Agriculture in the Zone of Perpetual Frost

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Eternal frost is spread over a wide expanse of the land area of our earth. It covers up to 25 percent of the total surface of the land of our planet.

The zone of perpetual frost in the Northern Hemisphere embraces almost the whole surface from the North Polar Circle (with the exception of some of the areas on the Scandinavian Peninsula), southward to the Asiatic and North American continents (Alaska and the northern part of Canada). In the Southern Hemisphere, eternal frost expands over the entire continent of Antarctica and the islands lying between the Antarctic and the South American continent. Also, areas where perpetual frost reigns supreme can be found in the mountainous regions of all continents, with the exception of Australia.

In the Soviet Union, the zone of perpetual frost comprises an area of 10.5 million square kilometers, or almost half of the entire territory of the U.S.S.R. About 7 million square kilometers of land—that is, one-third of the entire territory of the U.S.S.R.—is located in the belt of perpetual frost where the soil does not thaw enough to make its cultivation possible. The remaining 3.5 million square kilometers of land is in the subzone of the so-called "seasonal" perpetual frost, which thaws in summer to a degree more or less sufficient for agricultural cultivation. However, the layers that lie deep in the earth's crust remain in an eternally frozen state. The larger part of Siberia and the northern part of European U.S.S.R. are within the zone of perpetual frost, and this explains the intensive interest of the Soviets in this zone and their efforts in studying the phenomena of perpetual frost.

Perpetual frost, as the name may suggest, is a natural phenomenon that leaves certain layers of the earth's crust in a state of permanent congelation. These layers are to be found at a certain depth from the surface, and they continuously preserve a freezing temperature. Eternal frost is the result of a combination of low temperatures of the air in a given locality and a great many diverse physicogeographic conditions in the successive historical-geologic development.

The thickness of a snow covering on the surface of the earth, the thickness of moss growth and of peat, the broken-up physical relief of the locality—all these, apart from the low temperatures of the air, play a decisive part in the process of the formation of perpetual frost. And finally, the reason for its formation is in the greater loss than gain of warmth by the earth's crust, resulting in the crust's freezing to a greater extent in winter than it thaws in summer. The perpetual frost's origin is ages old, but in some places it is only of current or fairly recent date. Its ancient origin is confirmed by the presence in the eternally frozen layers of the carcasses of the mammoth, the haired rhinoceros, and other long-extinct animals whose carcasses have shown no signs of decomposition, as if they had been frozen only recently, and also by the presence of thick layers of ice in the earth's crust. Confirming the more recent origin of perpetual frost in various localities are the discoveries in the eternally frozen layers of objects of human usage and even human bodies, along with those of horses, which have been preserved perfectly. This was the case in the discovery of the Scythian graves in the Altay in which the bodies had been laid 2000 years ago.

The depth of the frozen layers is not uniform. As a rule, the more southerly, the thinner it becomes. Thus, for instance, on the shores of the Laptevykh Sea, perpetual frost reaches more than 500 meters into the crust of the earth; in central Yakutian region, to about 200 meters deep; in the eastern part of Chita region, up to 70 meters deep; in the latter's southern reaches, to 30 to 50 meters; in the southernmost part of the perpetual frost belt—beyond the limits of the Soviet Union, that is, in Mongolia and Manchuria—it is no more than 1 to 2 meters below the thawed horizon of the earth's crust.

The temperature of the permanently frozen crust also varies with the place—from $-35°C$ in the north to $1°$ below zero in the south. The clearing of woods, brush, moss, and peat from the surface and the measures taken to increase the thickness of the snow covering on the cleared areas in winter considerably alter the regime of perpetual frost with regard to the temperature of the subsoil and increase the depth of the thawing layer of the crust in summer. Also, the regime of perpetual frost is disturbed by constructions and their proximity to each other, in particular, by those that exude considerable warmth.

The presence of perpetual frost, obviously, constitutes great obstacles and difficulties for the economic activities of man, such as the construction of roads, canals, water supply systems.

This article is concerned with perpetual frost exclusively as it affects the possibilities of agriculture in its zone, and then only insofar as the activities of the Scientific Research Institute of Northern Grain Farming are concerned. The institute was set up in Moscow early in 1933 with quite a dense network of experimental stations throughout the entire European and Asiatic North of the U.S.S.R. with the aim of transforming the zone of perpetual frost into an agricultural area.

On the basis of years of experience with tests for growing agricultural crops under normal production conditions at the experimental agronomic stations, it would not be a mistake to maintain that agriculture in the zone of perpetual frost will probably never assume any industrial importance. In some exceptional cases, such as in the southernmost reaches, it may secure for the family grain and vegetables on a small scale, provided that the density of the population does not increase very much. The peculiarity of the conditions of agriculture there is that a farmer must have at his disposal large areas of land, since he is constantly faced with the need of breaking new soil to replace the land that has irretrievably lost its fertility. However, in the last few years, the government has exerted efforts toward increasing greatly the density of the population in these very localities of the perpetual frost belt (as well as promoting settlement of the deserts and semideserts of Kazakhstan). The artificial augmentation of the population by new settlers will result either in their death, dispersal, or their being supplied with food imported from elsewhere.

An obstacle to the development of agriculture in the belt of perpetual frost lies in the conditions of the subsoil and

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the climate. In the so-called "active" (tillable) horizon of the soil in the perpetual frost zone, which thaws on the surface to a sufficient depth to enable cultivation of agricultural products, the changes of temperature are quite considerable, ranging between 30° and 35°C below zero in winter, and 20° to 25° above zero in summer. The temperature also varies in the thawed layer of the earth's crust during the period of vegetation. As a result of these variations, an intensive oozing takes place in the tillable soil and with it hard particles are removed.

By regulating the water regime and temperature conditions of the active soil, the depth of the deeper layer can be changed, thereby increasing the thickness of the tillable soil from which the growing plants can draw nourishment. The regulation of water and temperature conditions under natural circumstances has brought about the following changes in the depth of the active horizon of the layer as compared with the normal depth of 30 to 50 centimeters and from 10 to 30 centimeters in the less easily warmed peat layers (Table 1).

The volume of the active horizon of the soil can be increased at the expense of the perpetually frozen layer by drying up lower layers, by removing the peat and moss covering of the earth's surface, and by removing factors that shade adjacent fields in summer. It should be remembered that the perpetually frozen layers often contain a good deal of ice that occurs not only in the form of thin inclusions and ice lenses but also in the form of ice layers as thick as 10, 30, and 50 meters and more. The efforts to increase the thickness of the active horizon, suitable for agriculture, have often brought about the thawing of the thicker layers of ice in the earth's crust, that are close to the surface—after the area has been cleared of all vegetation. As a result of the thawing, the earth's crust began to soften, settle down, and even sink, thereby creating large lakes of great depth.

It often happens that a certain area cleared of woods cannot be converted into arable land, because large amounts of ice in the perpetually frozen layers begin to thaw and, instead of land, there appears a lake. Only by probing deeply into the ice layer as the first step toward tilling the soil for agriculture in the perpetual frost zone can such a surprise be avoided.

Table 1. Influence of improved water and temperature conditions on the depth of thawing of the earth's surface

Location	On sand soil (m)	Sandy loam (m)	On peat (m)
Shores of Laptevykh Sea	1.2–1.6	0.7–1.0	0.2–0.6
On the Yakutsk parallel	2.0–2.5	1.5–2.0	0.5–0.8
South of 55th parallel	3.0–4.0	1.8–2.5	0.7–1.0

With rare exceptions, all reclaimed land for agriculture requires soil amelioration, which consists of draining it. First to be reclaimed should be light soils, such as light loam, sandy loam, and sandy soils, which have greater water infiltration qualities. The ever-frozen layers under such soils bed in much deeper. Water and air penetration of such soils is more favorable than it is in soils that are heavier in their structure. In the northernmost regions, areas for agriculture must be chosen on the basis of whether they are well protected from the cold northern, northwestern, and northeastern winds during the period of vegetation and whether they have a thick snow covering in winter (valleys of rivers and lakes, basins, and so forth).

Under the influence of the ever-frozen layers, special qualities are created for the active soil with respect to water, thermal, and other conditions, varying, however, in various districts of the zone. As a result of the fact that the ever-frozen layers containing ice inclusions in the lower strata are watertight, the water is retained in the active (tillable) soil, which is then waterlogged. Excessive wetness of the soil is encountered in places where the quantity of atmospheric precipitation considerably surpasses the amount of the evaporating water from the surface of the earth and from plants.

Farther to the south excessive wetness and waterlogging of the soil occur only in rugged and lowland relief of such areas. But this cannot occur at all in elevated and well-drained parts of these areas. The movement of moisture, both in its fluid and vapor form, also has substantial influence on the water supply in the perpetually frozen soil. Even during the most vigorous frosts, some water does not freeze at all. In summer, the movement of moisture takes place in the vertical direction—from the upper layers toward the lower ones—down to the frozen layers, accumulating directly just above the latter. A characteristic phenomenon in these soils, which is undesirable from the point of view of agriculture, is the frequent presence of dry thin wash in the region of the root system of cultivated plants, although the entire active soil may be oversaturated with moisture. There may also be an excessively damp thin wash in a layer of completely dry (or of medium moisture content) active soil. The causes of such defective phenomena of moisture infiltration into certain horizons of the soil in the region of the root system of growing plants are to be looked for in hydrological, geologic, and climatological factors.

The freezing and thawing of overmoistened soils cause the mechanical disintegration of the structural elements of the soil, as a result of which such soil quickly changes into a completely structureless, hardened soil, thereby creating a strong, thick soil crust on the surface. The active soil in the zone of perpetual frost increases in volume at the moment of freezing and grows like a yeast dough. Because of the unevenness of the freezing, and the pressure, water and the dust elements in the water in the lower horizons of the active strata have forced a way to the weaker places and peculiar mounds, the so-called "bulgunyakhs," have formed. In the course of 1 year they may grow to a height of several meters, and in several years they reach a height of many tens of meters.

The shallow rivers and lakes in the zone of perpetual frost freeze all the way down to the very bottom. In places where large amounts of deep-ground water force their way to the surface, immense ice fields and mounds, as well as hills, are formed. Such ice fields at times cover areas comprising hundreds of square kilometers and cause large areas of forest to perish. They also prevent the sprouting of seasonal agricultural plants, cutting even shorter the already brief growing season in these localities.

The lower ever-frozen layers obstruct the warming of the active soil and, hence, decrease the temperature of the stratum in which the root systems of cultivated plants spread. In these inadequately warmed strata microbiological activity lessens, and the process of nitrification and aerobic fixation of nitrogen is suppressed.

In the soils of light mechanical structure, it is necessary to add a large quantity of manure because of their scanty supply of nourishing substances for agricultural plants and the insufficient depth of tillable soil. Furthermore, owing to the feeble biochemical activity of these soils, it is necessary to add decomposed manure.

The best results come from a mixed manure with mineral fertilizers. The soils in most of these localities are of different kinds of podzol and marshy, sour soils that also require lime. The soils in the zone of perpetual frost are divided generally into two distinct groups: (i) "mineral soils" that have been formed in the process of decomposition of the rock deposits, and (ii) "organic soils" that have been formed as a result of the process of plant decomposition.

The subsoil rock under the "mineral

soils" is always found at a lower level than the "organic soils." However, in spite of all measures toward improving the water, air, and temperature conditions of the soils, the microbiological activity here remains most suppressed, and the sources of mineral nourishment for the plants are severely limited.

Usually, crops are best in the second year following the plowing of the new land, but after a year or so they catastrophically diminish, often failing to return even seed. Only by application of large amounts of organic, mostly manure, and mineral fertilizer can one maintain the subsequent crops on a more or less medium output level.

The peaty and peat-gley soils are more difficult to reclaim for agriculture because of the proximity of the ever-frozen layer (30 to 40 centimeters); this is true in spite of the presence of a high potential of fertility. Therefore, these areas must be dried, and the moss and peat must be burned. After this, perpetual frost will drop considerably, and the area can be used for the cultivation of agricultural plants, yielding adequate crops.

In the drouth areas of the zone of perpetual frost where the land can be dried, such as the central Yakutian region with its varying continental climate of between 195 and 235 millimeters of precipitation a year, agriculture stumbles into other difficulties. Although perpetual frost here is conducive to a certain degree to agriculture, with regard to the water supply of the soil and the influence on the economical evaporation by the plants, nevertheless, precipitation is not sufficient for the normal development of agricultural plants. Therefore, artificial watering of agricultural plants takes on importance as one of the main factors in the effort to grow them, particularly, in the solonetz and solonchak black soil.

Normal crops of agricultural plants cannot be achieved on the solonetz, solonchak, or the tiaga humus-poor soils without large amounts of organic manure and green-crop manuring. The solonetz and solonchak meadow black soils react quite favorably when gypsum is added.

Agricultural tools and machinery are best if they are of small dimensions, for then they are more suitable for the comparatively small areas here. The draft animals here are horses and cattle. Attempts to train deer as beasts of burden have had no success because of the weakness and wildness of these animals. Tractors of average power do not answer to the local conditions. It is necessary to have them in smaller sizes and of smaller power.

The best agricultural plants are of the precocious sorts, with the shortest growing period. Grain crops with a little longer growing period often are killed with the arrival of the first autumn frosts during the ripening period, particularly in the valleys and low-situated places.

Potatoes and vegetables are even grown in the remote north. Somewhat south of here, in the taiga belt, cereals are also cultivated. They are barley, oats, spring wheat, and spring rye. Farther to the south, in the belt of leafy woods, the variety increases with additional plants, such as buckwheat, millet, and peas. The assortment of vegetables increases at the expense of cucumbers and the like, which require a longer growing period and a greater amount of warmth. Under the most favorable conditions in the zone of perpetual frost, the greatest yield of cereals per hectare amounted to: wheat and rye, 15 to 17 centners; barley and oats, 19 to 23 centners; potatoes, 100 to 120 centners.

The northernmost places where attempts have been made to cultivate land and where potatoes, vegetables, and even melons are grown are Naryan-Mar, Narvik, Igarka, and the southern slopes of the dunes of the Arctic Ocean shores on the peninsula of Taymyr. But similar attempts in these localities could be regarded as something of a gamble.

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