Perennially frozen ground and vegetation

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PREFACE

This translation is the seventh arranged by the Permafrost Subcommittee of the Associate Committee on Soil and Snow Mechanics of the National Research Council of the Russian permafrost publication, "Principles of Geocryology".

The first translation in this group was of Chapter VI entitled "Heat and Moisture Transfer in Freezing and Thawing Soils" by G.A. Martynov (TT-1065). The second was Chapter IV "General Mechanisms of the Formation and Development of Permafrost" by P.F. Shvetsov (TT-1117). The third was Chapter VII "Geographical Distribution of Seasonally Frozen Ground and Permafrost" by I.Ya. Baranov (TT-1121). The fourth was Chapter IX "Ground (Subsurface) Ice" by P.A. Shumskii (TT-1130). The fifth was Chapter X "Groundwater in Permafrost" by V.M. Ponomarev and N.I. Tolstikhin (TT-1138) and the sixth Chapter XI "Cryogenic Physical Geological Phenomena in Permafrost Regions" by S.P. Kachurin (TT-1157).

This translation of Chapter XII by A.P. Tyrtikov describes the various types of vegetation encountered in permafrost regions and the relationship of them to this environment. This is followed by a discussion of the effects of vegetation on the temperature regime of permafrost, and soil freezing and thawing. The influence of the permafrost on vegetation is reviewed and the chapter concludes with a brief discussion of vegetation as an indicator of permafrost conditions.

The translation has been prepared by R.J.E. Brown, a research officer of the Division of Building Research. Mr. G. Belkov of the Translations Section of the National Research Council kindly checked the translation for which appreciation is here recorded.

Ottawa — R.F. Legget

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PERENNIALLY FROZEN GROUND AND VEGETATION

Introduction

A close relationship is observed in nature between the vegetation and the environment in which it grows. The development of a certain vegetation association is determined by all of the surrounding environmental conditions and with a change of these conditions there occurs a change in the vegetation. In its life activity the vegetation acquires certain characteristics, which, in turn, affect the surrounding environment. The influence of the vegetative cover is so important that various regions of a given country may have completely different climates although the sum of meteorological factors (precipitation, sunshine, etc.) may remain unchanged (Vil'yams, 1946).

The vegetative cover, which is found at the boundary of the atmosphere and the lithosphere participates actively in the heat exchange between them and to a significant degree determines the conditions of formation of the temperature regime of the ground. The main influence of the vegetation on the climate in general and on the temperature regime of the ground in particular is determined by its influence on the water regime of the soil, or more precisely, on the moisture regime existing between the soil and the atmosphere (Vil'yams, 1946; Kudryavtsev, 1954). This influence is due primarily to the changes which occur in the soil and above it under the influence of the life activity of the vegetation.

The most important changes which influence the moisture regime between the soil and the atmosphere result from the accumulation of organic matter. The above-ground and subsurface organs of various plants die every year. In favourable conditions the dead plant matter accumulates in the soil and on the surface. In this way a layer of litter, a peaty horizon of soil and sometimes thick peat deposits are formed. These organic formations are very distinctive from the underlying mineral soil. Their water properties are particularly significant. Thus the moisture content of the litter and the peaty horizon exceeds by 5 - 10 times that of the mineral soil (Bal'ts, Prokhov, 1913; Myshkovskaya, 1913). Very large differences are observed in the moisture content of organic and mineral soil (Table XXXIII).

Peat and litter are characterized by considerable hygroscopicity. Loose forest litter retains a quantity of water equal to 100 - 500% of its dry weight. As a result, the surface run-off of water is greatly reduced and in forested areas where the vegetation has not been disturbed, it constitutes less than 3% of the precipitation in contrast to treeless areas and fields where it may exceed 60% (Kitredzh, 1951).

The filtration properties of peat are close to clay and loam. The percolation of water into the soil from the peat and the lateral movement of water are negligible (Titov, 1952).

Peat has a low thermal conductivity when it is dry. The thermal conductivity of dry peat is close to the thermal conductivity of snow (Sumgin et al. 1940). The thermal conductivity of moist peat is less by the factor of 3 and when frozen and containing ice it is less by the factor of 33 than when it is dry (Benninghoff, 1952).

By virtue of the properties noted above, the conditions of warming and cooling of the top soil and consequently of the subsoil change with the accumulation of the peaty horizon and litter. During the warm season the peaty horizon, having a high ice content, prevents the warming of the underlying soil horizon owing to its large thermal capacity, the heat consumed in thawing the ice and the evaporation of water. During a dry period a thin layer of dry peat, having low thermal conductivity, is formed which prevents the warming and drying of the underlying layers of soil. Consequently as the layer of litter increases, the soil becomes colder and its swampiness intensifies during the summer period.

During the cold part of the year the litter and peat, because of their high moisture content and heat insulation properties, prevent the cooling of the soil and underlying horizons. A dry insulating peat layer is formed in the warm period of the summer; when it freezes and attains high ice content it becomes a good heat conductor and offers little resistance to cooling of the underlying horizons. Whereas in summer the heat is consumed in melting the ice and evaporating and warming the water, in winter there is only cooling and freezing of the water. Therefore the peat offers less resistance to the cooling of the soil in winter than to the warming of it in summer and in this way contributes to the predominance of winter cooling over summer thawing.

The various types of vegetation and even the various vegetative associations within a given vegetative formation are distinguished by the rate of accumulation of organic matter in and on the soil, by their properties and consequently by the influence on the temperature regime of the underlying horizons. It is known that grassy, i.e. meadow and steepe, vegetation accumulates less organic material in the soil and on the soil than forest and bog vegetation, and an organic layer accumulates more quickly in a coniferous forest than in a deciduous forest. The rate of accumulation of organic material in a forest changes also in relation to the presence or absence of moss and lichen cover, its species composition, the degree of swampiness of the soil and so forth. In a forest which has sphagnum cover, the peaty horizon is formed more quickly than in a forest with a soil cover of green moss and in sections where lichen predominates, the peaty horizon becomes mineralized. Organic deposits are very quickly accumulated in bogs. The thickness of the peat layer and consequently the degree of influence of it on the temperature regime of the soil and subsoil varies greatly not only in various associations but even in one and the same association in relation to the stage of its development, usually increasing with age.

A significant influence on the moisture regime and consequently on the thermal exchange between the soil and the atmosphere is the transpiration of vegetation. In absorbing water from the soil, the vegetation dries the soil and contributes to its warming at the same time as the evaporation of water lowers the temperature of the air, particularly in the layer adjacent to the soil, which lessens the warming of the soil.

The moss and lichen cover while evaporating a large quantity of water apparently greatly lowers the temperature of the layer of air adjacent to the soil. (See Table XXXIV.)

From Table XXXIV it is evident that various vegetation associations evaporate varying quantities of water and even one and the same soil cover transpires in an open area about twice as much as in a forested area.

The majority of geocryologists following M.I. Sumgin postulated that moss is a strong cooling agent of the soil, mainly because of the fact that it evaporates a large quantity of water and therefore strongly minimizes the amount of heat which can go to warm the soil (Kudryavtsev, 1954). Nevertheless, until now not one single experiment has been furnished to confirm this suggestion. In her time E.E. Myshkovskaya noted that "as soon as the rain stops the suns rays quickly dry up the tips of the moss. Nevertheless such a rapid disappearance of moisture proceeds only at the very surface (to a depth of 0 - 5 cm). The top of the moss, while drying out itself, protects the lower lying part of the moss cover from loosing moisture" (1913, p.136). These observations of E.E. Myshkovskaya show that the most hygroscopic sphagnum mosses not only are capable of evaporating moisture but also of maintaining it in unfavourable moisture conditions. The latter property of sphagnum mosses also explains the fact that the soil under them is always found in a highly saturated condition. The low thermal conductivity of the dry layer of moss apparently also has an important effect on the warming of the soil.

The question concerning the influence of the transpiration of vegetation on the thermal regime of the soil has not been completely clarified. Because intense transpiration occurs only during the vegetative period, it exerts the most influence on the warming (thawing) of the soil only at this time.

Nevertheless, while increasing the reserve of moisture in the soil, this process also exerts influence on the cooling (freezing) of it in the winter.

The vegetation, while reducing the force of the wind and while shading the soil, decreases the evaporation from the surface of the soil. Under the forest canopy, the evaporation from the soil surface during the year was on the average from 1.5 - 2 times less than from exposed areas (Titov, 1952). Evaporation in a forest was particularly reduced when the soil was covered with litter (Table XXXV).

In decreasing the evaporation from the soil surface and thus helping to conserve moisture in the soil, the vegetation influences the temperature regime of the soil. It is evident that the higher and denser the vegetation, the more it obstructs evaporation from the soil surface.

While condensing moisture from the air on its own surface at night, the vegetation contributes also to the moistening of the soil and in this way influences the heat exchange between the soil and the atmosphere.

While retaining precipitation on its surface, the vegetation decreases the moisture exchange between the soil and the atmosphere, and thus influences the heat exchange between them. The total loss of precipitation is from 10 - 40% (Kitredzh, 1951; Titov, 1952). In summer, warm water entering the soil contributes to an increased warming (thawing), therefore the retention of precipitation on the surface of the plants reduces the warming of the soil. In winter the snow is retained on the crowns of the trees, and so the soil under them freezes more quickly than in the clearings. Multi-storey, very dense vegetative associations (forest) retain more precipitation than one-storey thinned out associations such as meadow or tundra.

Under a canopy of vegetation, the intensity of solar radiation is reduced, which results in a slowing up of the heating (thawing) of the soil. A forest exerts a particularly strong influence in this regard. If the intensity of radiation equals 1.5 cal/cm^2 in 1 minute in an exposed area, then under a dense canopy of forest it is reduced to 0.01 cal/cm^2 in 1 minute (Kitredzh, 1951). In winter the vegetation impedes the radiation of heat from the soil.

Vegetation, particularly forest, lowers the rate of snow melt. The snow cover in the forest often remains for one month longer than in a field (Kitredzh, 1951; Titov, 1952). This influence is intensified with an increase of crown density.

While reducing the force of the wind, the vegetation in certain conditions contributes also to the accumulation of snow; in places where strong winds are observed in winter, more snow of lower density accumulates under trees than in exposed areas. Because of its low thermal conductivity, snow is one of the most important factors reducing the radiation of heat from the soil in the winter. The thermal conductivity of snow is directly proportional to the square of its density (Abel's, 1893) and the density is decreased in proportion to the increase of the density of vegetation (Mizerov, 1937). The accumulation of snow under the vegetation causes more intensive moistening of the soil on these areas than in exposed locations and because of this the temperature of the soil is reduced in summer.

The above-noted list of the influences of vegetation on the thermal exchange between the atmosphere and the lithosphere is far from complete. Nevertheless it shows how extensive and complicated and many-sided is the influence of the vegetation of this thermal exchange and in particular on the temperature regime of the soil and underlying horizons. Almost everyone of the noted influences acts in different directions depending on the conditions in which it occurs. The complexity, many-sided and varying directions of the influences of the vegetative cover on the temperature regime of the soil and subsoil often results in the fact that even one and the same vegetative association in some conditions acts as a factor which reduces and in other cases which increases their temperature.

The noted characteristics of the influence of vegetation on the thermal regime between the atmosphere and the lithosphere greatly hinder detailed investigation of the separate or individual facets of this phenomenon, and the multi-form of the vegetation associations still more aggravates this difficulty.

At the present time only some general qualitative data are available on the influence of vegetation on the temperature regime of the soil, the regime of its thawing and freezing. Material which throws light on the influence of vegetation on permafrost even in general lines is very sketchy.

The Influence of Vegetation on the Temperature Regime and Thawing of the Soil

Numerous investigations show that under any vegetation cover the temperature of the soil in summer, other conditions being equal, is lower and the depth of thawing less than in areas where the vegetation is absent (Abramov, 1913; Koloskov, 1918, 1925; and others).

It has been established also that the degree of peatiness of the soil is a most important factor controlling the temperature regime and thawing regime of it (Tyrtikov, 1952). In peat bogs it is observed as a rule that the lowest temperatures of the soil and shallow depth of thaw occur there (Kuzeneva, 1911; Tanfil'ev, 1911; Gorodkov, 1930; Tyrtikov, 1952). The depth of thaw of peat bog soils is usually 2 or 3 times less and the temperature of the soil lower than in forest soils (Table XXXVI).

The shallow depth of thaw and low temperature of peaty soils depends on the large content of ice in them, the high moisture content and consequently their thermal capacity, and also the low thermal conductivity in the dry state. Because of the low thermal conductivity of the peat soil, there is characteristically a sharp drop in temperature with depth (Table XXXVII).

Even a thin layer of peat retards the thawing of the soil (Table XXXVIII).

In forests the depth of thaw of the soil, in the presence of the other conditions given above, is less, the greater the thickness of the peaty horizon (Table XXXIX).

In this way the peat horizon greatly reduces the thawing of the soil and decreases the temperature fluctuation in it.

According to many investigators the moss cover exerts a very strong influence on the thawing and temperature regime of the soil (Abramov, 1913; Myshkovskaya, 1913; Sumgin, 1937). The presence of a moss cover as a rule decreases the depth of the seasonal thawed layer by 2 or 3 times and sometimes even more (Sumgin, 1937).

Among the various plant species which cover the soil surface the greatest influence on the thawing of the soil is exerted by sphagnum moss. The soil under sphagnum moss, including peat soil, thaws much more slowly than under green moss (or Hypnum) (Table XL).

Other types of moss and lichen also reduce the thawing of the soil in comparison with areas where the soil cover is removed (Table XLI). The removal of moss and lichen cover leaving the peat horizon intact, as observations in the Igarka region show (Tyrtikov, 1952), resulted in an increase of the depth of thaw by 20 - 50%, whereas data obtained by the Amur expedition showed a 2 to 3-fold increase (Bal'ts, 1913; Sumgin, 1937; and others). After the removal of the moss (lichen) cover and the peat horizon, the depth of thaw of the soil increased by 1.5 - 2.5 times (Table XLII).

Our observations showed that peat lying under mosses and lichens often retards heating (thawing) of the soil more than the moss on lichens. To clarify the role of the vegetation cover in the thawing and the formation of the temperature regime of the soil many investigators (Abramov, 1913; Myshkovskaya, 1913; and others) removed the mosses and the peat layer, i.e. they stripped the soil to the mineral horizons, to compare the temperature regime and thawing in these areas with those in natural conditions. It is evident that because of the absence of a demarcation between the vegetation cover and the peat horizon, the above-mentioned investigators in the first place were not able to explain the influence of the individual types of mosses (lichens) on the thawing and temperature regime of the soil and secondly they exaggerated the influence of the vegetation cover in this relationship. Among them V.F. Tumel (1939) showed that beach grass sod (Calamagrostis) exerted the same influence on the temperature regime of the soil and underlying horizons as did a moss cover. This suggestion must be considered as correct and completely explained. The fact is that woody, brush and herbaceous vegetation as well as moss cover during their life activity accumulate dead organic matter on the surface of the soil which form a peat horizon. Therefore, under any vegetative cover where a peat horizon exists, the temperature of the soil can be lower and depth of thaw less than under mosses, particularly when the thickness of the peat horizon on the first areas is greater than on the second. Because of this it is necessary to pay attention not only to the degree of development of the moss cover but also to make a particular study of the thickness of the peat horizon.

The removal of the peat horizon together with the vegetation cover results also in a very significant increase in the soil temperature in the case when the soil is ploughed (Table XLIII).

In the forest, the temperature of the soil in summer is lower than in unforested areas (Obolenskii, 1923). In the Amur district the cutting of the forest led to an increase of the soil temperature in summer of close to 3°C for a layer 0.5 m thick (Koloskov, 1925).

Under dense thickets of brush the depth of thaw is less (almost by 2 times), and the temperature of the soil is significantly lower than in a meadow (Table XLIV).

As a rule herbaceous vegetation exerts less influence on the temperature regime and soil thawing than does brush (Table XLV). Nevertheless, under it the temperature of the soil is lower in summer than where this vegetation is absent. The removal of the grassy sod in the Amur district resulted in an increase of the mean monthly soil temperature at a depth of 20 cm in summer by about 5.8°C (Pistsov, 1937).

It was established by investigators in the Igarka region that even under a low but dense brush cover (up to 30 cm high, and covering 80 - 90% of the ground - Ledum palustre) the depth of soil thawing in peat mounds was 9 - 12 cm less than where the brush was spare or absent.

Organic matter, which accumulates on the surface of the soil and which forms the peat horizon or litter often greatly reduces the warming of the soil in summer more than the living vegetative cover. Because of this the removal of the vegetative cover with subsequent ploughing, which leads to the mineralization of the peat horizon, and in this manner to a decrease of the moisture capacity, thermal capacity and to an increase of the thermal conductivity of the soil, results in a greater increase of its temperature the more the organic soil is ploughed and the more the dense vegetation is destroyed (Table XLV).

The inadequate study of the problems under consideration, particularly for permafrost, does not allow us to come to any conclusions concerning the comparative influence even of various types of vegetation on the temperature regime and the thawing of the soil, not to mention the smaller subdivisions of it (formations, etc.). Nevertheless from a complete basis it is possible to conclude that the vegetative cover exerts a great influence on the temperature regime and the thawing of the soil. Under a vegetative cover the depth of thaw is usually 1.5 - 3 times less and the summer mean monthly temperatures at a depth of 15 - 40 cm are 5 - 15°C lower than where the vegetation is destroyed and the peat horizon (litter) is removed or mineralized.

The Influence of Vegetation on the Freezing of the Soil

In winter the vegetation slows down the cooling of the soil because of the increase of thermal capacity and decrease of thermal conductivity, the weakening of air movement above the soil surface, the accumulation of snow, etc. This influence of the vegetation is the more significant, the more the soil contains organic matter and the more dense the vegetation cover. In the forest the freezing of the soil is retarded by 20 - 40 days in comparison with unforested areas (Kitredzh, 1951). In winter the soil outside of the forest is colder in the presence of less snow cover (5 - 10 cm) by 4 - 9°C, and with a greater snow cover (20 - 40 cm) by 2 - 4°C than in the forest (Koloskov, 1930). The destruction of the vegetative cover and subsequent mineralization of the peat horizon of the soil (by ploughing, burning, etc.) results in a significant lowering of the soil temperature in winter (Koloskov, 1930).

Quantitative data on the influence of vegetation on the freezing of the soil is extremely sketchy. Nevertheless the data given above gives evidence that any vegetation slows down the radiation of heat by the soil in winter time and this influence can be very significant.

The influence of the vegetation on the temperature regime of the soil depends not only on the character of the vegetative cover but also on conditions in which it has developed (Koloskov, 1925). Thus, with a light snow cover in the Far East the cutting of the forest results as a rule in cooling of the soil and with heavy snow cover it results in warming of the soil (Table XLVI). In the Far East the burning of dead organic cover of the soil increases the mean annual temperature of it in snowy regions by close to 1.5°C, ploughing of virgin soil in regions having little snow cover increases the temperature by 0.2 - 1.1°C and in snowy areas up to 3°C and more (Koloskov, 1925).

While influencing the temperature regime of the soil, the vegetation very evidently influences the temperature of the permafrost in the same manner and direction. Factual material on the influence of vegetation on the temperature regime of permafrost is almost completely lacking. While analyzing the few observations (basically in passing) on the change of the temperature regime of the permafrost after the burning or dying of vegetation (Tumel', 1939), V.A. Kudryavtsev (1954) noted that the temperature of the upper horizons of the permafrost increased by not more than 1 - 2°C and only in rare cases as much as 3°C.

In the Igarka River region on peat mounds covered with low brush, moss and lichens, the temperature of the permafrost was 1 - 2°C lower than on unforested mounts. In the forest tundra the temperature of the permafrost in forested areas is 1 - 2°C higher than in the tundra (Konstantinova, 1954; Popov, 1953). It is evident that in forest tundra areas the destruction of the woody vegetation leads to a lowering of the temperature of the permafrost.

The influence of the vegetation on permafrost is not limited to its influence on its temperature.

Observations on the consequences of destroying the vegetative cover give evidence that in specific conditions it is one of the most important factors obstructing the thawing of ice in perennially frozen strata, resulting often in a change of the appearance of the locality (Birkengof, 1934; Solov'ev, 1946; Tumel', 1939; Tyrtikov, 1956).

In the lowlands of the Yana and Indigirka Rivers, the perennially frozen strata of the positive elements of the relief (slopes) contain thick polygonal-fissure ice (up to 40 m in height and several metres width) which form a network with compartments filled with frozen soil (the dimensions of the compartments being 5 - 15 by 10 - 30 m). In areas where the vegetation is developed, the depth of the location of this ice is greater than the depth of seasonal thawing. The destruction of the vegetative cover as a result of fire, trampling, landslide, etc., leads to an increase of the depth of summer thawing of the soil and to an intensification of erosion of its surface. Because of this, the ice begins to melt and usually settlement of the soil occurs at first, followed by the formation of hollows. The accumulation of water in the hollows contributes to a significant accumulation of warmth in the summer and a further acceleration of the melting of the ice. The hollow expands and turns into a water basin with steep banks on which ice is exposed. The exposed ice melts still more rapidly, the collapse of the banks of the water basin accelerates and in this manner, in place of the area covered with a forest, a thermokarst depression with a lake is formed (alas).

The melting of ice on slopes results in the formation of gullies often with steep slopes on which hillocks are developed. The expansion of the depressions of the gullies continues as long as the products of the collapse of the hollows does not cover the ice so that the melting of the latter is stopped. Nevertheless, porous or friable sediments which cover the ice and unattached vegetation are quickly washed away by the surface water which again leads to melting of the ice. The establishment of meadow and later forest vegetation on exposed friable products of the collapse of hollows, by protecting their surface from erosion and by decreasing the depth of summer thawing of the soil, safely shields the ice from melting and the hollows from further collapse (Table XLVII).

In the lowland areas of the Yana and Indigirka Rivers (Primor'e lowland) the vegetation is one of the important factors, which hinders the melting of polygonal-fissure ice in hollows. In the absence of a vegetative cover the hollows would have disappeared long ago from the surface of the lowland.

The formation of alas* as a result of melting of the ice, caused by the disturbance of the vegetative cover, is a widespread phenomenon which has been observed by many investigators. It is very evident that the formation of thermokarst lakes as a result of melting of ice tends to cause an increase in the temperature of the underlying permafrost and results in partial or complete penetration of the permafrost by taliks.

In this manner, in certain regions on positive forms of relief the vegetation contributes to the preservation of the permafrost.

Observations on the processes of vegetation growth, the swampifying of water basins and dry land show that the vegetation is a factor which forms permafrost. In the lowland of the Yana River on deep parts of lakes there are no attached sessile plants. Nevertheless the shoaling of lakes, which is usually accomplished quickly around the shores, creates conditions for the colonization by water-herbaceous vegetation. This vegetation occurs frequently as continuous belts along the low banks of the lakes. On the deepest (60 - 80 cm) littoral sections are developed growths of Arctophyla fulva, which form the inner belt of attached vegetation. The annual dying off of aerial and subsurface organs of the arctophyles which are collected on the bottom, increase the level of the lake bottom in this area and around it. As a result of shoaling of this area the conditions for the existence of arctophyles becomes unfavourable and they move out towards the centre of the lake and they are replaced by marsh trefoil (Menyanthes trifoliata). In the same manner the marsh trefoil is replaced by Equisetum heleocharis, and later by sedge (Carex aquabilis), and in the place of the lake area a bog is formed. The sedge bog, with further accumulation of organic matter is replaced in turn by swamp willow brush and later by swamp birch brush. A further accumulation of

* A type of meadow.

organic matter increases the surface of the bog so much that it dries up and the swamp birch brush is replaced by birch brush on the dry peat bog. Thus, as a result of the accumulation of plant matter on a lake and the existence of the vegetation associated with these changes of conditions, there is a regular sequence of one plant community replacing another. At the same time the plant communities in the order mentioned above, are constantly moving forward to the centre of the lake (water basin), until they completely fill it. As the lake grows over conditions of warming and cooling of the soil and underlying strata in this area also change. Under the lakes, if the depth does not exceed the thickness of the ice formed in winter, taliks are observed. As the lake bottom rises owing to the growth of vegetation, the deposits at the bottom of the lake freeze, the permafrost table rises (Table XLVIII) and the talik disappears.

Thus in place of lakes, as a result of their being grown over, frozen peat bogs are formed. Moreover, organic frozen deposits are formed which are basically different from mineral deposits. The formation of permafrost at the location of water basins is observed in all permafrost areas (Tyrtikov, 1955, 1956_2). The formation of permafrost is observed also as a result of the swampy or peaty transformation of dry land. In southern Yakutia, as the amount of vegetation growth and peatiness increases in the flood plain, permafrost is formed in areas where earlier it was absent (Tyrtikov, 1955). Moreover both the newly formed peat deposits and the underlying mineral layers freeze.

The vegetation, while influencing the formation of permafrost, contributes to an increase of its heterogeneous nature; at each stage of development of the vegetation this influence is variable and in various ways is reflected in the composition and properties of the soil. Because of this, the study of the influence of the vegetation on the formation of permafrost in the process of the replacement of one of the vegetation associations by others has a great significance, in particular for the explanation of the origin of the soil.

The influences of the vegetation on permafrost noted above do not remotely exhaust all of the variations. The lack of study of the question being explored does not allow us to elucidate in detail the changes in character of the influences of vegetation on permafrost in individual vegetation zones, not to mention the smaller subdivisions of the vegetative cover. Because of this, some general considerations are given below on the question being touched upon.

The data given above give evidence of the fact that the quantity of organic material both in the soil and above it is a most important indicator of the degree of activity or influence of the vegetation on the permafrost, both by changing the water-heat properties of the soil, and by influencing the general climatic factors (precipitation, absorption of heat, etc.). Consequently, by the character of the vegetation cover it is possible, although rather approximately, to comment on the degree of influence of it on the permafrost. The permafrost of the U.S.S.R. occurs under soils of three-zones - tundra, taiga and steppe. As one moves southward from the Arctic Ocean the variety of vegetation associations gradually increases, the amount of vegetation increases, its density and height increases, the intensity of accumulation of organic matter in the soil and on the soil increases (peat formation). While attaining its maximum in the taiga, this variety again decreases in the steppe zone. Because of this the degree and variety of the influences of vegetation on permafrost also undergo regular change in the north-south direction.

In the northern part of the tundra the vegetation exerts little influence on permafrost, since the mass, density and height of it is small, and the influence is limited basically by the very short growth period (1 - 1½ months). The basic role of the vegetation here results in the fact that it, while impeding erosion of the surface layers of soil, preserves the permafrost. The destruction of vegetation only somewhat accelerates the process of melting of the ice in the permafrost. In the southern part of the tundra (particularly in the sub-zone of the brush tundra) the height and density of vegetation increase, and the peaty horizon of the soil is formed. The influence of the vegetation shows itself mainly in decreasing the depth of thaw of the frozen ground. The destruction of the vegetation leads to an increase of the depth of thaw (e.g. by about two times) and to an increase or erosion of the surface of the soil, because of which an intensity of melting of the ice in the frozen ground is often observed. The melting of the ice results in soil subsidence, thermokarst hollows, lake-swamp lowlands (alas), etc.

In the forest tundra, the mass of vegetation, the height and density of it is greater than in the tundra, and the accumulation of organic remains proceeds more intensely. In the forest tundra fairly extensive peat bogs are encountered, thick peat horizon in the soil, intensive growing over of water basins is observed and finally, tree vegetation develops. Because of this the influence of the vegetation is greater here and more varied than in the tundra.

In some areas covered with tree and brush vegetation, a large quantity of snow accumulates, resulting in a notable increase in temperature of the permafrost in comparison with the tundra areas (Konstantinova, 1954). In lake-bog lowlands permafrost forms as the lakes become overgrown with vegetation. The permafrost of the forest tundra is characterized by variations of temperature regime and composition (Konstantinova, 1954), which reflects the variety of the natural conditions and in particular of the vegetation. The destruction of the vegetative cover results here in a still greater development of the thermokarst process than in the southern tundra. In certain regions the destruction of the tree and brush vegetation results in a decrease of temperature of the permafrost in connection with a decrease of accumulation of snow on these areas.

In the taiga zone, where the mass, density and height of the vegetation and also the rate of accumulation of organic material in the soil and on the soil attain the maximum in comparison with other zones, the influence of it on the permafrost is most greatly developed in all the aspects mentioned above. The great variety of plant communities of the forest, swamps, brush and meadows leads to the fact that the influence of the vegetation on the permafrost is highly varied, often in a small area, thus increasing the variety of temperatures, composition, depth of occurrence and other characteristics of the permafrost.

In the steppe zone the mass, density and height of vegetation and also the rate of accumulation of organic material in the soil is less than in the taiga. The permafrost in the steppe occurs at greater depth than in the taiga. Because of this, the influence of the vegetation on the permafrost is apparently small; particularly in comparison with the taiga zone.

The Influence of Permafrost on Vegetation

The permafrost which underlies the soil exerts considerable influence on the environment in which the subsurface organs of the plants have developed. Firstly, the permafrost impedes the warming of the soil during the growing period and the temperature of the root zone is considerably below the optimal. Secondly, while acting as a water resistant layer, the permafrost contributes to the swampifying of the soil (Gorodkov, 1930), which leads to a decline in aeration and an impoverishment of nutritive substances, because of the weakening of the activity of micro-organisms which mineralize the organic matter and also leads to an acceleration of the accumulation of the latter.

The low temperature of the soil causes a physiological dryness of it, i.e. retarding the absorption of water by the roots so much that they cannot satisfy the requirement of the above-ground organs of the plants which leads to their destruction (Gorodkov, 1930; Kihlman, 1890; Schimper, 1947). Physiological dryness of the soil of the tundra is considered as one of the main causes of its lack of tree growth (Gorodkov, 1930; Schimper, 1947). Nevertheless certain experimental investigations are not in agreement with the theory of physiological dryness (Val'ter, Begacheva, 1940; Dadykin, 1952).

It has been established that the low temperature of the soil retards the growth of the roots in length and in mass, weakens their branching and impedes penetration into the soil (Dadykin, 1952; Tyrtikov, 1954). The weakening of the development of the root systems of the plants in these conditions is explained apparently by the fact that the low temperature retards the rate of biochemical reactions and in particular of reactions of the synthesis of albumens, without which no living cells can be built. The synthesis of albumens, as established by the investigations of A.L. Kursenov (1954), occurs in the roots.

Permafrost, as a result of the above-noted influences of it on the soil, exerts considerable influence on the spreading of the roots. In the regions where permafrost occurs, particularly at shallow depths, the roots of the plants are spread in the surface layers of the soil and are developed primarily in the horizontal direction. Thus the observations in the Igarka region give evidence that most of the root mass of trees is concentrated in the surface layers of soil (Fig. 105), at a depth to 20 cm (Tyrtikov, 1951_2). The maximum depth of root penetration even in areas where permafrost lies at a depth of about 3 m (in sandy soils), rarely exceeds 1 m and in the most typical conditions of sparse woodland the penetration is about 40 cm. The roots of brush, low shrubs and the main mass of roots of herbaceous plants are concentrated also in the surface horizons of the soil, although the individual roots of certain plants come into direct contact with the permafrost table.

Under the influence of low soil temperatures, plant roots develop adaptations which allow them more or less successfully to develop in these conditions. Thus, horizontal roots of trees are characterized by positive thermotropism, that is to say, the ability to grow in the direction of the warmest area of the soil (Tyrtikov, 1951_1). Moreover, trees and shrubs have the capacity to form accessory roots instead of trunks on the parts which die off, which are overgrown with mosses and buried by peat. This is caused by the fact that for many habitats in permafrost regions there is a rapid accumulation of peat which buries the roots of the plants and the burial of the roots leads to a full or partial stoppage of their functioning.

The deterioration of aeration and impoverishment of nutritive substances of the soils because of the presence of permafrost, also weakens the development of plant root systems, which is an aspect that has been barely studied. While exerting influence on the development of plant roots, the permafrost influences the development of the above-ground organs of the plants.

Different plants react in different ways to the unfavourable soil conditions caused by the presence of permafrost. Thus, of three species of conifers of western Siberia the low soil temperatures exert the greatest inhibiting influence on the development of the roots of pine, less on the development of the roots of spruce and the least influence on the root development of tamarack. Because the soil temperature decreases as one moves northward, it is possible to calculate that those species whose root development is more greatly effected by the lower soil temperature stop growing further from the tree line than those species whose roots are less effected. Actually, tamarack advances considerably further north than spruce and the northern limit of pine is further south than the spruce boundary. These data allow us to consider the problem of the causes of the lack of trees in the tundra and the variations in the advance of tree species to the north in a new way. Apparently, the low soil temperature during the growth period is a most important factor limiting the advance of tree species to the north and one of the main reasons of the lack of trees in the tundra (Tyrtikov, 1954). It is possible that for each species a limiting soil temperature exists in which the synthesis of albumens in the roots is somewhat retarded, which does not cover the requirements of the organisms being developed. This limiting temperature (which varies for different trees) also determines their unequal advances northward.

The influence of permafrost on the development of vegetation by creating a range of peculiar soil conditions (low temperature, swampiness, impoverishment of nutritive substances, etc.) is stronger, the closer the permafrost lies to the ground surface. Where it lies at considerable depth this influence is either insignificant or completely absent (Gorodkov, 1930). However, the presence of permafrost is not always the deciding factor in the development of this or another type of vegetation. Therefore in nature there are apparently few plants and vegetation associations which are developed exclusively on soils underlain by permafrost. On the contrary, it is possible to cite countless examples of plants and vegetation associations which are encountered both on soils underlain by permafrost and outside of the permafrost region. Thus, pine trees with lichen cover grow both in the Yakusk region on soils underlain by permafrost and in the Moscow region located many hundreds of kilometres from the southern limit of permafrost; weeds of the bogbean (Menyanthes trifoliata) variety are met both around Moscow and in the Yana River delta where the temperature of the permafrost is below -5°C and where permafrost is encountered at a depth of 0.7 - 1.2 metres from the surface of a water basin. Even such heat-loving plants as melons, and water melons, grow successfully in permafrost areas.

Permafrost exerts influence on the vegetation by contributing to the formation of various forms of relief (spot-medallions, mounds, thermokarst forms of relief), landslides, naleds, etc.

The formation of spot-medallions is particularly characteristic of permafrost regions leading to complete destruction of the vegetation on them.

The process of swelling in the soil and subsoil causes the formation of mounds up to 10 metres high and more. Soil conditions on mounds are significantly more varied than on level locations and even on various parts of mounds the vegetation cover is not uniform. The formation of mounds on forested areas leads to a sloping and bending or curving of the trunks of trees. The melting of ice in perennially frozen ground results in various thermokarst phenomena; the formation of hollows, depressions, waterbodies, uncoverings, mounds, etc. Thermokarst phenomena lead either to complete destruction of the vegetation (Fig. 106) or to its partial disturbance (the cutting of roots or sod, the sloping and bending of trunks of trees and so forth). Moreover fundamental changes of the conditions of plant habitat are frequently observed, particularly in the formation of lake-bog lowlands and eroded or stripped slopes (sometimes with mounds of the cemetery type) and consequently of the vegetative cover.

Landslides associated with the presence of permafrost lead to the partial disturbance of the vegetation (the cutting of sod or roots, the sloping and bending of tree trunks), or to the complete destruction of it and to the formation of areas of exposed soil. On denuded slopes another type of vegetation becomes established which is different from that which grew on these areas before the landslide.

Naleds or icings also change the conditions of plant habitat by shortening the growing period, lowering the soil temperature, increasing the swampiness, etc. A particular vegetation is often formed on places with naleds which is characterized by cold-resistant vegetation with a short growing period, the absence of trees, etc. In areas where naleds are formed annually and melt at the end of the summer or in general do not melt completely, vegetation does not develop (Tyrtikov, 1955).

In solifluction areas the vegetative cover is either partially disturbed or completely destroyed. In the latter case, areas of soil are exposed (Konstantinova, 1954).

A survey has been given above of the unfavourable influences of permafrost on vegetation, which result in the deterioration of conditions for its existence, disturbance of the vegetation or destruction of the vegetative cover. Nevertheless in dry areas (e.g. Central Yakutia) permafrost, being a water resistant horizon, creates favourable conditions for the growth of vegetation, by contributing to the holding of moisture in the soil (Abolin, 1929).

Thus in the permafrost region, particularly in its northern portion, the temperature of the soil plays an important and usually decisive role in the life of the plants (Gorodkov, 1930; Koloskov, 1918; Sochava, 1944; Tikhomirov, 1953; Tsyplenkin, 1937). The low temperature of the soil associated with the presence of permafrost retards the life activity of the plants, which is why the productivity of natural land resources (particularly forest areas) is extremely low (Tyrtikov, 1952). To improve conditions of plant growth and to increase the productivity of natural land resources and arable lands an artificial increase of temperature of the root zone of the soil in summer and winter is required, i.e. thermomelioration (Gorodkov, 1930; Koloskov, 1918, 1925; and others). An increase in the soil temperature during the growing period tends to increase the thickness of the root zone of the soil by increasing the depth of thaw, drying the soil, accelerating the mineralization of the organic substances, and in this manner improving the conditions of nutrition and effectiveness of the root system of the plants.

It was shown above that the temperature of the soil depends to a significant degree on the quantity of organic matter in it (peaty horizon) and on its surface (litter) as well as on the vegetation and snow cover, i.e. on the factors which to some extent can be regulated artificially. Thus, after the complete or partial destruction of the vegetative cover and the mineralization of the litter or of the peaty horizon of soil (by means of ploughing, burning, etc.), the temperature of the root zone layer during the summer is considerably increased and in this manner conditions for plant growth are improved (Koloskov, 1930). To improve conditions for plants during the winter, snow retention is employed to increase the mean annual soil temperature (Koloskov, 1932).

Because the low soil temperature may be due to various causes and the aims of thermomelioration are different, the measures employed must depend on actual conditions. For cultivation in the taiga regions, the main measures for thermomelioration of the soil are removal of trees and ploughing of forest sections, with the imperative condition of leaving forest belts for retaining snow in the winter (Koloskov, 1925; Tsyplenkin, 1937). To create meadows in the tundra zone, the ploughing of the tundra has been employed in recent times (Pryanishnikov, 1954). To improve the growth of the forest in certain regions the destruction of the moss cover is recommended, for example by means of applying toxic chemicals (Andreev, 1954; Tikhomirov, 1953). The destruction of the moss cover besides increasing the soil temperature also increases the mineralization of the peaty horizon of the soil and thus contributes to the improved nourishment of the plants. Observations in the Igarka region give evidence of the fact that in areas where there is no moss cover or peaty horizon, the growth of trees in the forests is 10 - 100 times greater than in areas where there is moss cover.

Vegetation as an Indicator of Permafrost

It has been established that the variation of types of permafrost is determined by the variation of climatic and geologico-geographical conditions. The variation of the latter is manifested in the variations of landscapes. Investigations showed that to each landscape in an individual region there corresponds a strictly determined type of permafrost (Barygin, 1953_1; Konstantinova, 1954). The vegetation is an indicator of the type of locality (landscape) and in particular of the type of permafrost.

Nevertheless the composition and properties of the permafrost are determined by a whole range of factors and not by vegetative cover alone, therefore the role of the latter as an indicator is relative. This relativity is evident from the fact that in various conditions one and the same vegetative cover can be an indicator of various types of permafrost or can be an indicator of its absence. Therefore, in the utilization of vegetation as an indicator of permafrost (e.g. for mapping permafrost from aerial photographs) the concrete conditions in which the vegetation and permafrost are developed must be studied. Only then is it possible to use the vegetation as one of the most reliable indicators of permafrost, which reflects at times the very slight changes of its properties and composition in moving from one area to another.

B.N. Gorodkov (1932, 1934) first used vegetation successfully as an indicator of permafrost. In particular, he noted that in the north the margins of the peat bog which are overgrown with scrubby pine give evidence of the complete absence of permafrost and the large mound unforested peat bogs are very characteristic of regions with sporadic permafrost and can be used as a good indicator of the proximity of the southern boundary of permafrost. Investigators of permafrost of the northern European part of the U.S.S.R. have established that under various types of tundra vegetation the temperature of the permafrost varies and changes regularly in the transition from one type of tundra to another (Barygin, 1953_1; Yanovskii, 1951). In the region of Chulman (southern Yakutia), where permafrost is sporadic, sphagnum bogs, sparse forests on sphagnum bogs, forests with a ground cover of sphagnum mosses, are always indicators of the presence of permafrost (Tyrtikov, 1955_1). In the Igarka region, the vegetation is a reliable indicator of the presence or absence of permafrost, its temperature regime, the depth to permafrost, and its composition. The specific vegetation of peat mounds of this region gives evidence of the very low temperatures of the permafrost, the shallow depth of the permafrost table, the high ice content and organic composition of its upper horizons. The presence of a sphagnum moss cover on these mounds is already an indicator of higher temperature of the permafrost in the given section. Sparse forest on mounds of mineral soil is one of the most typical indicators for the permafrost region and the presence of a very well developed moss cover, consisting primarily of Polytrichum commune in sink holes, show that the seasonal frost does not penetrate very far and permafrost lies deeper than on higher and level areas (Tyrtikov, 1952). Sedge bogs in the Igarka region give evidence of the absence of permafrost (Konstantinova, 1954).

Vegetation is an indicator of the soils on which it develops and at the same time is an indicator of the thickness of the seasonally thawed layer. From our investigations (Tyrtikov, 1952), it was established that to each vegetation association corresponds a specific thickness of the seasonally thawed layer (with small variations) and the various vegetation associations were clearly distinguished from one another by the depth of thaw of the soil. The established relationships allowed us to make sufficiently accurate large scale maps of the thickness of the seasonally thawed layer using a vegetation map compiled from data of aerial photographs.

Despite the obvious necessity of utilizing vegetation as an indicator of permafrost and in particular of the thickness of the seasonally thawed layer, the investigations of this problem have only begun. It should be hoped that with the large volume of work being proposed on the mapping of permafrost and the seasonally thawed layer, much attention will be paid to these investigations.

Conclusion

Several conclusions can be drawn from the material presented above.*

1. The main influence of vegetation on the thermal exchange between the lithosphere and the atmosphere, and consequently on the permafrost, is determined by its influence on the moisture regime between the soil and the atmosphere (Vil'yams, 1946; Kudryavtsev, 1954; Tumel', 1939).

2. The life activity of plants resulting in the accumulation of organic matter in the soil and on the soil (forest litter, peaty horizon, peat) leads to an increase in moisture (ice content) of the surface horizons and in this manner exerts considerable influence on the heat exchange between the lithosphere and the atmosphere.

3. Organic matter in the soil and on the soil have less effect on cooling of it in winter (freezing) than on warming (thawing) in summer.

4. The vegetation exerts considerable influence on the heat exchange between the lithosphere and the atmosphere in the following ways: by

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* Because of the relative lack of study of the interconnection between vegetation and permafrost, the conclusions are only of a general nature.

transpiration which dries the soil and which reduces the temperature of the air near the surface, by reducing evaporation from the soil surface, by trapping precipitation on the surface of the plants, and by condensing moisture from the air.

5. Under the vegetation canopy the intensity of solar radiation is decreased (sometimes by 100 or more times), resulting in less warming of the soil.

6. The vegetation in weakening the force of the wind contributes to the deposition of snow in a porous condition and in some regions to an accumulation of it which results in a decrease of heat radiation by the soil and subsoil in winter.

7. The influence of the vegetation on the temperature and certain other properties of the permafrost takes on many forms and tendencies and varies not only in relation to the character of the vegetation cover but also to the general climatic conditions in which it develops.

8. Any vegetative cover retards the warming (thawing) of the soil in summer. Under the vegetative cover the temperature of the soil at a depth of 15 - 40 cm is usually 5 - 15°C (mean monthly) lower and the depth of thaw is 1.5 - 3 times less than in areas from which vegetation has been removed and the organic matter in the soil and on the soil has been mineralized. This influence of the vegetation is the more significant the greater the mass, height, density and the greater the accumulation of plant matter in the soil and on its surface. Dead plant matter (litter, peat) often retards the warming (thawing) of the soil more than a living vegetation cover.

9. Any vegetation cover retards the cooling (freezing) of the soil in winter. Under a vegetation cover the temperature of the soil in winter is higher (sometimes up to 17°C for the mean monthly temperature), than in areas where the vegetation is absent and the soil does not contain organic matter.

10. Vegetation, by impeding the cooling of the soil in winter and the warming of the soil in summer, leads to a lowering (up to 3°C) or in some conditions to an increase (up to 2°C) of the temperature of the upper layers of the permafrost.

11. By decreasing the depth of thaw and retarding soil erosion, the vegetation impedes the melting of ice in the permafrost and is therefore a most important conservation agent of it.

12. The destruction of the vegetation cover causes melting of the ice in the permafrost, which sometimes leads, in these areas, to the formation of vast meadows (alas), gullies, sink holes, hollows and other thermokarst forms of relief.

13. By filling in lakes and covering dry land, vegetation often contributes to the formation of permafrost in areas where it was absent.

14. In the growing over of lakes, permafrost of organic composition is formed (at least in the upper layers) which differs fundamentally from mineral types (particularly by having a high ice content).

15. The degree and heterogeneity of the influence of vegetation on the permafrost increase along a line from the north of the tundra zone to the taiga in which the maximum is reached and then it decreases in the steppe zone.

16. Permafrost weakens the development and life activity of the subsurface and above-ground organs of the plants and soil microorganisms by contributing to the lowering of the temperature, swampiness, the impoverishment of aeration and nutritive substances of the soil (only in very dry areas do they create favourable conditions of moistening of the soil for the growth of plants). This influence is the more significant the closer to the surface of the soil the permafrost is located and may have no effect when the permafrost table is deep.

17. Where permafrost occurs near the surface it contributes to the formation of shallow root systems of plants and reduces the stability of trees against the wind.

18. To a certain degree, plants are capable of overcoming unfavourable influences of permafrost by forming additional roots and developing a positive thermotropism of the roots, i.e. the capacity to grow in the direction of the warmest part of the soil.

19. Permafrost influences the vegetation cover (by disturbing, changing or completely destroying it), by contributing to the formation of various forms of relief (spot medallions, mounds, thermokarst relief forms, landslides, naleds, lakes, etc.).

20. The unfavourable influence of permafrost on the development of vegetation can be completely or partially removed by thermomelioration.

21. Thermomelioration of the soil can raise considerably the natural output of agricultural areas in permafrost areas and extend agriculture further north in the permafrost region.

22. Vegetation is an indicator of the composition, properties of permafrost and thickness of the seasonally thawed layer and can be successfully used (and is partially used) for the compilation of large-scale permafrost maps both from field observations and from aerial photographs.

Literature

Abel's, G. Daily temperature variation of snow and the relationship between heat conductance of snow and its density. St. Petersburg, 1893.

Abolin, R.I. Geobotanical and soil description of the Lena-Vilyui plains. Tr. Komiss. po izuch. Yakutskoi ASSR, Vol. 10, Izd-vo AN SSSR, Leningrad, 1929.

Abramov, I.N. Meteorological and agricultural observations at the Bomnak Station during the summer of 1910. Tr. Amursk, eksped., No. 14, St. Petersburg, 1913.

Andreev, V.N. The advance of trees into the tundra in relationship to the protective properties of afforestation in the north. Botan. zhur., 1954, Vol. 39, No. 1.

Bal'ts, V.A. and Prokhorov, N.I. Data and observations of the Bomnak meteorological station for the year 1909. Tr. Amursk, eksped., No. 14, St. Petersburg, 1913.

Barygin, V.M. (1) Experiments in using aerial photography in studying permafrost in the Vorkuta region. Izd-vo AN SSSR, Moscow, 1953.

Benninghoff, W.S. Interaction of vegetation and soil frost phenomena. Arctic, 1952, Vol. 5, No. 1.

Birkengof, A.L. Observations of forest cover and permafrost (in the Indigirka River basin). Tr. Komiss. po izuch. vechn. merzl. AN SSSR, Vol. 3, Leningrad, 1934.

Dadykin, V.P. The growth of vegetation on cold soil. Moscow, Izd-vo AN SSSR, 1952.

Gorodkov, B.N. Permafrost and vegetation. Vechnaya merzlota. Sb. Materialy KEPS, No. 80, Leningrad, Izd-vo AN SSSR, 1930.

Gorodkov, B.N. Permafrost in the northern regions. Tr. SOPS AN SSSR, seriya sev., No. 1, Leningrad, Izd-vo AN SSSR, 1932.

Gorodkov, B.N. Problems of studying permafrost in connection with problems of northern development. Tr. Ural'sk. filiala AN SSSR, No. 2. Izd-vo AN SSSR, Leningrad, 1934.

Kihlman, A.O. Pflanzenbiologischen studien aus Russisch Lappland. Acta Soc. pro fauna et flora fennica, VI, 1890.

Kitredzh, D. (Kittredge). The effect of forest on climate, soil and water regime. Moscow, Izd-vo inostr. liter., 1951.

Koloskov, P.I. Climatic bases of agriculture in the Amur Oblast. Far eastern regional meteorological bureau. Vol. 8, Blagoveshchensk, 1925.

Koloskov, P.I. On the problem of thermal improvement of the soil. Izv. opytn. polei Amursk. obl., No. 2. Blagoveshchensk, 1918.

Koloskov, P.I. (1) The relationship between the temperature of the soil and the temperature of the air in regions of permafrost as an indicator of agricultural and climatic potentials. Tr. Komiss. po izuch. vechn. merzl. Vol. 1, Izd-vo AN SSSR, Leningrad, 1932.

Koloskov, P.I. On the problem of thermal improvement in regions of permafrost and deep frost penetration of the soil. Vechnaya merzlota. Sb. Materialy KEPS, No. 80, Izd-vo AN SSSR, 1930.

Konstantinova, G.S. Permafrost in the Yenisei-Pyasina river valleys. Rukopis', fondy In-ta merzlotoved., 1954.

Kudryavtsev, V.A. Temperature of the upper strata of permafrost within the U.S.S.R. Leningrad, Izd-vo AN SSSR, 1954.

Kursanov, A.L. The importance of isotopes and other recent methods of investigation in biology for solving problems in agriculture. Izv. AN SSSR, ser. biol., 1954, No. 1.

Kuzeneva, O.I. Evolution of swamps in the Amur Oblast and experiments in classifying them. Pochvovedenie, 1911, No. 2.

Mizerov, A.V. Data on snow cover on the northwestern shore of Kamchatka Peninsula. Izv. Gos. geogr. ob-va, 1937, No. 2.

Myshkovskaya, E.E. Meteorological soil and botanical-geographic observations at the Bomnak Station during the summer of 1910. Tr. Amursk. eksped., No. 14, St. Petersburg, 1913.

Oblenskii, V.N. The influence of trees on the temperature of the soil and on the temperature and humidity of the air. Zhur. geofiz. i meteorol., 1923, Vol. 3, No. 3, 4.

Pistsov, P.M. Problems of agricultural development in regions of permafrost of the far eastern krai. Tr. Vses. sel.-khoz. akad. im V.I. Lenina, No. 13, 1937.

Popov, A.I. (1) Permafrost in western Siberia. Izd-vo AN SSSR, 1953.

Pryanishnikov, A.V. Meadow formations in the tundra. Botan. zhur., 1954, Vol. 39, No. 1.

Schimper. Pflanzengeographie auf der physiologischen Grundlage. Jena. Fischer, 1947.

Sochava, V.B. Reason for forest-free areas in Eastern Siberia and Primor'e. Priroda, 1944, No. 2.

Solov'ev, P.A. Permafrost-hydrogeological investigations in the region of the villages of Mai and Lamuto. Rukopis', fondy In-ta merzlotoved., 1946.

Sumgin, M.I. Perennially frozen soil within the U.S.S.R. 1st edition. Vladivostok, 1927; 2nd edition, Moscow, 1937.

Sumgin, M.I., Kachurin, S.P., Tolstikhin, N.I. and Tumel', V.F. General permafrost studies. Leningrad-Moscow, Izd-vo AN SSSR, 1940.

Tanfil'ev, G.I. The tree line in northern Russia. Odessa, 1911.

Tikhomirov, B.A. Forest-free tundra and its development. Botan. zhur., 1953, Vol. 38, No. 4.

Titov, I.A. On the interaction of vegetation and conditions of the medium. Moscow, 1952.

Tsyplenkin, E.I. Permafrost and its importance in agriculture. Tr. Vses. sel.-khoz. akad. im. V.I. Lenina, No. 13, 1937.

Tumel', V.F. On some changes in the permafrost regime of soils in connection with the burning of the vegetation cover. Tr. Komit. po vechn. merzl., Vol. 8, Moscow-Leningrad, Izd-vo AN SSSR, 1939.

Tyrtikov, A.P. (2) The distribution of the root system of trees at the northern tree line. Vestn. MGU, Otd. biol., 1951, No. 10.

Tyrtikov, A.P. The length of tree roots at the northern tree line. Byull. Mosk. ob-va ispyt. prirody, Otd. biol., 1954, Vol. 59, No. 1.

Tyrtikov, A.P. (1) The effect of vegetation on permanently frozen soil. Mat. k osnov. uchen. o merzl. zonakh zemn. kory, No. 3, Moscow, Izd-vo AN SSSR, 1956.

Tyrtikov, A.P. (1) On the thermotropism of roots in nature. Dokl. AN SSSR, 1951, Vol. 78, No. 6.

Tyrtikov, A.P. The thawing of soil in the region of Igarka. Tr. In-ta merzlotoved., AN SSSR, Vol. 12, 1952.

Tyrtikov, A.P. (1) Vegetation in the Aldan mining region. Rukopis', fondy In-ta merzlotoved., AN SSSR, 1955.

Tyrtikov, A.P. (2) Vegetation in the lower reaches of the Yana River. Byull. Mosk. ob-va ispyt. prirody, 1956, No. 1.

Val'ter, O.A. and Begacheva, V.A. The activity characteristics of the root system of plants in the polar region. Eksperimental'naya botanika, No. 6, Moscow, 1940.

Vil'yams, V.R. Soil science. Moscow, 1946.

Yanovskii, V.K. Methods of investigating permafrost for engineering-construction purposes. Izd-vo AN SSSR, 1951.

Table XXXIII

Soil moisture content (%) in the vicinity of Pikan, 2-5 Aug. 1910 (according to V.A. Val'ts, 1913)

Depth cm	Moisture	
	Woody podzol soil	Peat soil (sedge peat)
1 - 5	60.1	420.5
8 - 10	30.9	421.4
15 - 20	21.0	402.1
25 - 30	21.3	246.0

Table XXXIV

Evaporation (grams/day) in average of three summer months from an area of 1000 cm^2 (after E.E. Myshkovskaya, 1913)

Vegetative cover	Habitat				
	Forest	Exposed locality			
	Polytrichum	Sphagnum polytrichum	Sphagnum	Polytrichum	Lichen
Evaporation	155	325	272	314	180

Table XXXV

Intensity of evaporation in various conditions (Kitredzh, 1951)

Evaporation surface	Relative evaporation %
Exposed water surface	100
Saturated bare soil in exposed area	93
Exposed water expanse in forest	36 - 39
Saturated bare soil in forest	35
Saturated soil under forest litter	13

Table XXXVI

Depth of thaw and soil temperature in Igarka region in 1950

Habitat	Soil	Depth of thaw to Sept. 3 (mean), cm	Soil temp. at 15 cm depth (mean of June 15 - Sept. 5) °C
Peat mounds and sphagnum bogs	Peat	38	3.0
Sparse forest (natural conditions)	Peaty-compact podzolic	81	3.8
Sparse forest (bare soil)	Compact podzolic	126	10.3

Table XXXVII

Temperature of peat soil in Igarka region in 1950

Date	Time	Temp. of soil on surface under moss cover 5 cm °C	Soil temp. at depth °C	
			5 cm	10 cm
June 17	13:00	11.4	2.2	0.0
July 13	12:30	11.9	3.1	1.7
July 23	14:00	11.7	5.2	2.4
Aug. 16	13:00	11.5	6.2	4.6

Table XXXVIII

Thawing of sandy soil in relation to thickness of peat horizon in Igarka region in 1950

Thickness of peat horizon, cm	Depth of thaw, cm		
	June 24	July 17	Sept. 3
4	46	84	145
Removed	64	104	179

Table XXXIX

Soil thawing in forest in relation to thickness of peat horizon in Igarka region in 1950

Thickness of peat horizon, cm	Depth of thaw, cm			
	June 19	July 13	Aug. 2	Sept. 2
5 - 10	20	44	61	80
10 - 15	13	35	49	64
20	12	22	40	48

Table XL

Thawing of peat soil in areas with various ground covers in Igarka region in 1950

Cover	Depth of thaw, cm		
	July 13	Aug. 3	Sept. 2
Sphagnum mosses	18	22	26
Green mosses	25	31	35

Table XLI

Thawing of forest soil in relation to cover in Igarka, 1950

Type of moss or lichen	Soil type	Thickness, cm		Depth of thaw to Sept. 3, cm		
		Cover	Peat horizon	June 27	July 27	Sept. 3
Cladonia alpestris	Peat, sand	6	7	16	64	98
removed	Peat, sand	-	4	46	95	145
Polytrichum commune	Peat, clay loam	10	12	16	56	72
removed	Peat, clay loam	-	9	18	64	90
Pleurosium schreberi	Peat, clay	7	20	13	37	48
removed	Peat, clay	-	18	15	49	70

Table XLII

Depth of soil thawing in forest in Igarka region in 1950

Type of moss or lichen	Soil type	Thickness, cm		Depth of thaw to Sept. 9, cm
		Cover	Thick-ness	
Cladonia alpestris	Sand, peat	6	7	98
removed	sand	-	-	179
Polytrichum commune	Clay loam, peat	10	12	72
removed	clay loam	-	-	110
Pleurosium schreberi	Clay, peat	7	20	48
removed	clay	-	-	115

Table XLIII

Soil temperature in natural conditions (a) and on areas from the cover and peat horizons have been removed (b)

Habitat	Vegetation	Type of moss or lichen	Thickness of cover, cm	Thickness of peat horizon, cm	Time of observation	Temp. °C in soil (mean for observation period) at depth, cm		
						15 cm	20 cm	30 cm
Bomnak 54°5'N*	Cut forest	(a) Polytrichum commune	Not indicated	Not indicated	July 1 - Aug. 26 (1909)	--	5.3	3.4
		(b) Cultivated area			same	--	17.5	16.0
Bomnak 54°5'N**	Sphagnum bog (chenopodium)	(a) Type sphagnum	10 - 20	Not indicated	June 9 - Sept. 16 (1910)	--	5.4	4.3
		(b) Cultivated area			same	--	11.0	10.0
Igarka 67°30'N	Sparse forest	(a) Cladonia alpestris	6	7	June 15 - Sept. 3	3.0	--	--
		(b) Cultivated area			same	10.3	--	--

* From the data of V.A. Bal'ts and N.I. Prokhorov (1913).

** From the data of N.I. Abramov (1913).

Table XLIV

Depth of thaw and soil temperature in a meadow and under brush

Habitat	Vegetation	Depth of thaw		Soil temp. (mean) at depth of 20 cm, June 29 - Sept. 13 1950
		July 14 1920	July 24 1950	
Tygan-Urgan 54°3'N*	Underbrush	68		--
	Meadow	108		--
Igarka 67°30'N	Underbrush	57		4.5
	Meadow	92		8.8

* According to the data of S.Z. Alyukhin (1913).

Table XLV

Increase of soil temperature after cultivation (in mean monthly temperatures) compared with natural conditions

Soil	Vegetative cover	Increase of mean July temp. at 40 cm depth °C
Semi-bog	Forest	14
Peat bog	Grassy	12
Semi-bog	Grassy	9
Poorly sodded gravelly	Grassy	3

Table XLVI

Increase (+) or decrease (-) of taiga soil temperature from forest cutting

Depth, m	Thickness of snow cover, cm	Increase (+) or decrease (-) of soil temp. in a year °C
0.2	20	+0.5
	10	-1.6
0.3	20	+0.7
	10	-1.2
0.4	20	+0.6
	10	-0.6

Table XLVII

Depth of thaw of soil on south facing slope at various stages of colonization in Kazach region

Phase of colonization	Depth of thaw at Aug. 26, 1952, cm
Vegetation absent	110
Meadow	105
Sparse forest with 5 cm moss cover	65

Table XLVIII

Depth of soil thaw at various stages of colonization of lakes in the Yana lowland

Stage of colonization	Depth of thaw at beginning of Sept. 1952, cm
Arctophyle brush	115
Marsh trefoil brush (*Menyanthes trifoliata*)	78
Equisetum brush	62
Sedge bog	60
Bog spruce scrub	40
Bog birch scrub	31
Birch scrub on dry peat bog	25

Fig. 105

Root system of birch in the Igarka region
(photograph by A.P. Tyrtikov)

Fig. 106

The destruction of vegetation resulting from the melting ice
in the lower reaches of the Yana River
· (photograph by A.P. Tyrtikov)