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CAUSES AND EFFECTS OF SOIL HEAVING

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The Soils Department of the Michigan State College, has been engaged in the study of the temperature of soils and the winter killing of plants for a number of years. In these studies, efforts have been made to ascertain soil temperature changes during the year in different soils and under different conditions, how the plants are injured, and the possible ways of lessening or preventing the losses so entailed. In this report, the causes of soil heaving and the injury of crops by heaving are discussed.

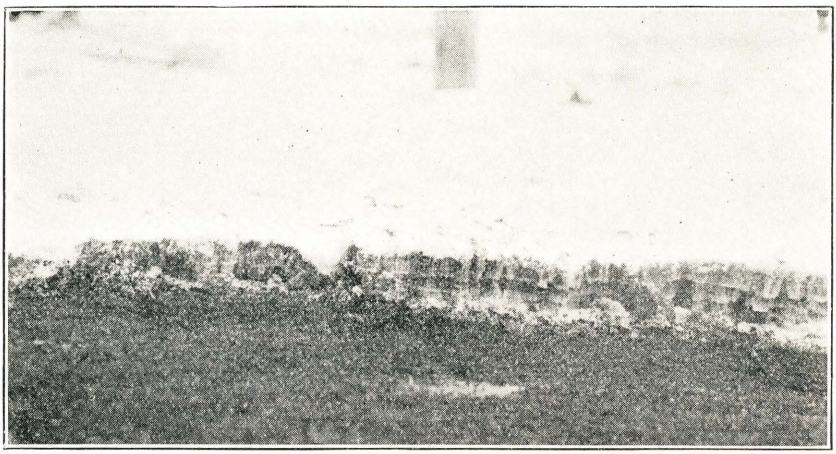

Fig. 1.—Layers of ice crystals several inches thick may be formed either at the surface or some distance below it on muck soils owing to their high water retaining capacity. The spaces between the horizontal lines show the thickness of ice formed during one night of freezing.

HEAVING OF SOILS

Until recently, it was generally believed that the heaving of soils was caused by the expansion of water as it changed to ice within the soil. It is a fact that water expands when it freezes, as is shown by the bursting of water pipes when ice forms in them. Experiments and studies at Michigan State College prove, however, that the expansion of water as it freezes is not the complete explanation for the heaving of soils. Soil heaving is due to the formation of ice crystals when the soil mois-

ture freezes, either at the surface or below the surface of the soil. During the formation of the ice crystals, unfrozen water is drawn to them by capillary or film movement and they grow in size and push upward, thus causing a greater degree of heaving than would result from the freezing of the water carried in the surface layer of soil without this constant addition of capillary water drawn to the crystals during the process of formation.

The amounts of water which were carried in one night above 12 square inches of muck, a loam, a clay and a sandy soil by the ice were determined. Above the surface of the muck, 285 grams of water were carried up in the form of ice capillary columns. The moisture content

Fig. 2.—In some instances the ice crystals formed just beneath a thin layer of soil pushing it upward, as indicated by the pebbles and plants on the surface.

of this soil before freezing was 118 per cent of the weight of the dry soil. In a loam soil which had a moisture content of 32 per cent, 56 grams of water was carried up. In a clay soil which had a moisture content of 40 per cent the amount brought up was 72 grams, and, in a sandy soil which had a moisture content of 18 per cent, it was 25 grams. The force exerted by the upward movement may become comparatively great, sufficient to heave road pavements and sidewalks out of place or stones out of the soil.

Two types of heaving which may take place in the soil have been observed. In the first type, if the temperature of the air during the day, either in the fall or spring when the soils are not frozen, begins to go down slowly and does not drop too low, beyond 20° F. for example, the film of water at the surface of the soil begins to freeze and

water drawn from the lower depths of the soil grows into long needle-like crystals. This type is shown in figure 1. If the air temperature remains at or below the freezing point, these ice columns will continue to grow and will assume considerable heights, sometimes as much as five inches. This happens most often where the moisture content of the soil is high. Additional stages of growth take place each night during freezing weather. The ice columns, or needle-like crystals, are formed at the surface without penetrating the lower depths of the soil, and the surface soil may not be frozen. The ice columns grow upward as straight needles massed together. The growth takes place at the lower end and pushes the entire column upward. At the top of the ice column, there may be a thin veneer of soil which may be erroneously taken as evidence that the soil is heaved.

Fig. 3.—Alfalfa plants badly heaved by the formation of ice crystals.

In order that the ice columns or needle-like crystals described above may form at the top of the soil, the soil must be wet. The number of ice columns formed will be proportionate to the moisture content of the soil. If the moisture content is comparatively low, the movement of water which is attracted to the surface is slight, and, as a result, the moisture freezes as snow or ice particles in the larger capillary or air spaces in the soil. This formation is shown in figure 2. Under such conditions, there is no heaving of the soil.

The second type of heaving takes place most frequently during periods when the temperature rises and is accompanied by heavy rainfall which, in turn, is followed suddenly by a cold wave. The temperature may drop overnight, or in the course of a few hours, from 50° F. to as low as 15° F. Under these conditions, one or two inches of the surface soil is frozen solid. The freezing is so rapid that the

force of crystalization or freezing does not have time to draw water from below and bring it to the surface to freeze as ice columns or even as solid ice, but, instead, the soil freezes solid with its original water content. The air temperature afterwards moderates somewhat, and, immediately under the frozen layer, the ice columns or needle-like crystals begin to form and continue to grow. These ice columns grow upward, and this growth raises frozen layers of soil. The frozen layer above is disconnected from the unfrozen soil below by the ice columns. If these ice columns are taken out, an empty space or cavity remains between the frozen layer above and the unfrozen soil below.

This type of heaving frequently takes place in mucks and peats but is not so common in mineral soils, especially when they are compacted. However, if the latter soils are loose, it is apt to occur. In

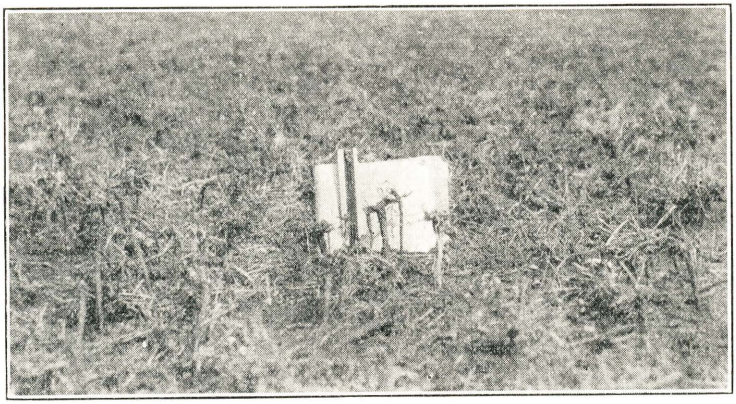

Fig. 4.—The lifting power resulting from the formation of ice crystals at or near the surface of the soil is exemplified by the position of the above alfalfa plants. The tap roots of many plants are broken during this process, especially when the surface few inches of soil thaws and freezes. The frozen soil beneath acts as an anchor and the roots are broken.

some instances, the ground is frozen to considerable depths from the surface, and thawing of the upper several inches of soil takes place. The temperature falls and heaving occurs.

Many people believe that heaving occurs only in poorly drained soils and that proper drainage would prevent heaving in such soils. It is true that poorly drained soils are more subject to heaving than those which are well drained, but heaving can take place even in well drained soils. Heaving occurs in the fall and spring when the soils are likely to be wet after rains or the melting of snow. Water passes downward in the soil much more slowly when it is cold than it does when it is warmer. Under these conditions, therefore, even well drained soils can heave. However, as will be shown later, the damage to crops may not be so great on well drained soils as it is on the poorly drained soils.

HEAVING OF PLANTS AND ITS PREVENTION

Our studies show that most, if not all, of the heaving of plants is caused by the first type of ice formation. Where the water accumulates at the surface and forms ice columns or ice sheets, soil and plants are pushed up by the ice. Undoubtedly, some heaving of plants takes place also by the second type of heaving, where the ice crystals or

Fig. 5.—Early seeding and proper soil preparation for clover by the use of lime and commercial fertilizers result in extensive root development and as a result heaving is greatly reduced. The plants at the right in this photograph were taken from soil which was well prepared and those at the left were taken from soil which was not. Almost complete distruction of the stand of the latter during the winter of 1928 resulted from heaving.

ice sheets grow upwards under a frozen layer of soil and push the latter upward, but this occurs mostly in mucks or soils which are very high in organic matter and which hold large amounts of water.

In the first type of heaving, the ice sheets or crystals which are formed at the surface of the soil attach themselves to the crown or stem of plants. Since the ice sheet or crystals grow from below and push upward, the plants are carried along and are lifted out of the

ground to a height which corresponds to the upward growth of the ice sheets or crystals. When warm weather comes, the ice melts but the plants are not carried back to their original position as the soil settles, but are left exposed. If cold weather follows the thaw, the heaving is repeated and the plants are pulled farther out of the ground. If this is repeated a sufficient number of times, the plants will be pulled out of the ground entirely. The lifting process might well be compared to the action of a jack in raising an automobile from the ground.

The extent to which the plants will be pulled out of the ground will depend upon the kind of plants, the stage of growth of the plants, the amount of surface protection, the amount of water in the soils, the type of soils, and the number of times of freezing and thawing.

Stands of alfalfa and sweet clover on heavy soils are rather frequently injured by heaving. The plants are pulled partially or entirely

Fig. 6.—Heaving and winter injury of wheat and rye are much more serious if the growth is slight. The light strip across this wheat field is the result of the omission of fertilizer. The injury induced by heaving and low temperature was severe and the yields were small. Where fertilizer was used on Miami loam, the killing by heaving was less than 10 per cent; where it was omitted 85 per cent of the stand was killed in 1928. Similar results were obtained with rye.

out of the soil and they afterwards lose moisture and perish. This is probably because they have one long or tap root, without many side or lateral roots, and are not held very strongly by very wet soils. In addition, they have a comparatively large crown and root surface to which the ice can become attached. Alsike, red, and mammoth clovers in their early stages of development or before the lateral roots are extensively developed are likewise easily heaved. Later on, when an elaborate fibrous root system has developed, the damage is not so great, because the plants are dislodged with much greater difficulty.

The total aggregate loss by heaving of fall seeded wheat and rye is enormous. When these crops are planted sufficiently early and make a good root and top growth, they suffer much less from heaving except in abnormally wet spots. If these crops are planted late, and make

Fig. 7.—Wheat should be seeded as near the earliest date for escaping the Hessian fly as possible. Early seeding of wheat and rye and proper fertilization result in adequate root and top development, each of which reduce heaving of the plants. Plants developed as those shown in the right of this figure are resistant whereas those with slight root growth as those in the left are not.

a very small growth in the fall, they suffer severely from ice action. When they have made a large growth, there are two conditions which assist them in resisting heaving. They have developed a large root system which has taken a good hold on the soil, and the ice sheet cannot pull the plants out so easily. Furthermore, sufficient roots may remain in the soil to supply the plants with water until new growth takes place. A large top growth tends to protect the soil somewhat and thus reduces the frequency of freezing and thawing.

If the ground is protected either with straw, growth of crops, or snow, heaving of the soil and of the plants may be either entirely prevented or considerably lessened because of more uniform temperature conditions.

Fig. 8.—A heavy stuble or crop residue, may reduce or prevent heaving and winter injury of seedings.

The amount of water in the soil and the kind of soil play a very important part in the heaving of plants. If the moisture content of soils is very high, the height to which the ice sheet or crystals will rise will be correspondingly high. Under such conditions, the resistance to the withdrawal of the roots is relatively low and the plants will be lifted much more than if the water content is low and the ice sheet does not rise very high. In mucks, peats, and some of the heavy soils where the water content is great, the plants are sometimes pulled out of the ground two or three inches by a single night's freezing. In sandy soils which are comparatively wet the water content is less than in other soil types and the ice sheet does not rise so high and the plants may never be entirely heaved out, even by numerous repetitions of freezing and thawing. If the drainage is poor, heaving is likely to take place in all the different classes of soils.

Although some plants may be almost completely withdrawn from the soil by one freezing in some of the wet soils, repeated freezings and thawings are usually required to completely heave out the plants or to injure them appreciably. Thus, frequent changes in temperature together with an abundance of moisture in the soil are conducive to heavy losses by heaving of plants.

Although winter injury of crops by heaving is not easily controlled, there are certain things that can be done in some years to prevent or, in other years, to considerably lessen the severity of the injury. These preventative measures are top dressing the ground with such materials as straw or manure, planting crops at the proper time, fertilizing them well so that the plants will make a large and vigorous growth, and draining the land.

Top dressing the ground with straw or manure prevents or greatly reduces heaving because the temperatures of soils so treated are more nearly uniform.

According to our field experiments and observations, planting rye and wheat at the earliest possible date, when possible damage by Hessian fly is considered, and the liberal use of fertilizer so that the plants will make a vigorous growth are the best practices to follow to prevent or lessen winter killing of these crops. If the plants make a large and vigorous growth in the fall, their roots penetrate deeply and are well spread in the ground and they will not be pulled out of the ground so easily. In addition, if heaving does take place, the chances are greater for the plants being supplied with water until new root growth takes place in the spring. The large top growth also tends to protect the ground and results in more uniform temperature and less freezing and thawing. Early seeding of the clovers and alfalfa and the use of lime and fertilizers reduce the losses by heaving. The use of the roller or cultipacker on wheat, rye, or seedings before the plants have become too dry cuts the losses by bringing about contacts between the plants and the moist soil. We have found this to be especially valuable in new grass seedings on mucks and other moist soils.

It was stated previously that, although heaving will take place even in well drained soils, there are many seasons when it will not occur, but heaving is always apt to occur in poorly drained soils. Furthermore, the damage to crops is usually more severe on poorly drained than on well drained soils. Hence, another good practice for minimizing the injuries to crops is to drain the land in some manner.