Vol. 7 (1998): 507–512.

Research Note

Soil temperature regimes in Finland

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Soil temperature regime substantially influences soil classification in Soil Taxonomy particularly in temperate areas. To facilitate correct classification of soils of Finland, the temperature regimes in soils of the country were determined. The mean annual soil temperature, measured at 50 cm below soil surface, ranged from 6.4°C at the warmest site (Anjala) to 1.9°C at the coldest one (Utsjoki, Kevo), and the mean summer soil temperature from 13.7°C to 6.2°C at the same stations, all being in the range of the cryic temperature regime. The mean annual soil temperature was 2 to 5°C higher than the mean annual air temperature, the difference (Y, °C) depending on the duration of snow coverage (X, days) according to the following equation:

$$Y = 0.0305\ X - 2.16,\ R^2 = 0.91,\ n = 9.$$

Even soils of the warmest areas in southern Finland and the mineral soils of the coldest areas in the north, at least for the most part, have cryic soil temperature regimes. Therefore, most soils of Finland, classified according to Soil Taxonomy, have names where the cryic temperature regime appears on the suborder or great group level.

Key words: cryic temperature regime, frigid temperature regime, pergelic temperature regime, snow cover, Soil Taxonomy

Introduction

Soil temperature influences pedogenesis in several direct and indirect ways. Freezing and thawing cause mechanical weathering by breaking mineral particles. During low temperatures, all chemical reactions are slow. Potential evaporation is less in soils with low temperatures than in warmer soils receiving the same precipitation, resulting in more humid soils in cool areas. In cool wet soils, redoximorphic features are common and leaching of weathering products is more intense than in warmer soils. Also the build-up and decomposition of organic matter is influenced by soil temperature.

In Soil Taxonomy, soil temperature regime substantially influences the name of a soil, par-

Manuscript received September 1998

ticularly in temperate areas. The new Gelisol soil order, established in 1998 (Soil Survey Staff 1998), includes soils with a pergelic soil temperature regime (mean annual soil temperature below 0°C). In Alfisols, Andisols, Aridisols, Inceptisols, Mollisols, Spodosols and Vertisols, the cryic soil temperature regime (mean annual soil temperature 0–8°C, mean summer soil temperature below 15°C) is expressed in the suborder level and many orders have cryic great groups (Soil Survey Staff 1998).

Mean annual soil temperature is commonly estimated from air temperature by adding 1°C to the mean annual air temperature (Soil Survey Staff 1975). Even though this relationship holds in most of the USA, it does not hold for example in Alaska and the Great Lakes States, where soil temperature is substantially higher than that predicted from air temperature, owing to insulation by snow (Smith 1986). Mokma and Sprecher (1995) reported that in Michigan mean annual soil temperature was 2.8°C higher than mean annual air temperature in regions that received at least 1.5 m of snow. On this basis, it can be concluded that the commonly applied difference of 1°C between mean annual air and soil temperatures does not hold in Finland either.

Tentatively, soils of Finland have been considered to have a cryic temperature regime (Mount et al. 1995, Yli-Halla 1997) and taxa like Haplocryods, Humicryods, Eutrocryepts, Dystrocryepts, Cryosaprists, Cryaquepts and Cryopsamments have been recognized (Mount et al. 1995, Yli-Halla and Mokma 1999). Soils of these taxa are likely to cover most of the country. The evidence of the prevalence of the cryic soil temperature regime is not yet conclusive in the south, where mean summer air temperatures may be above 15°C and the frigid soil temperature regime may occur. On the other hand, the palsa mires in the very northern parts of Finland (e.g. Seppälä, 1988) are characterized by permanent ice lences. They inevitably have a pergelic soil temperature regime and are Histels, belonging to the Gelisol soil order.

The purpose of the present investigation was to find out, which soil temperature regimes occur in Finland. This is necessary in order to be able to correctly classify soils of Finland according to Soil Taxonomy. The study was carried out on the basis of published data on soil and air temperatures. Firm evidence for the prevalence of the cryic temperature regime was collected, paying particular attention to the northern and southern tips of the country where also pergelic and frigid temperature regimes, respectively, are possible. Relationships were also developed between soil and air temperatures.

Materials and methods

Soil temperature is and has been measured at several weather stations of the Agricultural Research Centre of Finland (MTT) and Finnish Meteorological Institute. Soil temperature data of nine selected stations (Fig. 1) were taken from annual reports of the research stations of MTT (available at the library of MTT, 31600 Jokioinen, Finland) and reports of the Finnish Meteorological Intsitute. The data sources are given in detail in Table 1. All results are from mineral soils. Data of air temperatures and length of snow cover (Finnish Meteorological Institute 1961...1990, 1991) were also used. The methods of measuring soil temperature were presented by the Finnish Meteorological Institute (1979) and by Heikinheimo and Fougstedt (1992). Data on soil temperatures in different periods was used at the various stations. This difference was not considered a marked shortcoming because soil temperature at 50 cm varies relatively little from year to year. At the Jokioinen observatory, soil temperature was measured every day throughout the year during the entire time whereas at the other stations the measurements were carried out at least every five days. Summer refers to the months of June, July and August.

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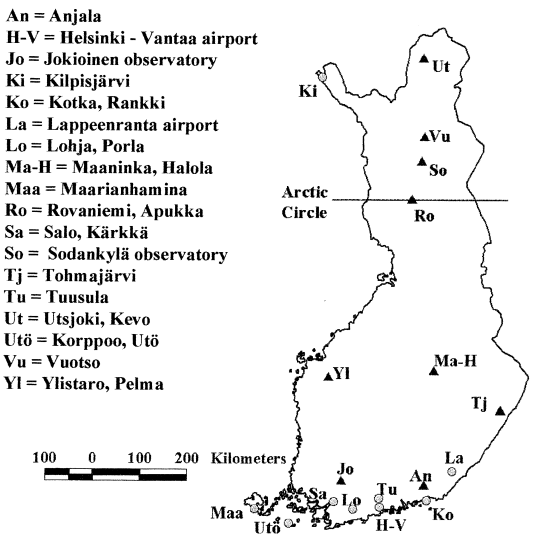

Fig. 1. Location of weather stations where soil temperature was measured (▲) and stations where soil temperature was estimated on the basis of air temperature (O).

Results and discussion

Mean annual soil temperature decreases from 6.4 to 1.9°C and the mean summer soil temperature from 13.7 to 6.2°C from the warmest site (Anjala) to the coldest one (Utsjoki, Kevo) (Table 1) which lie about 1000 km apart in the south-north direction (Fig. 1). At all stations that record soil temperature, the mean annual soil temperature is above 0°C and mean summer soil temperature is below 15°C, indicating the cryic soil temperature regime in the soils of the weather stations. Also the highest and lowest mean annual soil temperatures of a single year (6.8°C at Anjala in 1989 and 0.9°C at Utsjoki, Kevo in 1968, respectively) were within the range of the cryic regime. Only twice did mean summer soil temperature exceed 15°C (15.5°C at Maaninka in 1972 and 15.2°C at Ylistaro in 1980).

Table 1. Soil and air temperatures and duration of snow cover at different weather stations in Finland. Soil temperatures were measured at a depth of 50 cm below the soil surface.

Station and and source of data	Location	Period	Soil annual		Soil summer		Air annual	Air summer	Air annual 1961–90	Air summer 1961–90	Duration of snow cover
			Mean °C	Range °C	Mean °C	Range °C	°C	°C	°C	°C	days
Anjala, c	60°43'N 26°48'E	1982–90	6.4	5.1–6.8	13.7	11.8–14.8	4.2	15.3	3.9	15.3	153[1)]
Jokioinen, ab	60°49'N 23°30'E	1958–70	5.9	5.6–6.4	12.7	11.1–13.6	3.6	14.8	3.9	14.8	138
Maaninka, Halola, d	63°09'N 27°19'E	1968–80	5.3	4.6–6.2	13.5	12.3–15.5	2.3	15.1	2.4	14.8	166[2)]
Ylistaro, Pelma, d	62°56'N 22°30'E	1968–80	5.5	4.8–6.4	13.1	12.0–15.2	3.2	14.7	3.2	14.4	143[3)]
Tohmajärvi, Kemie, c	62°14'N 30°19'E	1987–92	6.1	5.5–6.7	12.7	11.8–13.9	3.0	14.5	2.2	14.5	177[4)]
Rovaniemi, Apukka, c	66°35'N 26°01'E	1984,87–90	3.8	2.3–5.3	10.1	8.2–10.8	0.6	12.9	–0.2	13.1	195
Sodankylä, bd	67°22'N 26°39'E	1963–80	3.0	1.8–3.8	12.1	10.2–13.9	–1.1	12.4	–1.0	12.3	208
Vuotso, b	68°05'N 27°11'E	1962–70	2.2	1.2–2.8	7.4	5.5–8.1	–2.3	11.1	–2.0	11.4	215
Utsjoki, Kevo, b	69°45'N 27°02'E	1966–70	1.9	0.9–2.4	6.2	3.9–8.2	–2.8	11.0	–2.0	10.9	210

Snow cover measured at: [1)] Utti, [2)] Kuopio airport, [3)] Kauhava airport, and [4)] Joensuu airport

The sources of the soil temperature data:
a Finnish Meteorological Institute 1968
b Finnish Meteorological Institute 1979
c Agricultural research Centre of Finland, Annual reports of the respective research stations (in Finnish)
d Finnish meteorological institute 1968...1980
The source of other meteorological data: Finnish Meteorological Institute 1958...1990

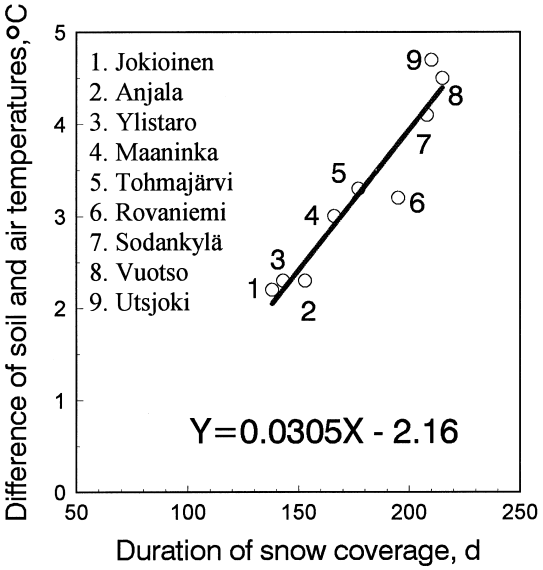

Fig. 2. Relationship between duration of snow cover (days) and difference between mean annual soil and air temperatures. The coefficient of determination (R^2=0.91) and the slope are statistically highly significant (P<0.001), F=71.27 and t=8.44, respectively.

Mean annual air temperatures of the observation periods were within ±0.8°C of the mean annual air temperatures of the whole 30-year period 1961–90 and the corresponding mean air summer temperatures were within ±0.3°C of the long-term averages (Table 1). The soil temperatures compare favorably with the (18- or) 20-year averages presented by Heikinheimo and Fougstedt (1992). The results of the observation period are thus representative.

The mean annual soil temperature at the nine weather stations is 2 to 5°C higher than mean annual air temperature (Table 1). The difference is greater in the north and it is related to the duration of snow cover (Fig. 2). The relationship between soil and air temperatures thus markedly deviates from the commonly used difference of 1°C developed for areas where snow is not common. In Finland, the snow cover lasts for about 60 days on the most southern islands and about 250 days in the extreme north (Solantie et al. 1996), resulting in a marked insulation of the soil from the cold air temperatures in winter.

The three northernmost weather stations that record soil temperature (Sodankylä observatory, Vuotso and Utsjoki, Kevo) have mean annual air temperatures below –1°C. At those stations, the mean annual soil temperature is 4.1 to 4.7°C higher than mean annual air temperature (Table 1). Application of this relationship to the weather station of Kilpisjärvi (see Fig. 1) which had the lowest mean annual air temperature in 1961–90 (–2.6°C) in Finland results in an estimated mean annual soil temperature of 1.5 to 2.1°C. Application of the relationship in Fig. 2 to Kilpisjärvi which has a snow cover for 240 days results in an estimate 2.4°C. These results suggest that also in northernmost Finland mineral soils have a cryic rather than a pergelic soil temperature regime. Organogenic soils are conducive to lower temperatures than the nearby mineral soils. Pessi (1957) reported that at Pelsonsuo, north-central Finland, a mean annual soil temperature of two years for an organogenic soil was 4.7°C lower than in a nearby sandy soil. Applying this difference to the current results of the most northern mineral soils suggests a pergelic temperature regime in the organogenic soils of the region, in accordance to the existence of the palsa mires.

Anjala is the southernmost weather station in Finland recording soil temperature at 50 cm below soil surface. Therefore, the soil temperatures on the southern coast line and in the south-western islands must be derived from air temperatures (Table 2). The highest average (1961–90) annual air temperature in Finland is 5.8°C, measured at Utö island. All weather stations on the southern coast of continental Finland have mean annual air temperatures below 5°C, except Kaisaniemi in downtown Helsinki (5.2°C). At Utö, the snow cover lasts for only 70 days and in Maarianhamina and Salo about 100 days which is well outside the range (138–215 d) of the equation in Fig. 2. However, it can be concluded from Fig. 2 that at these sites with a short snow coverage the mean annual soil temperature is less than 2°C above the mean annual air temperature, resulting in mean annual soil temperatures below 7.8°C. The mean annual soil

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Table 2. Measured air temperatures in 1961–90, estimated soil temperatures at 50 cm below soil surface and the duration of snow coverage at some weather stations in southern Finland (for locations of stations, see Fig. 1).

Station	Location	Mean annual air temperature °C	Estimated mean annual soil temperature °C	Summer air temperature °C	Estimated mean summer soil temperature °C	Duration of snow cover days
Utö	59°47'N 21°23'E	5.8	<7.8	14.7	13.1	70
Maarianhamina airport	60°07'N 19°54'E	5.2	<7.2	14.6	13.0	108
Salo, Kärkkä	60°22'N 23°06'E	4.8	<6.8	15.7	14.1	104
Lohja, Porla	60°15'N 24°03'E	4.8	6.7	15.6	14.0	132
Helsinki-Vantaa airport	60°19'N 24°58'E	4.5	6.4	15.5	13.9	132
Tuusula, Hyrylä	60°25'N 25°02'E	4.4	6.2	15.6	14.0	131[1)]
Kotka, Rankki	60°22'N 26°58'E	4.6	6.1	15.5	13.9	120
Lappeenranta airport	61°05'N 28°09'E	3.6	6.1	15.4	13.8	154

[1)] Data of 1971 missing.

temperatures for other stations in Table 2 were calculated using equation of Fig. 2 and estimates between 6 and 7°C were obtained. All weather stations on the southern coast and in the south-western islands thus have mean annual soil temperatures which are in the range of the cryic and frigid regimes (0–8°C).

In the cryic soil temperature regime, mean summer soil temperature is below 15°C and in the frigid regime it is above 15°C. Mean summer soil temperature can be estimated by subtracting 0.6°C from mean summer air temperature (Soil Survey Staff, 1975). According to data in Table 1, mean summer soil temperature of mineral soils in the southern half of Finland is 1.6°C lower than the mean summer air temperature. At weather stations in southern Finland, the mean summer air temperature is 15.7°C at the maximum (Table 2). Subtraction of 1.6°C from those temperatures results in mean summer soil temperatures below 15°C (Table 2), proving that the soils on the southern coast and in the south-western islands of Finland do have a cryic soil temperature regime.

The present study shows that without a doubt a vast majority of soils of Finland have a cryic temperature regime. It can be concluded that in the north, some organic soils, particularly palsa mires, have a pergelic temperature regime, co-existing with cryic mineral soils. No soil having a frigid temperature regime was identified in the weather stations in the south even though such soils may occur in sites which have an exceptionally warm microclimate. These sites include hillsides sloping to south and west, receiving much solar radiation. Coarse-textured soils are more conducive to the frigid soil temperature regime because the heat is transferred more rapidly into the soil as compared to clayey or organogenic soils. The mean summer air temperature in Finland has been predicted to increase by 1–2°C by the year 2050 (Carter 1996). If this shift takes place, many soils change from cryic to frigid. For the time being, however, the cryic temperature regime can be considered by far the primary alternative in soil classification in all parts of Finland.

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SELOSTUS

Maan lämpötila Suomessa

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Amerikkalaista alkuperää olevassa maannosten luokitteluun kehitetyssä Soil Taxonomy -järjestelmässä käytetään yhtenä luokitteluperusteena maan lämpötilaa 50 cm syvyydessä. Maan lämpötila vaikuttaa varsinkin viileiden alueiden maannosten nimiin. Tämän tutkimuksen aineistona käytettiin eri lähteissä julkaistuja tietoja maan lämpötilasta Suomessa. Kun maan vuotuinen keskilämpötila on 0–8°C ja kesäkuukausina alle 15°C, maa kuuluu Soil Taxonomy -järjestelmän lämpötilaluokkaan ‘cryic’. Tällaiset lämpötilaolot vallitsevat valtaosassa Suomen maaperää. Ainoa poikkeus ovat Pohjois-Lapin palsasuot. Niissä maan keskilämpötila on todennäköisesti alle 0°C ja ne kuuluvat lämpötilaluokkaan ‘pergelic’.