth of furrow determines the distance between rows. Salmon (65) believed that the yield would not be diminished greatly if the rows are from 12 to 16 inches apart. Warburton (83) recommended that they be placed 16 inches apart. The increase in winter survival in the furrows will make up for the increased distance between the rows. Cereals with their ability to stool may be spaced widely apart without danger of decreasing the yield which would be obtained under ordinary drilling. Foster (18), Georgeson (23), Hays (36), Montgomery (46), Morrow (48), Sanborn (67), Soule (74, 75) all have found that increasing the distance between the rows has slight influence upon the yield.

The seeding of winter grains in open furrows has its disadvantages, however. If land is poorly drained the plants are liable to be injured by water standing in the furrows. Weeds have a better opportunity to grow, but they may be easily killed by harrowing. There is also more chance for erosion if the land is inclined to be rolling. The principal objection as found by Salmon (65) is that no drill is on the market at present which will give satisfaction. A specially designed drill is being used by the Kansas Station at the present time, which, the writer is advised, is giving entire satisfaction.

Other methods for protection from winter injury are also used. Waldron (82) noted that planting fall wheat in the stubble causes a less amount of winterkilling. Salmon (64) has stated that in North Dakota the farmers practice seeding in the wheat stubble or between the rows of corn in order to catch the winter snows. Latta (34) mulched wheat for two years but no conclusive results were obtained.

VARIETIES RESISTANT TO WINTERKILLING

It is well known that certain varieties of wheat, barley, and oats are more resistant to winter injury than others. Of the three species mentioned wheat is the most hardy, barley next, and oats the least resistant of the three. The data presented by Salmon (65) shows this quite plainly.

Latta (35) in 1889 after conducting a test of 33 varieties of wheat reported a variation in yield from 6.3 to 24.3 bushels per acre which he believed was an indication of their relative hardiness to winterkilling. Of these varieties he found

Egyptian, Michigan Amber, and Velvet Chaff to be the most resistant. Georgeson (21) at the Kansas Station reported the following varieties as resistant to winterkilling: Badger, Currell, Golden Drop, M'Cregan, Nigger, Tasmanian Red, and Zimmerman. Four years later he (27) named Turkey and Currell as the most resistant. Moore and Delwiche (47) of the Wisconsin Station found that Beloglina, Kharkov, and Padii were the most resistant at the Ashland Substation, and Ulta and Beloglina at the Iron River Substation. Ten Eyck (79) at the Kansas Station reported in 1905 that the durum varieties were nearly all winter killed whereas the other varieties survived better than usual. Georgeson (24) at the Alaska Station reported that Kharkov was the most hardy variety tested. Salmon (64) reported that at the Belleforche Experiment Farm no wheat has been found to be superior to Kharkov or Turkey. He states that the ability of these varieties to recover is great, and because of their great stooling habit, a uniform thin stand in the spring will yield well by harvest time. Spragg (76) gives the per cent of winter resistance for fifteen varieties the best of which are: Craig's Favorite, Harris, Berkley, and Bearded Rock in the order named.

Warburton (83) stated that Winter Turf is the most hardy variety of oats.

Derr (12) named Tennessee winter barley as the most resistant in the east-central and southern part of the United States while west of the Rocky mountains he recommends White Winter and Utah barley.

PLANT BREEDING IN RELATION TO WINTERKILLING.

The northern limit of the winter grains is being pushed steadily northward. The practice of continuous selection of hardy plants within resistant, acclimated varieties is securing excellent results.

It is possible to secure resistant strains by selection. Buffum (8) obtained from the U. S. D. A. two quarts of Black Winter Emmer, which he planted. The first year only 72 plants survived. These plants were again grown and within three years he secured a variety resistant to winter injury.

According to Derr (12) the U. S. D. A. has succeeded in changing 16 spring varieties of barley into winter forms by the selection of the hardiest plants. On the other hand Hanson (28) believes that plants cannot be brought to endure any great degree of cold; that hardiness cannot be bred by selection alone, but that it must be gained either by hybridizing or mutation. Carleton (9) advises to select for cold resistance.

Nilsson-Ehle (57) has stated that: "The winter resistant character is transmitted similarly to other characters, that crossing results in the segregation of gradations of this character, whether the parents are of widely different or of medium winter resistant varieties, and that it seems to be the result of a variety of combinations of many Mendelian factors." He crossed two medium resistant varieties and obtained a progeny that exceeded both parents in degree of resistance, some being entirely destroyed and others being entirely uninjured. Hybridization experiments to secure resistant varieties are being conducted at the Dickinson, North Dakota substation (82) and the Michigan Station (76).

SUMMARY.

From the foregoing review a few points may be briefly summarized.

Winterkilling results from a combination of one or more of the following: (1) heaving, (2) physiological drought, (3) smothering, and (4) freezing of the plant tissue.

Heaving is a common source of injury. In this mode of injury the plant is lifted out of the soil by means of its contraction and expansion which is due to alternate freezing and thawing. The results of many experiments show that to escape this injury the plants should be of a deep rooted variety; they should be planted early and with a grain drill or in open furrows in preference to broadcasting; and they should be rolled in the early spring so as to press the plants firmly into the soil.

Physiological drought or the freezing of the soil moisture so as to cause the plant to suffer from a lack of water is a form of winterkilling which is of rare occurrence. There are no means to overcome or to remedy this kind of injury.

The most destructive type of winterkilling is that which results from the freezing of the plant tissue. The manner in which death occurs from this mode of injury is not clearly understood. It was thought by early investigators that death was due to the smashing of the cells as a result of ice formation. But it is now known that ice in the intercellular spaces and does not rupture or crush the cells. Other investigators believe that rapid thawing causes winterkilling but at the present time the most commonly accepted theory is that death is due to desiccation or the withdrawal of water from the plant cells. There are several other views regarding this point, one especially which should be mentioned, is that low temperature causes a precipitation of the cell proteids, which is fatal. Other theories explaining the cause of death due to the freezing of the plant tissues are; successive freezing and thawing, continued exposure, loss of turgidity, and tearing of the brittle tissues, and a rapid rate of freezing. All these theories are supported by certain men and disputed by others.

The resistance to freezing is another point which is much contested. The theory which is generally accepted is that the resistance to freezing increases as the density of the cell sap increases. Other factors which are mentioned in connection with resistance are: amount of moisture present in the cell, condition of previous exposure, maturity of the plant, size of seed from which the plant develops, rate of transpiration, and the length, thickness and breadth of the leaf blades. It is quite likely that the resistance of a plant to freezing is not due to any one condition or characteristic but to a combination of several of these.

It has been found that seeding winter grains in open furrows causes the plants to escape winter injury and to survive in better condition than if planted in level rows.

A number of experiment stations have reported resistant varieties of winter cereals, but until the winter of 1916-17 such data was not available at the Missouri Agricultural Experiment Station.

One of the most important and encouraging points in this study is offered from the standpoint of plant breeding. The progress made in selecting and breeding for winter hardiness and the well known northward trend of our leading field crops gives promise of great advancement.

EXPERIMENTAL

The winterkilling experiments, about to be discussed, were conducted on the Missouri Agricultural Experiment Station field. The soil is a well drained loam of the Shelby series and is of ordinary fertility. Study of the problem was begun late in the fall of 1916 so that it was not possible to conduct the test as it would have been outlined otherwise.

With the view of making only a preliminary study of this problem, several practical phases of winterkilling were considered. This work was outlined to include a study of:

(1) The resistance of varieties and strains of wheat, barley and oats to winterkilling;

(2) The effect of late and early plowing upon the extent of winter injury;

(3) The influence of the depth of seeding upon winterkilling;

(4) The influence of seeding winter grains in open furrows upon the degree of winterkilling.

CLIMATIC CONDITIONS.

It is well to consider the climatic conditions existing during the winter of 1916-17, so that a better understanding may be had of the difficulties encountered in this first years work.

The winter of 1916-17 was unusually dry and there was comparatively little snowfall when contrasted with the average winter for this locality. This fact is shown in table I, which gives for comparison the monthly average precipitation for the past 27 years, 1890-1917, and the monthly rainfall for the single year, 1916-17. (84)

Table I

A Comparison of the Rainfall of the Winter of 1916-17 with the Rainfall of an Average Winter.

Month	Monthly Rainfall for winter of 1916-17 Inches	Average monthly rainfall for yrs. 1890-1917 inc. Inches
September	4.35	4.43
October	2.33	1.55
November	2.17	2.21
December	1.74	1.66
January	2.13	1.05
February	2.15	0.25
March	2.92	1.93
Total	17.79	13.08

It may be seen from this table that the rainfall for the months of September and November exceeded the average rainfall of the last 27 years. The rainfall for January and March was less than one-half normal and in the month of February the normal rainfall is nine times greater than the amount recorded for 1917. The total rainfall for these seven months shows that the winter of 1916-17 had less rainfall by 4.71 inches than would have been received in a normal year.

Such an abnormal moisture condition would tend to influence the temperature of the soil. Petit (1) has concluded that the soil in the winter is cooler in proportion to the degree of dryness of the soil. According to Bouyoucos (4), the temperature of a moist soil will rise more slowly than the temperature of a dry soil. Patten (54) also found that when the soil moisture content is increased over a certain point the temperature of that soil will rise more slowly. This fact is further mentioned by Lyon and Fippen (39). But the converse of this fact should also be true, so that it is safe to assume that the temperature of a moist soil would be slow to fall just as it is slow in rising. Thus we may assume that the soil temperature - the temperature endured by the plant roots - was lower and more severe in the winter of 1916-17 than it would have been in a normal year.

The severity of the winter would have been greatly lessened if there had been more snowfall. Disregarding the increase in moisture content of the soil which would follow increased snowfall, thus tending to prohibit low temperatures, the action of the snow as a protective covering and as a means of retaining heat lost through radiation, was lacking. We have previously cited the work of Bouyoucos (5) and others who have shown that snow is an important factor in protecting winter grains from winter rigor. In table II is given the average snowfall by months for a period of 27 years and the monthly snowfall for the winter of 1916-17.

Table II

Comparative Snowfall of 1916-17. (84)

Month	Snowfall for 1916-17	Average Snowfall for 27 years - 1890-1917.
	Inches	Inches
October	Trace	0.1
November	Trace	0.7
December	1.9	4.3
January	2.3	5.3
February	0.3	7.3
March	2.5	4.3
Total	7.0	25.0

This table shows that only seven inches of snow fell during the winter of 1916-17 whereas the average snowfall is 25 inches - a difference of 18 inches!

During the month of February in which the temperature fell as low as -11° F only 0.3 inches of snow fell; in an average year the snowfall would have been 7.3 inches. This data shows that the plants were not so well protected by snow as they would have been in an average winter.

A comparison of the monthly temperatures for the winter of 1916-17 with the average of 27 years is shown in table III. This table gives the average maximum and minimum monthly temperatures, as well as the average monthly temperature, for the years 1890 to 1916 inclusive and these are compared to similar data for the single year 1916-17.

Table III.

Comparative Temperatures for 1916-17. (84)

Month	Monthly Average Temperatures					
	1916-1917			1890-1916		
	Max.	Min.	Ave.	Max.	Min.	Ave.
	In Degrees Fahrenheit					
November ..	56.8	35.9	46.4	55.2	33.4	44.3
December ..	38.5	21.2	30.4	42.0	24.0	33.0
January ..	41.4	20.5	30.9	39.9	20.6	30.3
February ..	39.4	17.2	28.3	40.1	20.6	30.4
March	54.8	34.0	44.4	53.1	32.0	42.6

Table III illustrates the fact that there was only a slight difference between the minimum temperatures for the winter of 1916-17 and an average winter in this section. In the months of December and February the average monthly temperature for 1916-17 was lower but in January and March higher than normal. An examination of the range between the maximum and minimum temperatures shows that the winter of 1916-17 was an average year in that respect.

Thus we may conclude that the winter of 1916-17 had normal temperature conditions but was extremely abnormal if one considers the amount of precipitation and snowfall. The plants, then, were subjected to more severe soil and air temperatures than they would have received had the winter been a normal one. This severity is due to the fact that the soil was much drier and that there was less snowfall than would be found in an average winter.

It was not possible to make any temperature readings in the field previous to December 7th. Table IV shows the air temperatures from the first of November until the time readings were made in the field from thermometers located on the plots. These readings, secured from the local Weather Bureau, (84) while not the same as would be experienced by the plants in the field show the approximate conditions.

Table IV.

Air Temperatures from November first to December seventh. (84)

Date	Air Temperatures Max.	Min.	Ave.
	Degrees Fahrenheit		
Nov.			
1	75	38	56.5
2	69	38	53.5
3	74	49	61.5
4	77	55	66.0
5	80	55	67.5
6	78	59	68.5
7	77	63	70.0
8	67	42	54.5
9	58	37	47.5
10	61	40	50.5
11	53	35	44.0
12	39	32	35.5
13	32	15	23.5
14	29	11	20.0
15	32	14	23.0
16	54	25	39.5
17	49	27	38.0
18	57	22	39.5
19	70	40	55.0
20	66	40	53.0
21	43	36	39.5
22	49	38	43.5
23	46	35	40.5
24	37	25	31.0
25	47	23	35.0
26	50	35	46.5
27	59	46	52.5
28	59	39	49.0
29	54	33	43.5
30	55	29	42.0
Dec. 1	56	32	44.0
2	63	35	49.0
3	65	47	56.0
4	62	52	57.0
5	56	35	45.0
6	60	38	49.0

After an inspection of this table it will be seen that the plants suffered a severe freeze on November 12th, the cold weather continuing for several days; during this early cold period the temperature fell as low as 11°F. The plants on some plots were barely through the ground at this time and so their growth was sharply checked. This early cold spell kept the plants from making a vigorous fall growth, which, according to Chandler (10) would undoubtedly cause the death rate to be higher.

The severity of the winter was such that all the experimental work outlined could not be carried out. It had been planned to continue the previous years work of the writer (78) and with two years data attempt to find a correlation between the degree of winterkilling and the length and width of leaf and habit of growth of winter cereals. The plants were frosted to the ground before the necessary data could have been taken.

The degree of cold to which the plants were subjected was secured by recording the air and soil temperatures on all plots from December 7th until all danger of frost was past, March 19th. The thermometers used in securing this data were twelve inch minimum registering spirit thermometers, #5490, manufactured by the Taylor Instrument Company. In addition to these Fahrenheit thermometers, two Centigrade thermometers which registered as low as -20°C were used.

An effort was made to record the temperatures which the plant itself endured. According to Sachs (63), soil thermometers may correctly indicate the temperature of the plant roots. Pfeffer (55) and Duggar (13) both believe that the plant temperature is the same as that of the surrounding medium. So the approximate temperature of the roots was found by obtaining the temperature of the soil at a depth of three inches. The approximate temperature of the leaves was obtained by placing the thermometer bulb 2½ inches above the surface of the ground. Thus the degree of cold which the plant leaves and roots experienced was determined and, although this is only approximate and there is a large chance for error, yet the registered temperatures are comparative.

The maximum and minimum temperatures on all plots were read daily. It was assumed that the maximum temperature would occur at 2:30 in the afternoon and that the minimum temperature occurred at 7:00 in the morning; therefore the readings were made at these hours. No attempt was made to use the thermometer's minimum recorder for that would necessitate removing the bulb from its position in the soil. It was considered best to never disturb the position of the thermometer bulb but to allow the soil to pack and settle about it; for in this way more exact soil temperatures would be obtained.

It was not possible to secure a sufficient number of thermometers to duplicate the temperature readings and consequently only one thermometer was located on a plot. All the thermometers were compared before they were placed in the soil and they were found to register alike. Since the early and late plowing test was located upon two different plots of ground the air temperature was read on both plots so that the soil temperatures on the two plots could be more easily compared; for if there was a difference in the air temperature of 5^{o} between the plots a corresponding variation would be expected in the soil temperatures.

In table V is placed all the temperature readings, as well as the daily precipitation and snowfall, made in this experiment. The columns refer to the following data:

(1) Date and hour of reading,

(2) Air temperature of the late plowing plot,

(3) Soil temperature of the late plowing plot,

(4) Air temperature of the early plowing plot,

(5) Soil temperature of the early plowing plot,

(6) Air temperature of the furrowed plots,

(7) Soil temperature of the surface planted plots,

(8) Soil temperature of the three inch furrowed plot,

(9) Soil temperature of the six inch furrowed plot,

(10) Soil temperature of the ridged plot,

(11) Total daily rainfall in inches (84),

(12) Total daily snowfall in inches (84).

Table V.

Daily Temperatures on Experimental Plots.

Date		Air and Soil Temperatures of Plots: Late plowed		Early plowed		Furrowed Plots					Daily Precipitation	
		Air	Soil	Air	Soil	Air	Sur.	3"	6"	Ridge	Snow	Rain
		In degrees Fahrenheit.									Inches	
Dec.	min.	--	55	--	54	60	55	54	54	56		
7	max.	--	57	--	56	56	56	56	56	57	1.13	--
8	min.	--	34	--	35	30	36	35	38	34		
	max.	--	34	--	34	30	34	34	36	32	0.01	T
9	min.	--	28	--	30	18	30	30	32	28		
	max.	--	34	--	38	46	36	36	34	34	--	--
10	min.	--	30	--	30	26	30	30	32	28		
	max.	--	32	--	32	32	32	32	32	32	0.04	--
11	min.	--	32	--	32	32	32	32	32	32		
	max.	--	30	--	32	24	31	32	32	30	0.11	1.3
12	min.	--	23	--	28	4	28	30	32	22		
	max.	--	30	--	30	24	30	30	32	29	0.01	1.0
13	min.	--	18	--	22	2	20	22	28	14		
	max.	--	28	--	30	21	30	30	30	26	T	1.3
14	min.	--	21	--	24	14	24	28	30	21		
	max.	--	23	--	27	14	26	26	30	22	0.03	1.0
15	min.	--	17	--	23	3	21	24	30	16		
	max.	23	29	25	30	30	30	30	29	28	T	T
16	min.	27	22	27	23	20	24	28	30	21		
	max.	48	36	48	36	52	36	31	31	30	--	T
17	min.	45	27	24	30	24	29	28	30	27		
	max.	37	31	37	32	37	31	30	30	32	0.01	T
18	min.	30	21	14	24	12	23	24	28	20		
	max.	36	31	28	32	30	31	31	31	30	---	T
19	min.	28	28	28	30	30	28	28	30	28		
	max.	43	33	41	33	43	32	32	30	32	--	T
20	min.	25	16	10	18	1	19	18	20	16		
	max.	14	21	16	24	5	21	22	24	20	T	T

Date		Air and Soil Temperatures of Plots: Late plowed: Air	Late plowed: Soil	Early plowed: Air	Early plowed: Soil	Furrowed Plots: Air	Furrowed Plots: Sur.	Furrowed Plots: 3"	Furrowed Plots: 6"	Furrowed Plots: Ridge	Daily Precipitation: Rain	Daily Precipitation: Snow
		In degrees Fahrenheit									Inches	
21	min.	3	11	3	14	4	12	14	18	10		
	max.	10	17	12	20	12	18	18	20	16	--	T
22	min.	0	7	0	12	1	8	9	14	6		
	max.	26	27	26	28	27	23	26	26	26	--	T
23	min.	17	20	17	21	18	20	20	20	20		
	max.	35	31	34	32	32	31	30	30	30	T	--
24	min.	37	32	37	32	39	32	31	30	32		
	max.	42	36	41	36	45	36	34	31	34	T	--
25	min.	23	24	23	26	24	25	26	26	24		
	max.	42	33	42	34	42	34	32	30	34	T	--
26	min.	42	36	43	36	43	36	34	32	36		
	max.	48	42	48	42	50	42	38	36	42	0.31	--
27	min.	21	30	23	30	22	30	30	30	30		
	max.	41	32	41	33	42	33	32	31	32	--	--
28	min.	19	24	18	26	18	24	26	30	24		
	max.	34	32	32	32	33	31	31	30	32	--	--
29	min.	14	20	16	22	16	20	20	24	29		
	max.	43	33	38	34	38	32	32	30	32	--	--
30	min.	16	19	16	22	14	18	20	24	20		
	max.	43	35	43	36	46	34	32	30	34	--	--
31	min.	25	24	25	24	26	24	24	24	24		
	max.	36	32	36	33	36	32	30	30	32	0.01	--
Jan.	min.	32	32	32	32	32	32	32	32	32		
1	max.	55	42	48	42	54	42	38	34	42	T	--
2	min.	32	32	32	32	32	32	32	32	32		
	max.	45	39	45	37	46	38	34	32	38	--	--
3	min.	32	32	32	32	31	32	30	30	32		
	max.	59	46	50	45	53	44	42	37	45	--	--
4	min.	36	32	36	32	35	32	30	30	32		
	max.	45	41	43	40	44	40	38	36	40	0.32	--

Date		Late plowed: Air	Late plowed: Soil	Early plowed: Air	Early plowed: Soil	Furrowed Plots: Air	Furrowed Plots: Sur.	Furrowed Plots: 3"	Furrowed Plots: 6"	Furrowed Plots: Ridge	Daily Precipitation: Rain (Inches)	Daily Precipitation: Snow (Inches)
		In degrees Fahrenheit										
Jan. 5	min.	30	31	30	30	30	31	32	32	31		
	max.	52	44	48	46	51	44	44	40	43	0.03	--
6	min.	30	31	30	31	30	31	31	30	31		
	max.	54	45	54	42	54	44	42	42	45	--	--
7	min.	32	31	32	32	31	32	32	32	31		
	max.	41	40	45	41	42	40	40	39	40	--	--
8	min.	30	32	30	32	30	32	32	32	32		
	max.	57	52	57	52	59	50	50	46	50	--	--
9	min.	30	31	30	32	30	31	32	32	32		
	max.	54	48	48	54	55	48	46	44	48	--	--
10	min.	36	33	34	34	35	33	34	34	34		
	max.	32	34	32	34	32	33	34	35	33	T	--
11	min.	7	18	8	20	8	18	20	24	18		
	max.	32	32	30	32	32	32	30	30	31	--	--
12	min.	25	26	25	28	26	26	28	28	26		
	max.	36	32	34	32	35	32	32	30	32	T	--
13	min.	10	16	12	20	10	18	20	22	16		
	max.	21	28	23	30	26	28	30	30	24	--	--
14	min.	5	11	5	16	6	14	15	19	10		
	max.	39	33	39	34	39	33	32	32	32	--	--
15	min.	18	24	18	26	18	24	24	26	24		
	max.	25	27	22	26	23	27	28	28	26	0.1	1.1
16	min.	5	16	5	19	4	20	20	22	14		
	max.	25	27	23	29	24	27	28	28	26	--	0.7
17	min.	19	25	19	27	20	25	26	27	24		
	max.	28	29	28	30	29	29	29	30	28	0.07	1.2
18	min.	21	26	21	27	21	26	28	28	25		
	max.	34	31	37	32	38	31	31	31	32	--	0.8
19	min.	5	19	7	22	8	20	22	24	16		
	max.	44	34	41	34	42	34	32	30	34	--	0.3

Date		Air and Soil Temperatures of Plots									Daily Precipitation	
		Late plowed		Early plowed		Furrowed Plots						
		Air	Soil	Air	Soil	Air	Sur.	3"	6"	Ridge	Rain	Snow
		In degrees Fahrenheit									Inches	
Jan.	min.	18	24	16	24	18	24	25	26	22		
20	max.	41	34	40	35	42	34	32	30	34	0.3	0.1
21	min.	43	38	41	26	44	36	34	30	38		
	max.	54	48	54	48	56	46	43	40	48	0.01	--
22	min.	9	18	9	20	9	19	22	24	16		
	max.	28	30	23	31	29	30	30	30	28	--	--
23	min.	9	14	5	17	10	14	16	20	12		
	max.	43	34	41	36	42	34	32	31	34	--	--
24	min.	16	22	16	24	18	22	23	25	22		
	max.	39	34	39	34	42	34	32	31	34	--	--
25	min.	21	20	23	22	21	21	21	22	21		
	max.	48	37	47	39	49	36	34	33	38	--	--
26	min.	16	19	16	21	17	20	20	21	18		
	max.	43	34	43	37	42	34	32	31	34	--	--
27	min.	18	22	19	24	18	23	23	24	22		
	max.	50	40	50	41	56	38	35	32	39	--	--
28	min.	32	29	32	29	34	28	28	28	29		
	max.	65	44	66	44	66	50	45	40	45	0.21	--
29	min.	41	38	41	36	41	36	34	32	37		
	max.	72	62	71	61	73	59	56	53	62	0.01	--
30	min.	28	30	28	32	28	31	31	30	31		
	max.	57	50	56	52	65	49	47	44	50	--	--
31	min.	41	35	39	36	41	34	33	32	36		
	max.	23	29	23	28	22	29	31	30	27	T	--
Feb.	min.	-2	7	-2	8	-2	8	12	14	4		
1	max.	18	20	18	22	13	20	24	25	18	--	--
2	min.	--	-5	--	-1	-10	-3	0	0	-8		
	max.	16	19	18	21	16	19	22	22	17	--	--
3	min.	10	12	10	14	10	12	13	15	11		
	max.	42	34	39	36	41	33	32	31	34	--	--
4	min.	5	18	5	14	6	18	18	24	14		
	max.	6	12	5	12	6	12	12	14	9	0.03	0.3

Date		Late plowed: Air	Late plowed: Soil	Early plowed: Air	Early plowed: Soil	Furrowed Plots: Air	Furrowed Plots: Sur.	Furrowed Plots: 3"	Furrowed Plots: 6"	Furrowed Plots: Ridge	Daily Precipitation: Rain	Daily Precipitation: Snow
		Air and Soil Temperatures of Plots — In degrees Fahrenheit									Inches	
Feb.	min.	7	6	10	11	8	10	11	20	8		
5	max.	32	30	30	33	30	30	30	30	29	--	T
6	min.	27	24	27	24	28	24	24	24	24		
	max.	50	41	48	43	52	39	35	30	42	--	--
7	min.	34	32	34	32	35	32	30	30	32		
	max.	53	44	50	47	53	42	38	34	44	--	--
8	min.	32	32	32	32	32	32	32	30	32		
	max.	32	33	36	34	39	32	32	30	33	T	--
9	min.	5	9	7	11	6	10	12	14	8		
	max.	35	32	34	34	33	32	32	30	32	--	--
10	min.	23	24	23	24	24	24	24	24	24		
	max.	37	34	39	38	44	34	33	32	35	--	--
11	min.	9	10	10	12	11	11	12	15	10		
	max.	32	32	39	39	39	32	32	30	33	--	--
12	min.	10	10	10	12	9	12	13	16	10		
	max.	37	34	36	36	36	33	32	30	34	--	--
13	min.	28	28	28	28	30	28	27	26	28		
	max.	46	40	45	42	46	39	36	33	41	--	--
14	min.	19	23	19	23	21	23	23	26	23		
	max.	41	34	39	39	40	35	34	32	35	--	--
15	min.	21	24	21	24	22	24	24	25	23		
	max.	37	34	37	36	38	34	34	32	36	--	--
16	min.	25	24	25	25	26	24	25	26	26		
	max.	61	51	57	56	61	50	46	42	54	--	--
17	min.	45	37	45	39	46	37	35	34	39		
	max.	61	48	56	55	64	51	49	46	53	T	--
18	min.	25	28	25	28	25	28	28	28	28		
	max.	34	31	34	30	35	32	32	30	32	T	--
19	min.	37	33	36	33	37	32	32	30	33		
	max.	57	48	54	52	56	50	48	45	49	0.22	--
20	min.	21	27	21	27	22	26	27	30	25		
	max.	45	36	43	42	42	35	34	32	36	T	--

Date		Air and Soil Temperatures of Plots: Late plowed Air	Late plowed Soil	Early plowed Air	Early plowed Soil	Furrowed Plots Air	Furrowed Plots Sur.	Furrowed Plots 3"	Furrowed Plots 6"	Furrowed Plots Ridge	Daily Precipitation Rain	Daily Precipitation Snow
		In degrees Fahrenheit									Inches	
Feb.	min.	30	30	30	30	30	30	30	30	30		
21	max.	56	43	56	52	61	46	46	44	50	--	--
22	min.	27	29	27	29	28	28	29	30	28		
	max.	54	42	55	50	56	45	46	45	52	--	--
23	min.	39	38	39	38	40	38	37	36	39		
	max.	50	41	47	48	52	43	42	40	43	T	--
24	min.	28	29	28	30	30	28	28	30	28		
	max.	46	41	45	46	44	42	41	38	42	--	--
25	min.	39	33	37	34	38	33	32	32	34		
	max.	56	45	58	48	58	48	47	46	50	--	--
26	min.	41	38	41	39	42	38	38	36	40		
	max.	55	50	55	53	58	52	52	50	53	--	--
27	min.	25	28	25	28	24	28	28	30	27		
	max,	35	32	32	33	34	32	32	30	32	--	--
28	min.	22	26	22	24	24	24	26	28	24		
	max,	52	42	51	49	54	44	44	41	44	--	--
Mar.	min.	23	28	23	27	24	27	28	30	27		
1	max.	39	36	39	38	40	38	36	36	36	--	--
2	min.	28	30	28	30	28	30	30	30	30		
	max.	38	34	38	36	38	34	33	32	34	0.06	T
3	min.	27	31	28	32	28	31	32	32	31		
	max.	32	31	32	32	32	31	33	33	31	0.06	2.0
4	min.	12	18	12	17	11	18	24	30	17		
	max.	26	30	26	30	30	28	32	32	27	--	0.01
5	min.	12	14	13	16	12	18	20	28	14		
	max.	37	36	36	37	37	36	34	31	35	--	--
6	min.	36	33	32	34	34	32	32	32	33		
	max.	61	58	60	58	61	54	50	46	54	--	--
7	min.	39	37	40	38	40	36	36	36	37		
	max.	50	46	47	46	50	45	44	42	44	--	--
8	min.	34	32	33	34	36	32	32	32	32		
	max.	60	54	56	56	58	54	54	50	54	--	--

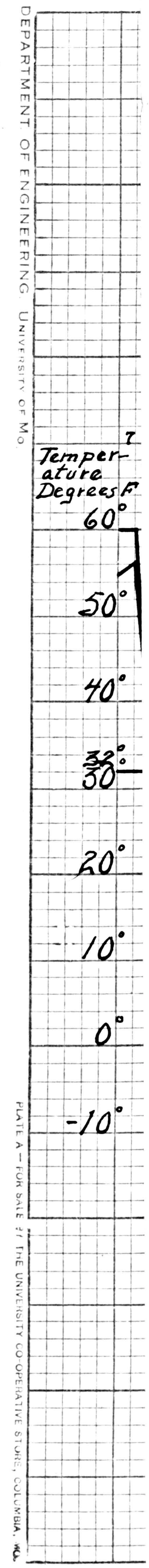
Date		Air and Soil Temperatures of Plots: Late plowed: Air	Late plowed: Soil	Early plowed: Air	Early plowed: Soil	Furrowed Plots: Air	Furrowed Plots: Sur.	Furrowed Plots: 3"	Furrowed Plots: 6"	Furrowed Plots: Ridge	Daily Precipitation: Rain	Daily Precipitation: Snow
		In degrees Fahrenheit									Inches	
Mar.	min.	35	31	34	31	34	31	31	31	31		
9	max.	65	62	65	64	69	62	61	56	62	--	--
10	min.	54	47	54	50	54	47	45	44	48		
	max.	69	60	68	61	69	60	59	58	60	--	--
11	min.	48	48	47	46	47	47	48	48	47		
	max.	67	58	67	63	67	59	59	58	59	--	--
12	min.	41	41	41	42	42	41	41	41	41		
	max.	42	41	42	41	41	40	41	41	41	--	--
13	min.	46	44	46	45	46	44	43	42	44		
	max.	50	49	50	49	50	49	49	48	49	--	--
14	min.	33	33	34	34	34	33	34	34	33		
	max.	50	50	50	50	50	50	52	52	48	--	--
15	min.	32	32	32	32	32	32	32	32	32		
	max.	57	51	57	54	56	52	52	50	52	--	--
16	min.	50	46	50	46	48	46	46	46	46		
	max.	56	54	57	54	58	54	54	54	53	--	--
17	min.	32	33	32	32	32	32	32	34	32		
	max.	41	40	41	40	40	40	41	41	39	--	--
18	min.	32	33	32	33	35	32	32	32	32		
	max.	50	45	50	49	49	46	50	50	45	--	--
19	min.	35	32	36	32	36	32	32	32	32		
	max.	69	58	70	62	69	58	58	56	60	--	--
Avg. min.		--	26.3	--	27.3	24.3	26.7	27.2	28.3	25.9		
Lowest min.		--	-5.	--	-1.	-10.	-3.	0	0	-8.		
Avg. min. for days below 32° F		--	--.	--	--	21.8	24.8	25.5	26.8	23.8		

WINTER HARDY VARIETIES OF WHEAT.

The varieties of wheat grown at the Missouri Agricultural Experiment Station which are the most resistant to winterkilling were determined. In this test 180 different varieties of wheat growing in the Station's variety test, were studied.

The air and soil temperatures which these plants endured is shown graphically in Figure III. The black line represents the air temperature and the red line represents the temperature of the soil at a depth of three inches.

See supplemental file Figure 3 for unfolded version.



A study of Figure III shows that throughout the winter the plants were subjected to abrupt changes in temperature and to alternate freezing and thawing, which, according to Morse (49) would affect the extent of winterkilling. A typical instance of these sudden changes is found on February 21st when the soil temperature dropped 26°, from 46° to 20°, in twelve hours; at the same time the air temperature fell 46°F. Similar variations were frequent. Such changes are very injurious, according to observations made by Winkler (87), Chandler (10), and Göeppert (55). From table V it may be noted that the average daily minimum air temperature for the 103 days was 24.3° and the average daily minimum soil temperature, at a depth of three inches, was 26.7°F. The lowest air temperature recorded was -10° and the lowest soil temperature read was -3° F.

Notes taken after each period of continued cold, expressed in per cents of plant frosted, are tabulated in table VI. These frosted percentages were determined from field observations and although they do not denote a definite degree of freezing yet they do express comparative differences in the various varieties of wheat.

Table VI.

Resistance of Wheat Varieties to Frosting.

Variety	Per cent of Plant Frosted on: Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of plants on Mar. 21st.
Bald	slight	5	10	20	30	99	Poor
Beechwood Hybrid	wilted	5	10	20	30	99	Poor
Black Rudy	wilted	5	10	20	30	99	Poor
Councilman	wilted	5	10	20	30	99	Poor
Dawson' G.Chaff	wilted	5	12	20	30	99	Poor
Dakota Wonder	wilted	5	10	20	30	99	Poor
Dietz	wilted	5	10	20	30	99	Poor
Defiance	wilted	2	4	15	25	99	Fair
Early Ontario	wilted	5	10	20	30	99	Poor
Early Ripe	wilted	5	10	20	30	99	Poor
Early Ripe #26	wilted	5	10	20	30	99	Poor
Early Ripe #29	wilted	5	10	20	35	99	Poor
Early R.Clawson	wilted	5	10	20	30	99	Poor
Eclipse	wilted	20	25	25	35	99	Poor
Fulcaster	wilted	5	10	20	30	99	Poor
Fulcaster #2	wilted	5	10	20	30	99	Poor
Fulcaster #12	wilted	5	10	20	30	99	Poor
Fulcaster #1-y	wilted	5	10	20	30	99	Poor
Fulcaster #8-y	wilted	5	10	20	30	99	Poor
Fultz (Archias)	wilted	5	5	20	25	99	Poor
Fultzo Medit.	wilted	5	10	20	30	99	Poor
Gold Coin	wilted	5	10	20	30	99	Poor
Green Co. Wheat	wilted	5	10	20	30	99	Poor
Harvest King	wilted	5	10	20	30	99	Poor
Harvest King #7	wilted	5	10	20	30	99	Poor
Harvest Queen	slight	3	6	15	25	99	Fair
Hickman	wilted	5	10	20	30	99	Poor
Imperial Amber	wilted	5	10	20	50	99	Poor
Jones Longberry	wilted	5	10	20	30	99	Poor
Jones Red Wave	wilted	5	10	20	30	99	Poor
King's Mich.Won.	wilted	5	10	20	30	99	Poor
Klondike	wilted	5	10	20	30	99	Poor
Lebanon	wilted	5	10	20	30	99	Poor
Leop Prolific	wilted	5	15	40	45	99	Poor
Mammoth Red	wilted	5	10	20	30	99	Poor
Marvelous	wilted	5	10	20	30	99	Poor

Variety	Per cent of Plant Frosted on Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of plants on Mar. 21st.
Mealy	wilted	5	10	20	30	99	Poor
Mediterranean	wilted	5	10	20	30	99	Poor
Mediterranean #8	wilted	5	10	20	30	99	Poor
Mediter. #17	wilted	5	10	20	30	99	Poor
Mediter. #20	wilted	5	10	20	30	99	Poor
Mediter. #30	wilted	5	10	20	30	99	Poor
Mediter. #31	wilted	5	10	20	30	99	Poor
Mediter. #39	wilted	5	10	20	30	99	Poor
Mediter. #47	wilted	5	10	20	30	99	Poor
Michigan Amber	wilted	5	10	20	30	99	Poor
Mich. Amber #7	wilted	5	10	20	30	99	Poor
Mich. Amber #9	wilted	5	10	20	30	99	Poor
Mich. Amber #12	slight	5	7	20	30	99	Poor
Michigan Wonder	wilted	5	10	20	30	99	Poor
Miracle (B)	wilted	5	10	20	30	99	Poor
Niagara	wilted	5	10	35	30	99	Poor
Nigger	wilted	3	6	15	25	99	Poor
Old Ironclad	slight	1	5	12	25	99	Fair
Ontario Wonder	wilted	5	15	40	30	99	Poor
Pettis Co.wheat	wilted	5	10	20	30	99	Poor
Poole	wilted	5	10	20	30	99	Poor
Poole #2	wilted	5	10	20	30	99	Poor
Poole #3	wilted	5	10	20	25	99	Poor
Poole #35	wilted	5	10	20	30	99	Poor
Poole B-3	wilted	5	10	20	30	99	Poor
Purple Straw	wilted	5	10	25	40	99	Poor
Pride of Indiana	wilted	5	10	20	30	99	Poor
Pride of Genesse	wilted	5	10	20	30	99	Poor
Red Hussar	wilted	2	5	15	25	99	Fair
Reliable	wilted	5	10	20	30	99	Poor
Rudy	wilted	5	10	20	30	99	Poor
Red Cross	wilted	5	10	20	30	99	Poor
Red May	wilted	5	10	20	30	99	Poor
Red Wave	wilted	5	10	20	30	99	Poor
Rochester Red	wilted	5	10	20	30	99	Poor
Rural New Yorker	wilted	5	10	20	30	99	Poor

Variety	Per cent of Plant Frosted on Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of plants on Mar. 21st.
Stoner	wilted	5	10	20	30	99	Poor
Texas	slight	2	6	15	25	99	Fair
Turkey	slight	2	5	15	20	99	Fair
Turkey 1-43	wilted	5	10	20	30	99	Poor
Turkey 24	wilted	5	10	20	30	99	Poor
Turkey (Kans)	slight	1	5	15	25	99	Fair
Turkish Amber	wilted	5	10	30	35	99	Poor
Turkey Island	wilted	5	10	25	30	99	Poor
Turkey Red Hybrid	none	½	5	18	25	99	Fair
Treadwell	wilted	5	10	20	30	99	Poor
U.S.D.A.11616	slight	5	8	20	30	99	Fair
Valley	wilted	5	10	20	30	99	Poor
Velvet Chaff	wilted	5	10	20	30	99	Poor
Velvet Chaff #2	wilted	5	10	20	30	99	Poor
Velvet Chaff #6	wilted	5	10	20	30	99	Poor
Velvet Chaff #8	wilted	5	10	20	30	99	Poor
Velvet Chaff #11	wilted	5	10	20	30	99	Poor
Virginia Hybrid	slight	5	15	25	30	99	Poor
Wyandotte Red	wilted	5	10	20	30	99	Poor
25984 - Kharkov			25	30	35	99	Poor
25995 - Rice			25	30	35	99	Poor
31781 - Mecca Winter			25	30	35	99	Poor
31783 - Khotan Red Spring			25	30	35	99	Poor
31791 - Kashgar Red			25	30	35	99	Poor
3D - 9a	wilted	5	10	20	30	99	Poor
3D - 10a	wilted	5	10	20	30	99	Poor
11C - 1a	wilted	5	10	20	30	99	Poor
12D - 5	wilted	5	10	20	30	99	Poor
12D - 1a	wilted	5	10	30	40	99	Poor
13a - 4a	slight	5	10	20	30	99	Poor
18D - 1a	wilted	5	10	20	30	99	Poor
18D - 3	wilted	5	10	20	30	99	Poor
18D - 4	wilted	5	10	20	30	99	Poor
19E	wilted	5	10	20	30	99	Poor
24a - 2a	wilted	5	10	20	30	99	Poor
29C - 2	none	2	5	15	25	99	Fair

Variety	Per cent of Plant Frosted on Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar.21st.
32a	wilted	5	10	20	30	99	Poor
32a - 2a	wilted	5	15	20	30	99	Poor
32a - 3a	wilted	5	10	20	30	99	Poor
34B - 2a	none	5	10	20	30	99	Poor
26012			25	30	35	99	Poor
26013			25	30	35	99	Poor
26014			25	30	35	99	Poor
26015			25	30	35	99	Poor
26017			25	30	35	99	Poor
26018			25	30	30	99	Poor
26019			25	30	35	99	Poor
26020			25	30	35	99	Poor
26021			25	30	35	99	Poor
26022			25	30	35	99	Poor
26023			25	30	35	99	Poor
26024			25	30	35	99	Poor
26025			25	30	35	99	Poor
26027			25	30	35	99	Poor
26028			40	45	80	99	Poor
26029			25	30	35	99	Poor
26079			25	30	35	99	Poor
26085			25	30	35	99	Poor
29006			25	30	35	99	Poor
29007			25	30	35	99	Poor
31790			25	30	35	99	Poor
3808			25	30	35	99	Poor
3828			20	25	30	99	Fair
3846			25	30	35	99	Poor
3961			25	30	35	99	Poor
3972			25	30	35	99	Poor
3977			25	30	35	99	Poor
3980			25	30	35	99	Poor
3988			25	30	80	99	Poor
3998			25	30	35	99	Poor
4004			25	30	35	99	Poor

As shown in table VI from the time of the very first frost, November 18th, certain varieties were frosted more severely than others. Those varieties which were least injured in the initial frost proved to be the most hardy throughout the winter. The notes taken on February 14th show that on that date all the varieties were frosted to the ground. The cold was so severe that even the varieties which had shown resistance in the early part of the winter could not be distinguished, late in the winter, from those varieties of less resistance, But in spite of the fact that all were frosted to the ground, certain varieties, when spring opened sent up new shoots and thus their greater vigor was made apparent. Notes recorded March 21st denote the condition of the plants on that date. The terms "poor" and "fair" are used to express the general vigor and conditions of the varieties. "Poor" indicates that from 75% to 100% of the plants were entirely dead and while the term "fair" is used if less than 50% of the plants were dead.

These data, gathered in one years study, indicate that the most resistant varieties of wheat grown in this variety test are: Defiance, Harvest Queen, Old Ironclad, Red Hussar, Texas, Turkey, Turkey (Kansas), Turkey Red Hybrid, U.S.D.A. 11616, 29c-2, and 3828, the last three named being hybrids strains. These varieties, throughout the winter, gave evidence of superior hardiness to cold.

In another test of wheat varieties which were being grown in a variety test, more accurate and reliable results were obtained. The 35 varieties compared in this test were sown with a grain drill in plots 120 feet long. They had been grown at this Station for a number of years and were thoroughly acclimated.

The frosting notes for these varieties are tabulated in table VII. The same comparative standard of frosting per cent was used with these varieties as with the varieties planted in the rod rows. However, there is one important difference to bear in mind, the drill width varieties of wheat were sown October 10th, one week earlier than the rod row varieties were sown.

Table VII.

Winter Resistant Wheat Varieties

Variety	Per Cent of Plant Frosted on Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st
Michigan Wonder	wilted	10	15	25	30	95	Fair
Dietz	wilted	10	15	25	30	95	Fair
Dawsons G.Chaff	wilted	10	15	25	30	95	Fair
Early Ripe	wilted	10	15	25	30	95	Fair
Fultz	wilted	10	15	25	30	95	Fair
Jones Red Wave	wilted	10	15	25	30	95	Fair
Harvest King	wilted	10	15	25	30	95	Fair
Valley	wilted	10	15	25	30	95	Fair
Michigan Amber	wilted	10	15	25	30	95	Fair
Rudy	wilted	10	15	25	30	95	Fair
Velvet Chaff	wilted	10	15	25	30	95	Fair
Va. Hybrid	wilted	5	7	25	30	95	Fair
Early R.Clawson	wilted	10	15	25	30	95	Fair
Harvest Queen	wilted	10	15	25	30	95	Good
Reliable	wilted	10	15	25	30	95	Fair
Rochester Red	wilted	10	15	25	30	95	Fair
Hickman	wilted	10	15	25	30	95	Fair
Lebanon	wilted	10	15	25	30	95	Fair
Defiance	wilted	10	15	20	25	95	Good
Mealy	wilted	10	15	25	30	95	Fair
Fulcaster	wilted	10	15	25	30	95	Fair
Beechwood	wilted	10	15	25	30	95	Fair
Poole	wilted	10	15	25	30	95	Fair
U.S.D.A.11616	wilted	10	15	25	30	95	Good
Mediterranean	wilted	10	15	25	30	95	Fair
11C-1a	wilted	10	15	25	30	95	Fair
Poole #12	wilted	10	15	25	35	95	Poor
Fulcaster #2	wilted	5	10	25	30	98	Poor
Medit. #17	wilted	5	10	25	35	98	Poor
Beech.Hyb.#87	wilted	5	10	25	40	98	Poor
Illinois #509	uninjured	1	5	20	30	95	Fair
Marvelous	wilted	10	15	25	40	98	Dead
Marvelous	wilted	10	15	25	40	100	Dead
Mich. Wonder	wilted	10	15	25	30	98	Fair
Fultz	wilted	10	15	25	35	98	Poor

There is evidence from this data that the varieties Harvest Queen, Defiance, Illinois #509, and Michigan Wonder are more hardy than the other varieties which were compared. The varieties, Poole #12, Mediterranean #17, Beechwood Hybrid #87, Marvelous, and Fultz were severely injured, the Marvelous being entirely killed.

The statement that a certain variety is more resistant to cold than another, based upon field observation, is too sweeping an assertion. According to the frosting notes previously given, two varieties might seem to be equally resistant, yet from an actual count of the number of plants winterkilled one variety would be far superior to the other.

To overcome this difficulty the actual extent of winterkilling in each variety was determined. This was accomplished by recording the actual number of plants in the fall and again in the spring, assuming the difference to represent the number of plants winterkilled. To secure this data a single row, selected to represent the average of the plot, was taken and a strip 10 feet long was marked upon it. The number of plants in this 10 foot strip was determined late in the fall so that all the plants which would be killed by disease, competition between plants, etc., would not influence the death rate. A count was again made in the spring after all danger of frost was past and at a time when the plants were sending up new shoots. From this data the amount of winterkilling could be definitely calculated. Table VIII gives the per cent of winterkilling of these varieties of wheat, as determined by actual count.

Table VIII.

Winterkilling in Wheat Varieties.

Variety	Number of Plants: Nov. 7	Number of Plants: Mar. 19	Difference	Assumed winterkilling
Michigan Wonder	191	100	91	47.64
Dietz	171	101	70	40.93
Dawson's Golden Chaff	168	115	58	34.52
Early Ripe	191	154	37	19.37
Fultz	186	135	51	27.41
Jones Red Wave	197	117	80	40.60
Harvest King	186	145	41	22.04
Valley	198	149	49	24.74
Michigan Amber	200	109	91	45.50
Rudy	177	123	54	30.50
Velvet Chaff	188	146	42	22.34
Virginia Hybrid	150	115	35	23.33
Early Red Clawson	192	130	62	32.29
Harvest Queen	204	160	44	21.56
Reliable..................	203	123	80	39.40
Rochester Red	198	133	65	32.82
Hickman	194	135	59	30.41
Lebanon	196	136	60	30.61
Defiance	222	159	63	28.37
Mealy	230	144	86	37.39
Fulcaster	182	128	54	29.67
Beechwood Hybrid	196	113	83	42.34
Poole	190	112	78	41.05
U.S.D.A. 11616	176	161	15	8.52
Mediterranean	169	126	43	25.44
11c-1a	171	99	72	42.10
Poole #12	181	122	59	32.59
Fulcaster #2	126	90	36	28.57
Mediterranean #87	136	99	37	27.20
Beechwood Hybrid #87	153	55	98	64.05
Illinois #509	147	120	27	18.36
Marvelous (4 pks per A) ..	100	40	60	60.00
Marvelous (2 pks per A) ..	60	21	39	65.00
Michigan Wonder	170	122	48	28.23
Fultz	143	88	55	38.46
Beechwood Hybrid #207	187	170	17	9.09

This table shows that U.S.D.A. 11616 ranks first in the list of hardy varieties with only 8.52 per cent of its plants winterkilled. Beechwood Hybrid #207 is a close second with a winterkilling of 9.09 per cent, while Illinois #509 ranks third with 18.36 per cent winterkilled. Other resistant varieties are Early Ripe, Harvest Queen, Harvest King, Velvet Chaff, Virginia Hybrid, Valley, and Mediterranean - ranking in the order named.

It is interesting to note that the winterkilling per cent for the different varieties of wheat ranged from 8.52 per cent in the case of the U.S.D.A. 11616 to 65.00 per cent for the Marvelous variety. This shows the great difference in the degree of winterkilling between varieties of wheat.

Although these are the results of only one years work and the test was not run in duplicate, yet there is some correlation to be found between the per cent of plant frosted, shown in table VII, and the actual per cent of winterkilling. This should prove that the notes taken on the per cent of the plant frosted may be considered as indicative of the hardiness of that plant or variety.

WINTER RESISTANCE OF WHEAT STRAINS.

The object of this test was to study winter hardiness of pure lines of wheat and to determine which strains grown at the Missouri Station are the most hardy.

Twenty strains of Beechwood Hybrid and twenty-five strains of Michigan Wonder were compared. These strains are pure lines of wheat which originated as single head selections made in 1913. They were sown in head rows in 1913-14 and in rod rows during the two years 1914-16.

The temperature conditions endured by these strains are illustrated graphically in figure III. These conditions have been previously discussed (page 59) and will not be taken up again at this place.

The field notes taken for these strains, giving the estimated per cent of the plants frosted, are shown in table IX.

Table IX.

Resistance to Cold in Wheat Strains.

Strain	Per Cent of Plants Frosted Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st.
Beech. Hyb. 12			25	30	35	99	Poor
Beech. Hyb. 34			25	30	35	99	Fair
Beech. Hyb. 40			25	30	35	99	Poor
Beech. Hyb. 45			25	30	35	99	Poor
Beech. Hyb. 77			25	30	35	99	Poor
Beech. Hyb. 81			25	30	35	99	Poor
Beech. Hyb. 83			25	30	35	99	Poor
Beech. Hyb. 85			25	30	35	99	Poor
Beech. Hyb. 106			25	30	35	99	Poor
Beech. Hyb. 107			25	30	35	99	Poor
Beech. Hyb. 121			25	30	35	99	Poor
Beech. Hyb. 152			25	30	35	99	Poor
Beech. Hyb. 164			25	30	35	99	Poor
Beech. Hyb. 172			25	30	35	99	Poor
Beech. Hyb. 175			25	30	35	99	Poor
Beech. Hyb. 195			50	75	80	99	Poor
Beech. Hyb. 202			25	30	35	99	Fair
Beech. Hyb. 207			25	30	35	99	Poor
Beech. Hyb. 208			25	30	35	99	Poor
Mich. Won. 4			25	30	90	99	Poor
Mich. Won. 8			25	30	35	99	Poor
Mich. Won. 9			25	30	35	99	Poor
Mich. Won. 12			25	30	35	99	Poor
Mich. Won. 14			25	30	35	99	Poor
Mich. Won. 17			25	30	35	99	Poor
Mich. Won. 21			25	30	35	99	Poor
Mich. Won. 53			25	30	35	99	Poor
Mich. Won. 54			25	30	35	99	Poor
Mich. Won. 62			25	30	35	99	Poor
Mich. Won. 83			25	30	35	99	Fair
Mich. Won. 96			25	30	35	99	Poor
Mich. Won. 102			20	25	30	99	Fair
Mich. Won. 103			25	35	35	99	Poor
Mich. Won. 113			20	30	30	99	Fair
Mich. Won. 116			25	30	35	99	Poor
Mich. Won. 118			25	30	35	99	Poor

Strain	Per Cent of Plants Frosted Nov. 18	Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st.
Mich. Won. 120			25	30	35	99	Poor
Mich. Won. 130			25	30	35	99	Poor
Mich. Won. 140			25	30	35	99	Poor
Mich. Won. 141			25	30	35	99	Poor
Mich. Won. 155			15	25	30	99	Fair
Mich. Won. 209			25	30	35	99	Poor
Mich. Won. 211			25	30	35	99	Poor
Mich. Won. 221			25	30	35	99	Poor

According to table IX the most resistant strains of Beechwood Hybrid are numbers 34 and 202. These strains gave no evidence of their hardiness until in the early spring, when their vigorous growth became a striking contrast to the half deadened appearance of the neighboring strains. The strains of Michigan Wonder that gave promise of being cold resistant are numbers 83, 102, 113, and 155. Of these, numbers 102 and 155 showed their superior resistance throughout the winter.

The striking difference in the percentage of the different strains frosted combined with the marked variation in vigor between strains as observed in the spring, points to the fact that there is a difference in winter hardiness between pure line strains of wheat. This would offer an excellent opportunity to continue to select from these resistant strains and thereby obtain a winter hardy variety. Similar improvement has been done by Buffum (8) with winter emmer and Derr (12) with barley.

THE RESISTANCE OF OAT AND BARLEY STRAINS TO COLD.

In this test strains of oats and barley were studied in order to determine their resistance to low temperatures. All the strains tested were pure lines which originated as head selections in 1913. There were ten strains of Culberson Winter oats and 131 strains of winter barley in this test; the 131 strains of barley consisted of 10 strains of Two-rowed Hybrid barley, 10 strains of Tennessee Winter barley, 15 strains of Wisconsin Winter barley, 25 strains of Tennessee Winter barley which originated from Canadian seed, and 70 strains of Tennessee Winter barley which originated from head selections made in 1915.

The soil and air temperatures which these strains withstood are illustrated in Figure III, the actual degrees of cold are tabulated in table V.

Field observations were made on these strains, the same standard of comparison being used in these notes as was used with the other field notes previously reported. The field notes are given in table X.

Table X.

Cold Resistance of Oat and Barley Strains.

Strain	Per Cent of Plant Frosted Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st.
Culberson Oats #1	--	--	99	100	Dead
Culberson Oats #6	--	--	99	100	Dead
Culberson Oats #8	--	--	99	100	Dead
Culberson Oats #9	--	--	99	100	Dead
Culberson Oats #12	--	--	99	100	Dead
Culberson Oats #15	--	--	99	100	Dead
Culberson Oats #17	--	--	99	100	Dead
Culberson Oats #20	--	--	99	100	Dead
Culberson Oats #21	--	--	99	100	Dead
Culberson Oats #24	--	--	99	100	Dead
2-Rowed Hyb.Barley 3	45	90	99	100	Dead
2-Rowed Hyb.Barley 4	45	90	99	100	Dead
2-Rowed Hyb.Barley 6	45	90	99	100	Dead
2-Rowed Hyb.Barley 7	45	90	99	100	Dead
2-Rowed Hyb.Barley 11	45	90	99	100	Dead
2-Rowed Hyb.Barley 14	45	90	99	100	Dead
2-Rowed Hyb.Barley 19	45	90	99	100	Dead
2-Rowed Hyb.Barley 21	45	90	99	100	Dead
2-Rowed Hyb.Barley 30	45	90	99	100	Dead
2-Rowed Hyb.Barley 33	45	90	99	100	Dead
Tenn. W. Barley 3	45	90	99	100	Dead
Tenn. W. Barley 4	45	90	99	100	Dead
Tenn. W. Barley 5	45	90	99	100	Dead
Tenn. W. Barley 7	45	90	99	100	Dead
Tenn. W. Barley 8	45	90	99	100	Dead
Tenn. W. Barley 9	45	90	99	100	Dead
Tenn. W. Barley 12	45	90	99	100	Dead
Tenn. W. Barley 15	45	90	99	100	Dead
Tenn. W. Barley 17	45	90	99	100	Dead
Tenn. W. Barley 19	45	90	99	100	Dead
Wis. W. Barley 2	45	90	99	100	Dead
Wis. W. Barley 3	45	90	99	100	Dead
Wis. W. Barley 4	45	90	99	100	Dead
Wis. W. Barley 9	45	90	99	100	Dead

Strain	Per Cent of Plant Frosted: Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st.
Wis. W. Barley 10	45	90	99	100	Dead
Wis. W. Barley 13	45	90	99	100	Dead
Wis. W. Barley 17	45	90	99	100	Dead
Wis. W. Barley 19	45	90	99	100	Dead
Wis. W. Barley 21	45	90	99	100	Dead
Wis. W. Barley 27	45	90	99	100	Dead
Wis. W. Barley 30	45	90	99	100	Dead
Wis. W. Barley 31	45	90	99	100	Dead
Wis. W. Barley 35	45	90	99	100	Dead
Wis. W. Barley 38	45	90	99	100	Dead
Wis. W. Barley 39	70	95	99	100	Dead
Tenn.W.Barley'15 1	45	90	99	100	Dead
Tenn.W.Barley'15 2	45	90	99	100	Dead
Tenn.W.Barley'15 3	36	80	99	100	Dead
Tenn.W.Barley'15 4	45	90	99	100	Dead
Tenn.W.Barley'15 5	45	90	99	100	Dead
Tenn.W.Barley'15 6	45	90	99	100	Dead
Tenn.W.Barley'15 7	45	90	99	100	Dead
Tenn.W.Barley'15 8	45	90	99	100	Dead
Tenn.W.Barley'15 9	45	90	99	100	Dead
Tenn.W.Barley'15 10	45	90	99	100	Dead
Tenn.W.Barley'15 11	45	90	99	100	Dead
Tenn.W.Barley'15 12	45	90	99	100	Dead
Tenn.W.Barley'15 13	45	90	99	100	Dead
Tenn.W.Barley'15 14	45	90	99	100	Dead
Tenn.W.Barley'15 15	30	85	98	100	Dead
Tenn.W.Barley'15 16	45	90	98	100	Dead
Tenn.W.Barley'15 17	45	90	98	100	Dead
Tenn.W.Barley'15 18	45	90	98	100	Dead
Tenn.W.Barley'15 19	45	90	98	100	Dead
Tenn.W.Barley'15 20	45	90	98	100	Dead
Tenn.W.Barley'15 21	45	90	98	100	Dead
Tenn.W.Barley'15 22	45	90	98	100	Dead
Tenn.W.Barley'15 23	45	90	98	100	Dead
Tenn.W.Barley'15 24	45	90	98	100	Dead
Tenn.W.Barley'15 25	45	90	98	100	Dead

Strain	Per Cent of Plant Frosted: Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st.
Tenn.W.Barley'15 26	45	90	98	100	Dead
Tenn.W.Barley'15 27	45	90	98	100	Dead
Tenn.W.Barley'15 28	45	90	98	100	Dead
Tenn.W.Barley'15 29	45	90	98	100	Dead
Tenn.W.Barley'15 30	45	90	98	100	Dead
Tenn.W.Barley'15 31	45	90	98	100	Dead
Tenn.W.Barley'15 32	45	95	98	100	Dead
Tenn.W.Barley'15 33	45	90	98	100	Dead
Tenn.W.Barley'15 34	45	90	98	100	Dead
Tenn.W.Barley'15 35	45	90	98	100	Dead
Tenn.W.Barley'15 36	45	90	98	100	Dead
Tenn.W.Barley'15 37	45	90	98	100	Dead
Tenn.W.Barley'15 38	45	90	99	100	Dead
Tenn.W.Barley'15 39	45	90	99	100	Dead
Tenn.W.Barley'15 40	45	90	99	100	Dead
Tenn.W.Barley'15 41	45	90	99	100	Dead
Tenn.W.Barley'15 42	45	90	99	100	Dead
Tenn.W.Barley'15 43	45	90	99	100	Dead
Tenn.W.Barley'15 44	45	90	99	100	Dead
Tenn.W.Barley'15 45	45	90	99	100	Dead
Tenn.W.Barley'15 46	45	90	99	100	Dead
Tenn.W.Barley'15 47	70	97	99	100	Dead
Tenn.W.Barley'15 48	45	90	99	100	Dead
Tenn.W.Barley'15 49	45	90	99	100	Dead
Tenn.W.Barley'15 50	45	90	99	100	Dead
Tenn.W.Barley'15 51	45	90	99	100	Dead
Tenn.W.Barley'15 52	45	90	99	100	Dead
Tenn.W.Barley'15 53	45	90	99	100	Dead
Tenn.W.Barley'15 54	45	90	99	100	Dead
Tenn.W.Barley'15 55	45	90	99	100	Dead
Tenn.W.Barley'15 56	45	90	99	100	Dead
Tenn.W.Barley'15 57	45	90	99	100	Dead
Tenn.W.Barley'15 58	45	90	99	100	Dead
Tenn.W.Barley'15 59	45	90	99	100	Dead
Tenn.W.Barley'15 60	45	90	99	100	Dead
Tenn.W.Barley'15 61	45	90	99	100	Dead

Strain	Per Cent of Plant Frozen: Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor of Plants on Mar. 21st.
Tenn.W.Barley'15 61	45	90	99	100	Dead
Tenn.W.Barley'15 62	45	90	99	100	Dead
Tenn.W.Barley'15 63	45	90	99	100	Dead
Tenn.W.Barley'15 64	45	90	99	100	Dead
Tenn.W.Barley'15 65	45	90	99	100	Dead
Tenn.W.Barley'15 66	45	96	99	100	Dead
Tenn.W.Barley'15 67	45	90	97	100	Dead
Tenn.W.Barley'15 68	45	90	99	100	Dead
Tenn.W.Barley'15 69	45	90	99	100	Dead
Tenn.W.Barley'15 70	45	90	99	100	Dead
Tenn.W.Barley Can. 1	45	90	99	100	Dead
Tenn.W.Barley Can. 2	45	90	99	100	Dead
Tenn.W.Barley Can. 3	45	90	99	100	Dead
Tenn.W.Barley Can. 4	45	90	99	100	Dead
Tenn.W.Barley Can. 5	45	90	99	100	Dead
Tenn.W.Barley Can. 6	45	90	99	100	Dead
Tenn.W.Barley Can. 7	45	90	99	100	Dead
Tenn.W.Barley Can. 8	45	90	99	100	Dead
Tenn.W.Barley Can. 9	45	90	99	100	Dead
Tenn.W.Barley Can.10	45	90	99	100	Dead
Tenn.W.Barley Can.11	50	90	99	100	Dead
Tenn.W.Barley Can.12	45	90	99	100	Dead
Tenn.W.Barley Can.13	45	90	99	100	Dead
Tenn.W.Barley Can.14	45	90	99	100	Dead
Tenn.W.Barley Can.15	85	95	99	100	Dead
Tenn.W.Barley Can.16	45	90	99	100	Dead
Tenn.W.Barley Can.17	45	90	99	100	Dead
Tenn.W.Barley Can.18	45	90	99	100	Dead
Tenn.W.Barley Can.19	45	90	99	100	Dead
Tenn.W.Barley Can.20	45	90	99	100	Dead
Tenn.W.Barley Can.21	45	90	99	100	Dead
Tenn.W.Barley Can.22	45	90	99	100	Dead
Tenn.W.Barley Can.23	45	90	99	100	Dead
Tenn.W.Barley Can.24	45	90	99	100	Dead
Tenn.W.Barley Can.25	45	90	99	100	Dead

Owing to the unusually severe winter the oat strains were entirely killed, as noted in table X. The notes taken previous to February 14th, at which date they were recorded as being 100 per cent frosted, show that there was apparently no difference in the resistance of the different strains. It may be concluded therefore that there is no difference in the winter hardiness of the ten oat strains tested.

The same unfortunate conditions occurred in the case of the various barley strains. The cold was so severe that all strains were entirely killed. Notes taken early in the season would indicate that there were a few strains more hardy than others but by January 27 all strains were dead so that it is difficult to state that any strain is "hardy."

THE EFFECT OF DATE OF PLOWING AND DEPTH OF SEEDING UPON WINTERKILLING.

A test was conducted to determine the influence of the date of plowing and the depth of seeding upon the degree of winterkilling.

Two plots of ground, one plowed the last week of August and the other plowed October 16th, were sown with Fulcaster, Beechwood Hybrid, and Fultz wheats; Wisconsin Winter and Tennessee Winter barley; and Winter Turf and Culberson Winter oats. These varieties of wheat, barley, and oats had been grown at the Missouri Agricultural Experiment Station for a number of years and so were well acclimated. They were sown with a grain drill at three different depths, 1½, 3, and 5½ inches and at the rate of 5 pecks per acre for the wheats, 10 pecks per acre for the oats, and 8 pecks per acre for the barleys. At the time of seeding, October 18th, the plot which was plowed immediately before planting was extremely loose and uneven, a man sinking to his ankles when walking over it, whereas, the early plowed ground was firm and in fine tilth.

The plot of ground which was plowed early was lower and would perhaps contain more moisture than the late plowed plot. This would possibly affect the soil temperatures. Air thermometers were placed on both plots of ground and from table V it may be seen that the air temperatures on the two plots varied but little; thus the results obtained on the two plots may be safely compared since the differences in soil temperatures would be due to the physical condition of the soil and not to any differences in the air temperatures upon the two plots.

The average daily minimum soil temperature of the early plowed plot was 27.3°F while that of the late plowed ground was 26.3° - a difference of 1°. The lowest temperature recorded on the early plowed plot was -1°; the lowest on the late plowed plot was -5°. These data show that the soil temperature of the late plowed plot was slightly lower than the temperature on the early plowed plot. The lowest temperature recorded was also read on the plot which was late plowed.

The curves in figure IV illustrate the soil temperatures for the two plots. The black line represents the soil temperature at a depth of three inches on the early plowed plot while the red line shows the same for the late plowed ground. Again note how uniformly higher the temperature is on the early plowed than on the late plowed plot. This is in accord with the observations of Sandborn (67) who states that unpacked soils have lower temperatures than rolled soils.

See supplemental file Figure 5 for unfolded version.

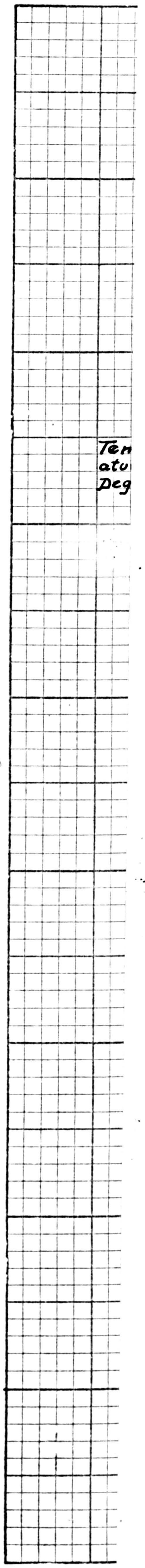


Table XI gives the frosting percentage notes for the early and late plowed plots at the three depths of planting; 1½, 3, and 5½ inches.

Table XI

The Effect of Depth of Seeding and Date of Plowing Upon Frost Resistance

Grain	Date	Per Cent of Plant Frosted					
		Early Plowed			Late Plowed		
		1½"	3"	5½"	1½"	3"	5½"
Wheat:							
Fulcaster	Jan.27	30	30	30	40	40	40
	Feb.14	99	99	99	99	99	99
	Mar.21	poor	poor	poor	poor	poor	poor
Beechwood Hyb.	Jan.27	65	65	65	65	65	65
	Feb.14	100	100	100	100	100	100
	Mar.21	poor	poor	poor	poor	poor	poor
Fultz	Jan.27	65	65	65	100	100	100
	Feb.14	100	100	100	100	100	100
	Mar.21	dead	dead	dead	poor	poor	poor
Barley:							
Wis. Winter	Jan.27	95	95	95	95	95	95
	Feb.14	100	100	100	100	100	100
	Mar.21	dead	dead	dead	dead	dead	dead
Tenn.Winter	Jan.27	95	95	95	95	95	95
	Feb.14	100	100	100	100	100	100
	Mar.21	dead	dead	dead	dead	dead	dead
Oats:							
Culberson	Jan.27	99	99	99	100	100	100
	Feb.14	100	100	100	100	100	100
	Mar.21	dead	dead	dead	dead	dead	dead

After an examination of the above data it is apparent that the depth of seeding is in no way correlated with frost injury. It is equally unsatisfactory to make a comparison between the extent of frosting upon the late and the early plowed plots for in every instance, except one, the plants upon the two plots were equally injured.

The actual per cent of winterkilling for the early and late plowed plots, at the different depths of seeding, is given in table XII.

Table XII.

The Effect of Depth of Seeding and Date of Plowing upon Winterkilling.

Grain	Depth of Seeding	Early Plowing			Late Plowing		
		No. Plants: Fall	No. Plants: Spr.	Winter-killing	No. Plants: Fall	No. Plants: Spr.	Winter-killing
	inches			Per cent	inches		Per cent
Wheat:							
Fulcaster	1½	79	51	35.44	93	48	48.38
	3	87	60	31.03	64	30	53.12
	5½	68	48	29.41	67	18	73.13
Beechwood Hyb....	1½	86	10	88.57	76	0	100.00
	3	81	9	88.88	70	1	100.00
	5½	74	15	78.72	51	0	100.00
Fultz	1½	86	53	38.37	83	35	57.83
	3	97	48	50.51	84	40	52.38
	5½	68	32	52.94	66	30	54.54
Barley:							
Wis. Winter	1½	57	0	100.00	56	0	100.00
	3	49	0	100.00	53	0	100.00
	5½	39	0	100.00	46	0	100.00
Tenn. Winter	1½	43	0	100.00	66	0	100.00
	3	44	0	100.00	58	0	100.00
	5½	47	0	100.00	29	0	100.00
Oats:							
Culberson	1½	68	0	100.00	43	0	100.00
	3	45	0	100.00	55	0	100.00
	5½	53	0	100.00	42	0	100.00

Disregarding the barley and oat data which cannot be considered since the plants did not survive the winter and studying only the data for the three varieties of wheat, we must conclude that the results obtained do not justify any conclusion regarding the effect of the depth of seeding upon the degree of winterkilling. The table shows that the results from the Fulcaster wheat, on both late and early plowed plots, favor shallow seeding; the results from the Beechwood Hybrid favor deep seeding; while the Fultz was the most hardy when seeded shallow on the early plowed ground but on the late plowed ground it was more resistant when seeded deep.

There is sufficient evidence in table XII to believe that winterkilling is less upon ground which is plowed early than upon ground which was plowed immediately before planting. In every instance there was greater injury among the plants which were sown on the late plowed plot than among those which were seeded in the early plowed ground.

After studying the soil temperatures illustrated in figure IV and observing the uniformly higher temperature of the early plowed plot, the increased amount of winterkilling on the late plowed ground is possibly explained. In an average year this difference might not have been so great since in a normal winter there is greater snowfall and a snow blanket would have equalized the temperatures. The fact that the early plowed plot was situated so as to contain more moisture would also account for a slightly higher soil temperature on that plot.

SEEDING IN FURROWS TO PREVENT WINTERKILLING.

The practice of sowing winter grains in open furrows is not uncommon and is generally recommended for certain areas in this country, particularly in the South. A preliminary experiment was conducted at the Missouri Agricultural Experiment Station to determine the amount of protection from winter injury that is afforded to plants by sowing them in open furrows.

The plots for this experiment were laid out as follows:

Series I --- rows running north and south.

Plot 1 - Fulcaster wheat, Tennessee Winter barley, and Culberson oats sown in rows, no furrows.

Plot 2 - Three varieties of wheat (Fulcaster, Beechwood Hybrid, and Fultz); two varieties of barley (Wisconsin Winter and Tennessee Winter); and two varieties of oats (Winter Turf and Culberson); sown in furrows three inches deep.

Plot 3 - Three varieties of wheat, (Fulcaster, Beechwood Hybrid, and Fultz); two varieties of barley (Wisconsin Winter and Tennessee Winter); and two varieties of oats (Winter Turf and Culberson) sown in furrows six inches in depth.

Plot 4 - Fulcaster wheat, Tennessee Winter barley, and Culberson oats sown on the top of an eight inch ridge.

Series II.--- Duplicate of Series I with rows extending east and west.

The rows were twenty feet long and sixteen inches apart. The ridging and planting was all done with hand labor and especial care was taken to have the furrows well drained. It was not possible to sow the plots before October 23rd and so the plants were mere seedlings at the time of the first killing frost, which occurred November 12th. Thermometers were placed in the soil at a depth of three inches, and thus the soil temperatures for the surface, three inch furrow, six inch furrow, and ridge plantings were obtained. The temperature data recorded in this test is tabulated in table V; this has been briefly summarized and is shown in table XIII.

Table XIII.

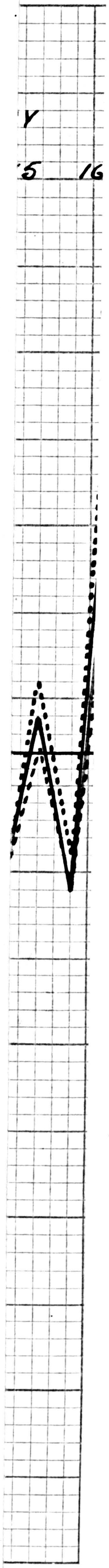
A Summary of Table V.

Location of Thermometer	Ave. daily min. temp. from Dec.7 to Mar.19	Ave. daily min. temp. for days below 32°F	Lowest min. temperature recorded
	degrees F	degrees F	degrees F
Surface	26.7	24.8	-3
3 inch furrow	27.2	25.5	0
6 inch furrow	28.3	26.8	0
Ridge	25.9	23.8	-8
Air	24.3	21.8	-10

It is plainly seen in table XIII that the plants growing in the furrows did not have to withstand as low soil temperatures as did the plants growing on the surface. The six inch furrow for the days in which the thermometer fell below 32°F averaged 2^{o} higher than that of the surface planted plots; and in the three inch furrow it averaged 1^{o} higher. The soil on the ridge was by far the coldest soil, being 3^{o} colder than the surface. The difference shown here is even more striking than the results given by Salmon (65), which are noted on page 32 of this thesis.

The soil temperatures for the surface, three inch furrow, and ridge are illustrated in figure V. The sold black line represents the soil temperature of the surface planted plot, the dotted black line the ridge temperature, the solid red line the three inch furrow temperature, and the dotted red line the six inch furrow temperature.

See supplemental file Figure 4 for unfolded version.



The role of snow in lowering soil temperature is plainly seen in this figure. Upon the dates of December 11th to 17th, January 15th to 20th, and March 3rd to 4th it will be noted from table V that there was snow upon the ground. Turning from table V to figure IV and observing the curves for these snow present dates one cannot fail to notice the relative high temperature recorded for the 3 and 6 inch furrows. Upon the 15th of December, according to the Local Weather Bureau (84) all snow had disappeared but according to field notes the drifted snow in the furrows had not entirely melted. The protection which a snow blanket gives is shown by the fact that on this day the minimum temperature for the ridge was 16° F, the surface 21° F, the 3 inch furrow 24° F, and the 6 inch furrow 30° F. The plant roots, then, in the six inch furrow were 9° warmer than those of the surface planted plants.

There can be no doubt, therefore, but that the furrows exercise a pronounced influence on the temperatures which the plants endure. A difference of even a few degrees might save the life of the plant. The point to which the plants in the six inch furrow are subjected, may be above the death temperature but at the same time a killing temperature may be experienced by the plants which are surface planted.

The actual results of these different temperatures may be seen in the following tables. The field notes upon the frosting of the plants are shown in table XIV.

Table XIV.

Open Furrows as a Protection from Frost.

Method of Seeding	Kind of Grain	Per Cent Plant Frosted Nov. 28	Dec. 7	Jan. 6	Jan. 27	Feb. 14	Vigor on Mar.21
Rows N & S							
Surface	Fulcaster wheat	30	50	80	100	100	Dead
	Tenn. W. barley	60	80	100	100	100	Dead
	Culberson oats	75	90	100	100	100	Dead
3" Furrow	Fulcaster wheat	25	30	30	35	98	Poor
	Beechwood Hybrid	25	30	35	40	98	Poor
	Fultz wheat	25	30	35	40	98	Poor
	Wis. W. barley	40	55	85	98	100	Dead
	Tenn. W. barley	40	55	85	98	100	Dead
	Winter Turf oats	50	60	90	100	100	Dead
	Culberson oats	50	60	90	100	100	Dead
6" Furrow	Fulcaster wheat	25	30	35	40	98	Fair
	Beechwood Hybrid	25	30	30	35	98	Fair
	Fultz wheat	25	30	30	35	100	Poor
	Wis. W. barley	40	50	75	95	100	Dead
	Tenn. W. barley	45	50	75	95	100	Dead
	Winter Turf oats	40	50	85	95	100	Dead
	Culberson oats	50	50	90	100	100	Dead
Ridge	Fulcaster wheat	75	90	100	100	100	Dead
	Wis. W. Barley	100	100	100	100	100	Dead
	Culberson oats	100	100	100	100	100	Dead
Rows E & W							
3" Furrow	Fulcaster wheat	25	25	25	30	100	Fair
	Beechwood Hybrid	25	40	80	95	100	Dead
	Fultz wheat	25	50	85	95	100	Dead
	Wis. W. barley	40	60	90	100	100	Dead
	Tenn. W. barley	40	60	90	98	100	Dead
	Winter Turf oats	50	80	95	100	100	Dead
	Culberson oats	50	80	95	100	100	Dead
6" Furrow	Fulcaster wheat	25	25	30	50	98	Fair
	Beechwood Hybrid	25	25	25	35	98	Fair
	Fultz wheat	25	25	25	35	100	Fair
	Wis. W. barley	40	45	60	75	100	Dead
	Tenn. W. barley	40	45	60	80	100	Dead
	Winter Turf oats	50	60	90	100	100	Dead
	Culberson oats	50	75	90	100	100	Dead
Ridge	Fulcaster wheat	50	95	100	100	100	Dead
	Wis. W. barley	75	99	100	100	100	Dead
	Culberson oats	100	100	100	100	100	Dead

The plants grown in the six inch furrows, with the rows running both north and south, and east and west, were the least injured of any in the test. The oats and barleys were killed; but from a study of the frosting percentages it is noticed that the injury was more severe and occurred earlier in the surface planted rows than it did in the furrows. There is a slight indication that the rows extending east and west were injured to a less degree than those running north and south.

In addition to the observation notes taken of these series the actual per cent of winterkilling under the different conditions was determined. Strips five feet long were staked out in each row and the number of plants in that area accurately counted. The count was made late in the fall so that death from disease, competition between plants, etc., would not enter into the per cent of plants killed by cold. The count was again made in the spring after all danger from frost was past. From this data the per cent of winterkilling was calculated. This data is given in table XV.

Table XV.

The Influence of Open Furrows upon Winterkilling.

Method of Seeding	Kind of Grain	Number of Plants on Nov.16	Number of Plants on Mar.26	Winter-killing Per cent
Rows N & S				
Surface	Fulcaster wheat	128	2	98.30
	Tenn. W. barley	99	0	100.00
	Culberson oats	119	0	100.00
3" Furrow	Fulcaster wheat	79	43	45.56
	Beechwood Hybrid	112	40	64.28
	Fultz wheat	105	32	69.52
	Wis. W. barley	93	0	100.00
	Tenn. W. barley	73	0	100.00
	Winter Turf oats	188	0	100.00
	Culberson oats	146	0	100.00
6" Furrow	Fulcaster wheat	102	57	44.11
	Beechwood Hybrid	79	36	54.43
	Fultz wheat	116	63	45.68
	Wis. W. barley	135	0	100.00
	Tenn. W. barley	136	0	100.00
	Winter Turf oats	145	0	100.00
	Culberson oats	148	0	100.00
Ridge	Fulcaster wheat	90	0	100.00
	Wis. W. barley	81	0	100.00
	Culberson oats	113	0	100.00
Rows E & W				
3" Furrow	Fulcaster wheat	120	87	27.50
	Beechwood Hybrid	106	3	97.16
	Fultz wheat	83	1	98.79
	Wis. W. barley	84	0	100.00
	Tenn. W. barley	87	0	100.00
	Winter Turf oats	126	0	100.00
	Culberson oats	97	0	100.00
6" Furrow	Fulcaster wheat	68	33	51.47
	Beechwood Hybrid	89	30	66.29
	Fultz wheat	85	29	65.88
	Wis. W. barley	74	0	100.00
	Tenn. W. barley	84	0	100.00
	Winter Turf oats	106	0	100.00
	Culberson oats	92	0	100.00
Ridge	Fulcaster wheat	52	0	100.00
	Wis. W. barley	66	0	100.00
	Culberson oats	103	0	100.00

This table shows that all the barley and oats were 100 per cent winterkilled; the wheats however survived and this data is brought together and summarized in table XVI. This table gives the averaged per cent winterkilling of the wheats which were planted on the surface, in furrows and on the ridges and also compares the rows extending north and south to those running east and west.

Table XVI.

The Protection from Winterkilling Afforded by Furrows.

Variety	Surface sown	Winterkilling in Per Cent for 3" Furrows N&S	E&W	Ave	6" Furrows N&S	E&W	Ave	Ridge N&S	E&W	Ave
Ful.	98.30	45.56	27.50	36.53	44.11	51.47	47.79	100	100	100
Beech.	-----	64.28	97.16	80.72	54.43	66.29	60.36	---	---	---
Fultz	-----	69.52	98.79	84.15	45.68	65.88	55.78	---	---	---
Ave.	98.30	59.78	74.47	67.13	48.07	61.21	54.64	100	100	100

The grain sown on the level surface winterkilled 98.30%, in the 3 inch furrows 67.13%, in 6 inch furrows 54.64%, and upon the ridge 100.00%. This shows that while the wheat planted in the ordinary manner was nearly all killed, yet that which was sown in the six inch furrows survived with a 50% stand in the spring. Results similar to this have been reported by Georgeson (21), Redding (58), Warburton (83), Remy and Kreplin (59), Duggar (14), McClelland (44), Carleton (9), Ricks (60), Thiry (80), and Salmon (65). The results as shown in table XVI indicate that the seeding of winter cereals in open furrows in this locality would, in such severe winters as 1916-17, be beneficial.

The data further shows that the direction in which the furrows are laid out influences the degree of winter injury. The plants in the three inch furrows which extended north and south were 59.78 per cent winterkilled, whereas the east and west rows winterkilled 74.47 per cent. In the six inch furrows the north and south rows winterkilled 48.07 per cent and the east and west rows 61.21 per cent. Thus in both depths of furrows the rows which extended north and south had the lowest per cent of winterkilling. Similar results have been previously mentioned as being found by Warburton (83), who advised planting at right angles to the prevailaing winds.

Several writers, namely Redding (58), Warburton (83), Remy (59), Duggar (14,15), McClelland (44), Ricks (60), Salmon (65), and Schmitz (69), have observed the protection from heaving given by the furrows. Such action was particularly noticed in this experiment. The ridges were early cracked and weathered so that the plants in the furrows were, in some instances, nearly covered with soil. The dirt thus washed down about the plants served as an excellent mulch and without doubt it served to minimize the winter injuries.

It may be safely said that the results obtained in this experiment indicate strongly that the seeding of winter cereals in furrows lessens the injury received by the plants from heaving and low temperatures. It is also shown that the plants in the furrows may be still further protected by extending the furrows at right angles to the prevailing winds.

SUMMARY.

A preliminary study of winterkilling in cereals was outlined to determine: first, the resistance of varieties and strains of wheat, barley and oats to winterkilling; second, the effect of late and early plowing upon the extent of winter injuries; third, the influence of the depth of seeding upon winterkilling; and fourth, the effect of seeding in open furrows upon the degree of winterkilling.

The climatic conditions in the winter of 1916-17 were unfavorable for this study. The winter was unusually dry and there was comparatively little snowfall when contrasted with the average winter for this locality. Such conditions subjected the plants to intense cold and owing to this fact the experimental results are not indicative of results which might be obtained in normal winters. The winter was so severe that the methods tested for protecting the plants, although they might be sufficient protection in a normal winter, proved to be insufficient. It had been planned to study the relation between the extent of winterkilling and the length and breadth of leaves and habit of growth but this study had to be abandoned because the plants were so badly injured early in the winter.

In spite of these unfavorable conditions the one year's experimental results indicate the following points:

(1) As determined by actual per cent of winterkilling the most hardy varieties of wheat tested are: U.S.D.A.11616, Beechwood Hybrid #207, Illinois #509, Early Ripe, Harvest

Queen, Harvest King, Velvet Chaff, Virginia Hybrid, Valley, and Mediterranean - ranking in the order named.

(2) The most hardy wheat strains tested are: Michigan Wonder strain numbers (Missouri) 102, 155, 83, and 113; and, Beechwood Hybrid strain numbers (Missouri) 34 and 202.

(3) No difference was found in the resistance of the oat strains tested; all were killed.

(4) There was only a slight difference in winter resistance between the different barley strains tested; none survived the winter.

(5) An actual determination of the per cent of winterkilling, shows that there is less winterkilling of plants sown upon early plowed than upon late plowed ground.

(6) The actual winterkilling percentages show that the depth of seeding does not influence the degree of winter injury.

(7) The plants which were sown in open furrows survived the winter with a lower per cent of winterkilling than the plants which were sown on level ground.

(8) The results indicate that for this section of Missouri the furrows extending north and south are of greater protection than those running east and west.

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UNIVERSITY OF MISSOURI
COLUMBIA

COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
DEPARTMENT OF FARM CROPS

May 14, 1917.

RAISE A WAR CROP!

Dean Walter Miller,

Academic Hall.

Dear Dean Miller:

Under another cover I am sending you a thesis entitled, "Studies in the Winterkilling of Cereals" by Mr. H. R. Sumner, candidate for the degree of Master of Arts. The thesis is acceptable and satisfactory to the Department of Farm Crops in which department the investigation which forms the subject matter of the thesis was pursued.

Yours very truly,

W C Etheridge

WCE-HA