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ON THE SIGNIFICANCE OF SOIL TEMPERATURE IN PLANT CULTIVATION

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I. Introduction

Temperature is one of the growth factors of cultivated plants. When speaking of temperature as a growth factor, one mostly refers to air temperature. However, in certain circumstances at least, it is expedient to pay attention to the air temperature as well as to that of the soil and to distinguish between their effects.

The temperature of the root system of a plant is determined by the temperatures in the soil. The temperature of its superterrestrial parts, again, is influenced by several factors, e. g., air temperature, radiation, evaporation, etc. Consequently, roots and super-terrestrial parts have only rarely the same temperature. The relation between air temperature and soil temperature is also different in different soil types (cf. Pessi 1957 a, 1957 b). Furthermore, it has to be noted that although a kind of correlation exists between air temperature and soil temperature, this correlation is not very distinct (Baier 1952, p. 192, Pessi 1957 e, p. 36). Taylor (1928, p. 120) did not observe any correlation between the said temperatures in his investigations. This circumstance, too, indicates that in a more detailed study of temperature as a growth factor attention should be paid separately to both air and soil temperatures.

The growth of a plant involves a great number of physical, chemical and physiological phenomena. The phenomena occurring in the root system are obviously associated with temperature, since the temperature affects all phenomena of the kind mentioned, as will be demonstrated briefly in the following.

If the molecular system of a substance is chosen as the basis of consideration, we may observe that its kinetic energy is directly proportional to absolute temperature. Changes in kinetic activity, again, produce thermal expansion or contraction of the substance and give rise to changes in its viscosity, solubility, degree of dissociation, reaction velocity and equilibrium ratios. For instance, the viscosity of water at 10°C is only about 73 %, and at 20°C only 56 %, of its magnitude at 0°C. The viscosity of the cell plasma will thus vary with varying temperature.

Several of the vital activities of a plant depend on processes of diffusion. The coefficient of diffusion, in turn, is directly related with absolute temperature, according to Höber (1945).

A great variety of chemical reactions take place both in the soil and in the root system of the plant. As Van't Hoff has observed, the speed of chemical reactions is multiplied by a factor of 2—3 for each 10°C rise in temperature. Biochemical phenomena, which play a central role in the life processes of plants, are similarly dependent on temperature.

The absorption of nutrients and water is an essential process with regard to the growth of plants. The rate at which plant nutrients and water enter the cells is related to the permeability of the cells. Since the activity of the protoplasm is dependent on temperature and in turn affects the permeability, even these phenomena in plants are dependent on temperature. For instance, Döring (1935, p. 315) found in his investigation on the water uptake of plants that reduced water uptake ensued when the root system of a plant was transferred from a temperature of 20°C to one of 0°C, the new equilibrium being attained after about 35—40 minutes. Remarkable differences with regard to the reduction of water uptake were noted between different plant species.

Rouschal (1935, p. 325) has made the same observations as Döring. Furthermore, he noticed that upon being returned to the original, higher temperature the plant did not regain its original water uptake; that is, the low temperature period had an after-effect (p. 330).

Furthermore, the soil temperature has immediate significance in respect to the growth of the roots. Germination, tillering and growth of the shoot are also immediately dependent on temperature.

The soil temperature also possesses a remarkable indirect significance in respect to cultivated plants, owing to the fact that the growth, propagation and activity of microorganisms are greatly dependent on temperature (cf., e. g., Martin and Craggs 1946, Kaila 1952, Tamm 1952, Kivinen 1954). It is well-known that microbes are responsible for such phenomena as the decomposition of organic matter, ammonification, nitrification, formation of nodules, etc.

For each plant there exists an optium temperature at which the growth and activity of the root system can best take place, although this optimum temperature may vary in accordance with the different stages of development of the plant. In the first place, a distinction should be made between the stage at which the seed germinates and sprouts, and the stage subsequent to these occurrences. It can be concluded on the basis of the data on optimum temperatures for the root system of cultivated plants presented in the literature (Fitch 1915, Dickson 1923, Bushnell 1925, Brown 1939, Wort 1940, Sprague 1943, Hoagland 1944) that the optimum temperatures of the plants cultivated in Finland, subsequent to tillering, are a few degrees above or below 20°C, those of the hibernating plants being perhaps slightly lower than those of the other plants.

The optimum temperature for the action of microorganisms in the soil is in excess of 15—20°C as a rule (cf. SWINGLE and WALTER 1947, p. 129). However, TAMM (1952) has found that one temperature region favourable from the viewpoint of microorganisms also lies above 10°C, within the range of a few degrees.

What then are the thermal conditions of the soil of cultivated fields that prevail in Finland during the growing period?

Prolonged soil temperature measurements in cultivated fields in our country are very few in number. Only the measurements performed by HOMÉN (1896), VESIKIVI (1933), JUUSELA (1945) and PESSI (1956, 1957 c, 1957 d) permit inferences to be drawn as to the general trend of thermal conditions in certain circumstances. Of these authors, VESIKIVI has carried out temperature measurements in bog soil at Leteensuo ($\lambda = 24.21$°E, $\varphi = 61.06$°N), JUUSELA in mineral soil near Helsinki ($\lambda = 24.58$°E, $\varphi = 60.17$°N) and PESSI in bog soil at Pelsonsuo ($\lambda = 26.5$°E, $\varphi = 64.3$°N).

It should be noted, however, that VESIKIVI performed his measurements on plots from which the plant cover had been removed. Such measurements have also been carried out by PESSI (1957 c, 1957 e) at Pelsonsuo, in addition to the above-mentioned measurements both in peat and mineral soil, and by KERÄNEN (1920) in mineral soil. In the absence of plant cover, the soil temperature will be several degrees higher than in plant-covered soil. Taking this into account, the said investigations appear to justify the general conclusion that in cultivated bog areas the soil temperature at depths equal to or greater than 5 cm remains lower than 15°C throughout nearly the entire growing period. In the measurements of JUUSELA (1945, p. 159), the monthly mean temperatures of July and August have been above 15°C for depths of 20 cm and less.

If the before-mentioned figures are accepted as optimum temperature values for the systems of cultivated plants, it can be noted that in mineral soils the temperature of the tilled layer attains fairly favourable values from the viewpoint of cultivated plants. On the other hand, the corresponding temperature in cultivated bog areas is low enough to suggest the possibility that, at least in the northern parts of our country, the soil temperature may constitute a factor restricting the crop yield of cultivated plants. It is therefore worth while to describe, in the following, the investigations performed at the Frost Research Station which throw light upon this question.

II. The significance of soil temperature with regard to germination and tillering

As early as in the last century, HABERLANDT (1874) observed that cereals germinate even at temperatures below 5°C. At present it is indeed generally maintained that the germination of cereals commences at a temperature of nearly 0°C. For instance, it could be established in pot tests performed by PESSI (1957 c) that the germination of spring cereals started at temperatures below 3°C.

Although the soil temperature in cultivated bog areas is low at the beginning of the growing period, one is not immediately entitled to assume that the grain yield of spring cereals could be increased by raising the germination temperature. This could obviously be attained by postponing the sowing. However, experiments relating to the time of sowing of spring cereals have shown that a low germinating temperature probably has no detrimental influence upon the grain yield, inasmuch as almost without exception the earliest seedings gave the highest grain yield, although the straw yield remained smaller than in the tests where the sowing was done at later times (PESSI 1957). One possible explanation (PESSI 1957, p. 30) is that the low germinating temperature itself may cause the grain crop to be highest from the earliest seedings. This contention finds support in the investigations relating to jarovization performed by LYSENKO (1951). It must be admitted, however, that also other factors which may be of influence occur in connection with the sowing time tests.

It seems to be true that, in practice at least, it is not necessary to pay attention to the soil temperature during germination with the intention of stipulating the highest possible soil temperature. There is probably greater importance attached to the moisture content of the soil. If an attempt should be made to provide the highest possible germinating temperature for open-field plants, the likely result would be postponement of the sowing, which would bring no advantage in Finnish conditions.

III. The significance of soil temperature after tillering

There are certain difficulties in connection with the arrangement of field experiments with the purpose of determining the effect of temperature upon the crop yield. In numerous types of test where temperature differences in the soil are produced, the other properties of the tilled soil layer are also changed to such an extent that it is difficult to distinguish the effect upon the crop yield of some particular factor, e. g., the temperature. For instance, the admixture of mineral soil to peat soil will bring about changes in the thermal conditions in the soil, but at the same time it will also change the moisture conditions and the porous volume of the soil. Changes in thermal conditions can also be caused to occur by rolling, but the compaction of the soil will produce simultaneous changes with regard to moisture.

In spite of these complications, the question in hand will be considered in the following on the basis of soil improving tests also, and additionally on the basis of field tests in which differences in regard to soil temperature have been produced between the test members by means of different artificial colouring of the soil surface.

1. *Soil improving agents*

Experiments relating to soil improving have been instituted at the Frost Research Station in the years 1951—1955. The soil improving agent was coarse sand. According to the performed investigation (Pessi 1956), the admixture of mineral soil to peat soil raised the temperature of the tilled layer, particularly in the early part of the summer.

The plant cultivation tests were arranged primarily with plots each consisting of one strip between two open ditches. For fertilizers the following were used annually: 300—400 kg phosphate, 200—300 kg potassium salt, and 100 kg calcium nitrate or the corresponding quantity of Oulu saltpetre, per hectare. In the bog area copper deficiency was also experienced, for which reason copper concentrate was given in the following quantities in the different years: 1951 20 kg, 1952 10 kg, 1953 12 kg, 1954 30 kg, 1955 10 kg per hectare. Despite the copper fertilization the copper deficiency was not compensated on the plot to which no mineral soil was added. On the other hand the indications of copper deficiency were almost completely eliminated just by addition of 100 m³ of mineral soil per hectare.

The results of the soil improving tests are shown in Tables 1—8. The weather conditions of the test years have been described in a previous publication (PESSI 1957), to which it may suffice to refer.

Results of the soil improving test with barley.

Maanparannusainekokeen tuloksia. Koekasvina ohra.

Table 1. 1952. 400 m² plots, no replicates. Test area sown on 29. V., cut on 15. IX. Night frost —5.0°C on 15—16. VIII. Variety: Tammi barley.

Taulukko 1. 1952. Koeruudut 4 aaria. Ei kerranteita. Kylvetty 29. V. Niitetty 15. IX. 15—16. VIII. 5.0°C halla. Lajike: Tammi-ohra.

Mineral soil, m³ per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha *Jyväsato kg/ha*	relative *suhdeluku*	Tillered on *Orastunut*	Panicles appeared on *Tuli tähkälle*
0	50	4	13. VI	21. VII
100	1 150	100	12. VI	19. VII
200	1 400	122	11. VI	18. VII
400	1 700	148	11. VI	18. VII

Table 2. 1953. 1 000 m² plots, no replicates. Test area sown on 27. V., cut on 5. IX. Variety: Tammi barley.

Taulukko 2. 1953. Koeruudut 10 aaria. Ei kerranteita. Kylvetty 27. V. Niitetty 5. IX. Lajike: Tammi ohra.

Mineral soil, m³ per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha *Jyväsato kg/ha*	relative *suhdeluku*	1 000-grain weight, g *1 000 jyvän paino g*	Tillered on *Orastunut*	Panicles appeared on *Tuli tähkälle*	Completely ripened on *Täystuleentunut*
0	35	13	—	6. VI	13. VII	29. VIII
100	1 950	100	32.5	6. VI	8. VII	25. VIII
200	2 190	112	32.8	6. VI	8. VII	25. VIII
400	1 590	82	32.5	6. VI	8. VII	25. VIII

Table 3. 1954. 1 500 m² plots, no replicates. Test area sown on 15. V., cut on 18. IX. Variety: Tammi barley.

Taulukko 3. 1954. Koeruudut 15 aaria. Ei kerranteita. Kylvetty 15. V. Niitetty 18. IX. Lajike: Tammi ohra.

Mineral soil, m³ per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha *Jyväsato kg/ha*	relative *suhdeluku*	1 000-grain weight, g *1 000 jyvän paino g*	Completely ripened on *Täystuleentunut*
0	379	44	27.6	20. VIII
100	863	100	28.2	16. VIII
200	1 123	130	29.4	16. VIII
400	1 700	198	30.6	16. VIII

Table 4. 1955. 1 600 m^2 plots, no replicates. Test area sown on 8. VI., cut on 14. IX. Variety: Tammi barley.

Taulukko 4. 1955. Koeruudut 16 aaria. Ei kerranteita. Kylvetty 8. VI. Niitetty 14. IX. Lajike: Tammi ohra.

Mineral soil, m^3 per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha *Jyväsato kg/ha*	relative *suhdeluku*	Tillered on *Orastunut*	Panicles appeared on *Tuli tähkälle*	Completely ripened on *Täystuleentunut*
0	330	45	25. VI	27. VII	13. IX
100	730	100	25. VI	26. VII	10. IX
200	1 080	148	25. VI	26. VII	10. IX
400	830	114	25. VI	26. VII	10. IX

Results of the soil improving test with oats.

Maanparannusainekokeen koetuloksia. Koekasvi kaura.

Table 5. 1951. 100 m^2 plots, no replicates. Test area sown on 19. V., rolled on 30. V. and cut on 11. IX. Night frost —6°C on 10—11. IX. Variety: Orion III.

Taulukko 5. 1951. Koeruudut 1 aari. Ei kerranteita. Kylvetty 19. V. Jyrätty 30. V. Niitetty 11. IX. 10—11. IX. —6°C halla. Lajike: Orion III.

Mineral soil m^3 per hectare *Kiv.maata m³/ha*	Grain yield, k/ha *Jyväsato kg/ha*	relative *suhdeluku*	Tillered on *Orastunut*	Panicles appeared on *Tuli tähkälle*	Completely ripened on *Täystuleentunut*
0	2 424	61	15. VI	25. VII	11. IX
200	3 980	100	10. VI	21. VII	3. IX
400	4 010	101	10. VI	19. VII	3. IX
800	4 000	100	10. VI	19. VII	3. IX

Table 6. 1953. 2 500 m^2 plots, no replicates. Test area sown on 26. V., cut on 14. IX. Night frost —4°C on 5—6. IX. Variety: Tammi.

Taulukko 6. 1953. Koeruudut 25 aaria. Ei kerranteita. Kylvetty 26. V. Niitetty 14. IX. 5—6. IX. —4°C halla. Lajike: Tammi.

Mineral soil, m^3 per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha *Jyväsato kg/ha*	relative *suhdeluku*	1 000-grain weight, g *1 000 jyvän paino g*	Tillered on *Orastunut*	Panicles appeared on *Tuli tähkälle*	Completely ripened on *Täystuleentunut*
0	305	13	24.0	6. VI	15. VII	14. IX
100	2 270	100	32.0	5. VI	13. VII	10. IX
200	2 475	109	31.5	5. VI	13. VII	10. IX
400	2 635	116	—	5. VI	12. VII	10. IX

Table 7. 1954. 1 500 m² plots, no replicates. Test area sown on 15. V., cut on 24. IX. Variety: Kytö

Taulukko 7. 1954. Koeruudut 15 aaria. Ei kerranteita. Kylvetty 15. V. Niitetty 24. IX. Lajike: Kytö.

Mineral soil, m³ per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha relative *Jyväsato kg/ha suhdeluku*		Completely ripened on *Täystuleentunut*
0	198	20	9. IX
100	1 020	100	6. IX
200	1 385	136	6. IX
400	1 440	141	6. IX

Table 8. 1955. 1 600 m² plots, no replicates. Test area sown on 7. VI., cut on 28. IX. Variety: Tammi

Taulukko 8. 1955. Koeruudut 16 aaria. Ei kerranteita. Kylvetty 7. VI. Niitetty 28. IX. Lajike: Tammi.

Mineral soil, m³ per hectare *Kiv.maata m³/ha*	Grain yield, kg/ha relative *Jyväsato kg/ha suhdeluku*		Tillered on *Orastunut*	Panicles appeared on *Tuli tähkälle*	Completely ripened on *Täystuleentunut*
0	510	31	26. VI	4. VIII	26. IX
100	1 650	100	26. VI	2. VIII	24. IX
200	2 280	138	26. VI	1. VIII	23. IX
400	2 290	139	26. VI	1. VIII	23. IX

In the test result attention is called to the fact that the crop yield remained very low in every case where no mineral soil was added as a soil improving agent. This is mainly attributable to the copper deficiency already mentioned before, which could be ascertained from the observed symptoms.

The test results reveal clearly that the development of the cereals was more rapid on the plots treated with mineral soil. The reason for this will be discussed in the following.

In the first place we may assume that the development is accelerated, either directly or indirectly, exclusively by changes in thermal conditions. That, more accurately speaking, the effect of changes in the thermal conditions in the soil are concerned is made evident by the investigation in question (Pessi 1956). It has thus been found that the mean soil surface temperature attained approximately the same level in all test plots (ascertainable by extrapolation from, e. g., Table 21, p. 51). In consequence of this also, the mean air temperatures are practically the same in the various instances. It is true, on the other hand, that differences occur with regard to the air temperature extremes, particularly in the early part of the summer, the lowest night temperature being lower in absence of mineral soil additions

(p. 71). However, at the same time this implies that the highest temperature in correspondingly higher. Thus during daytime, when the assimilation processes of the plants take place, the temperature in the air surrounding the super-terrestrial parts of the plants will be rather more favourable in the plots without mineral soil addition than in the other plots. If the optimum temperature is considered to be about 25°C, the temperature may admittedly sometimes rise above optimum, but only rather rarely. In practice, the air temperatures for the different test plots will still be similar to such a degree that hardly any differences in the development of the plants can be expected to occur on account of the air temperature, if the night frost phenomenon is left out of account.

2. *Whitening tests*

Since the addition of mineral soil had several immediate effects in soil improving tests as has been explained before, no definite inferences can be drawn from these results with regard to the contribution of some single factor to the observed differences in crop yield. For this reason it was decided to arrange the field tests described in the following.

In principle, these tests constitute an attempt to produce temperature differences in the cultivated layers by means of artificially induced differences in colour of the soil surface. It is well-known that a dark surface absorbs more radiation than a surface of light colour. Since peat is dark in colour, the biggest difference in colour between the test members is obtained by whitening the soil surface. However, the results of a test with exclusively artificially whitened peat soil on the soil surface would be difficult to put into practice, and it was considered better to apply the principle to a test area which had been admixed throughout with 300 m³ of mineral soil per hectare. In such a test the whitened plots, too, possess the various properties caused by the added mineral soil, but the temperature of these plots during the growing period is lower. The thermal conditions of the whitened plots would thus primarily approximate those of pure peat soil, depending on the degree of success in eliminating the thermal effect of the mineral soil addition by means of the whitening treatment.

It should further be noted that differences in soil surface colour cause different surface temperatures and therefore differences in evaporation. Less water will evaporate from a whitened plot than from one that has remained dark. A third test member was therefore introduced, consisting of an unwhitened plot to which was given by spraying the water quantity evaporating from the unwhitened test member in excess of the evaporation from the whitened plot. This evaporation difference was established by means of moisture determinations from soil samples.

a. Arrangement and treatment of the tests

The tests were arranged with barley and oats. The soil type was sedge peat. 300 m^3 sand and 8 000 kg powdered limestone per hectare were used for soil improvement. As fertilizers, 600 kg Kotka phosphate, 400 kg 50 % potassium salt, 130 kg Oulu saltpetre and 50 kg roasted product of igneuner copper were given per hectare. All the fertilizers were spread at the same time. Sowing was done by machine, with the barley and oats seed quantities amounting to 120 and 140 kg of germinating seeds per hectare respectively. Upon sowing, the soil was rolled with a concrete roller. Stitchwort (*Stellaria media*) grew fairly copiously on the test area, but this was destroyed by means of hormone sprays.

The substance employed to whiten the soil surface was barium sulphate powder ($BaSO_4$). It was not spread on the test plots until after tillering of the cereals. Owing to mixing of the powder with the soil on account of rain, the whitening procedure was repeated twice in the test with barley. In the oats test it was not renewed, and consequently no equally distinct differences in colour were obtained between the test members as in the barley test. It was established by means of radiation measurements (cf. SUOMI 1954) that during the daytime the whitened plot absorbed about 30 % less thermal radiation than the untreated plot, during the time when the vegetation did not yet shade the soil surface in any noteworthy degree. During the night the same radiation balance was obtained from both types of plots.

It was established by soil moisture determinations that the evaporation from the unwhitened test member was higher by 10 litres of water per square metre than that from the whitened plot up to the time at which the vegetation began to throw full shade on the soil surface. The evaporation was not followed any further after this time. The third test member was accordingly sprayed with an equivalent of altogether 10 mm rainfall, applied as two separate doses at an interval of about one week.

The test plots were nearly square in shape and the number of replicate plots was five. The cereals were harvested from a 23 m^2 area of each plot, strips of 20 cm width along the borders of the plots being excluded from the recorded crops. The same tests were furthermore arranged with test plots of 1 m^2 each.

b. Air temperature, total radiation and rainfall during the growing period of 1956

In Table 9 some data describing the growing conditions have been compiled. The air temperature has been measured at the climatological station of Pelsonsuo, while the measurements of total radiation and rainfall have been made in the immediate vicinity of the test area.

The mean temperatures of the most important months of the growing period differ from normal in that the temperature of June was higher, but those of July and August lower than normal. The mean temperature of September, too, remains below normal.

Night frost occurred abundantly during the summer. In the night between the 12th and 13th of August a night frost of —5°C was recorded; it caused damage to the barley, but not to the oats. The night frost on 29—30. VIII (—5°C) caused damage to the oats as well. In the first part of September the night frosts continued (3—4. IX: —7.5°C, 5—6. IX: —10.5°).

Table 9. Temperature, rainfall and total radiation at Pelsonsuo during the growing period of 1956.

Taulukko 9. Kasvukauden lämpötila, sademäärä ja kokonaissäteily Pelsonsuolla 1956.

Month *Kuukausi*	Normal mean temperature, C° *Normaali keskilämpötila C°*	Rainfall, mm — *Sademäärä mm*			Number of rainy days *Sadepäivien lukumäärä*	Total radiation, cal/cm² *Kokonaissäteily cal/cm²*
		Deviation from normal *Poikk. normaalista*	Normal value *Normaali arvo*	Deviation from normal *Poikkeama normaalista*		
May — *Toukokuu*	5.9	+ 2.2	42	— 10	5	—
June — *Kesäkuu*	11.8	+ 2.8	61	— 30	10	12 883
July — *Heinäkuu*	15.2	— 0.4	71	— 1	12	12 804
August — *Elokuu*	12.3	— 1.3	77	— 65	23	9.150
September — *Syyskuu* ..	7.2	— 1.2	62	+ 27	13	—

c. Temperature of the soil and of the air next to the ground

The soil temperature was measured with the aid of thermocouples (cf. Pessi 1956, p. 17), the measuring depths being 5, 10 and 20 cm. Two thermocouples were used at each depth. The daily mean temperatures were computed as the mean of the observations at 8.00 a. m. and 8.00 p. m. The soil temperatures were measured in the whitened and unwhitened barley test plots which had not received any spraying.

Table 10 shows the soil temperature in the different test plots.

As has been mentioned before, the whitening of the oats test plots was not renewed, for which reason the differences in colour between the test members were not as pronounced as in the barley tests. Thus, also, the temperature differences between the different plots naturally did not attain the same magnitude as in the barley tests.

Table 10. Daily mean temperature in the cultivated layer at 5, 10 and 20 cm depth.
Taulukko 10. Vuorokauden keskilämpötila 5, 10 ja 20 cm:n syvyyksissä.

Depth, cm *Syvyys cm*	Plot *Koeruutu*	Temperature, C° — *Lämpötila C°*											
		1. VI.	9. VI.	15. VI.	21. VI.	2. VII.	13. VII.	21. VII.	1. VIII.	6. VIII.	15. VIII.	21. VIII.	29. VIII.
5	Unwhitened plot *Valkaisematon*	6.0	14.5	14.0	13.9	14.1	13.5	12.0	14.8	13.8	11.0	10.6	10.0
	Whitened plot *Valkaistu*	6.0	14.5	12.8	12.8	12.7	12.1	10.8	13.7	13.1	10.8	10.4	9.9
10	Unwhitened plot *Valkaisematon*	3.5	11.0	11.0	11.5	11.5	10.9	9.5	11.0	11.0	9.3	9.6	9.5
	Whitened plot *Valkaistu*	4.0	11.0	10.3	11.0	11.0	10.3	8.8	10.1	10.8	9.5	9.4	9.4
20	Unwhitened plot *Valkaisematon*	2.0	4.5	6.4	7.4	8.4	8.5	7.0	8.5	8.6	8.0	7.8	9.0
	Whitened plot *Valkaisematon*	2.0	4.5	6.4	7.4	8.2	8.5	7.0	8.3	8.5	8.1	7.8	9.0

Table 11. The influence of soil temperature upon the crop yield of oats. Variety: Kytö. Test area sown on 28. V., tillered on 9. VI. and cut on 22. IX. 1956.
Taulukko 11. Maan lämpötilan vaikutus kauran satoon. Lajike: Kytö. Kylvetty 28. V. Orastunut 9. VI. Niitetty 22. IX. 1956.

Treatment *Käsittely*	Grain yield, kg/ha relative *Jyväsato kg/ha suhdeluku*		Straw yield, *Olkisato* kg/ha	1 000-grain weight, g *1 000-jyvän paino g*	Strength of stalk *Korren lujuus*	Panicles appeared *Tuli tähkälle*
Whitened — *Valkaistu*	2 227	100	8 195	18.7	3	24. VII
Unwhitened — *Valkaisematon*	2 545	115	8 530	18.1	4	24. VII
Unwhitened sprayed — *Valkaisematon sadetettu*	2 438	110	8 700	18.7	3	24. VII

F value *E-arvo* 2,4°, Certain difference *Varma ero* 253 kg/ha, m % 3,3

Table 12. The influence of soil temperature upon the crop yield of barley. Variety: Tammi. Test area sown on 28. V., tillered on 8. VI. and cut on 7. IX. 1956.
Taulukko 12. Maan lämpötilan vaikutus ohran satoon. Lajike: Tammi. Kylvetty 28. V. Orastunut 8. VI. Niitetty 7. IX. 1956.

Treatment *Käsittely*	Grain yield, kg/ha relative *Jyväsato kg/ha suhdeluku*		Straw yield, *Olkisato* kg/ha	1 000-grain weight, g *1 000-jyvän paino g*	Strength of stalk *Korren lujuus*	Panicles appeared *Tuli tähkälle*	Germinating percentage *Orastumis-%*
Whitened —*Valkaistu*	2 850	100	5 500	30.6	6	13. VII	17.0
Unwhitened — *Valkaisematon*	3 160	110	5 180	32.5	6	10. VII	28.0
Unwhitened, sprayed — *Valkaisematon, sadetettu*	3 140	108	5 380	29.2	7	10. VII	17.5

F value *F-arvo* 10,6 ** Certain difference *Varma ero* 338 kg/ha, m % 3,5

Table 13. 1 000-grain weights in the test with 1 m^2 test plots.
Taulukko 13. 1 000-jyvän painot kokeessa, jossa koeruutujen koko 1 m^2.

Treatment *Käsittely*	1 000-grain weight, g *1 000 jyvän paino g*	
	Barley *Ohra*	Oats *Kaura*
Whitened — *Valkaistu*	29.2	16.1
Unwhitened — *Valkaisematon*	32.8	16.1
Unwhitened, sprayed — *Valkaisematon, sadetettu*	31.2	16.5

Air temperature measurements were made with the aid of minimum and maximum thermometers (R. Fuess). The minimum thermometers were provided with cylindrical radiation shields and the maximum thermometers with Budig shields (Pessi 1954). The thermometers (four replicates) were placed at the upper edge of the plant cover and close to the soil, at about 5 cm from the soil surface. However, these measurements were soon discontinued, as it was evident that no seemingly reliable air temperature differences could be observed.

d. Test results

The results from the whitening tests can be seen from Tables 11 and 12. Table 13 shows, moreover, the 1000-grain weights from 1 m^2 test plots which had been provided in parallel with the other test plots. The test results have been treated according to the methods of variation analysis.

In a study of the results the occurrence and effect of night frosts should be taken into account. It was established by means of tests performed relating to the time of cutting that the night frost on the night between the 12th and 13th of August reduced the germinating power of the barley, but not its crop yield. It had no effect upon the oats. On the other hand, the night frost at the end of August lowered the germinating power as well as the crop yields of both cereals. The severe night frost at the beginning of September completed the damage wrought by the two preceding night frosts.

3 4930—58/1,73

IV. Discussion of results and applications

One important inference can be drawn from the results of the tests described in the foregoing, namely, that also changes of soil temperature alone have an effect upon the rate of development of the plants. This circumstance has to be considered significant from a practical viewpoint. If we reflect on the degree in which we are able by means of cultivating techniques to influence the air temperature within the vegetation, with a view to speeding up the development of the plants, we find that our possibilities are very limited. It is true that we may affect the daily air temperature extremes, but whenever we succeed in raising the lowest night temperature within the plant cover, this results automatically in lower daytime temperatures. The thermal conditions of the air thus cannot be made such that the development of the plants would be accelerated.

On the other hand by increasing the soil temperature alone it is possible to quicken the development of the plants, and the practical application of this knowledge offers a variety of possibilities. It should be remembered that the soil temperature is dependent on the physical state of the soil, the density of the plant cover and numerous other factors that can be influenced by means of expedients of cultivating procedure.

On the basis of the tests described in the foregoing no definite conclusions are possible as to the significance of increased soil temperature with regard to crop yield in the case where the cereal has time to ripen completely before the earliest frosty nights in the autumn. On the other hand, it may be concluded that it has considerable practical significance whenever the crops do not attain the fully ripened stage prior to the occurrence of night frost. The differences in grain yield in the soil improving test arranged in 1952 (Table 1), for instance, are probably mainly due to the different stage of development of the plants at the time of occurrence of the first night frost, caused by the different soil temperatures. The differences in stage of development are also responsible, at least in part, for the differences in grain yield in the whitening tests in 1956, when the cereals were damaged by night frosts.

Since the soil temperature has significance in relation to the rate of development of the plants, knowledge of this temperature is useful in the interpretation of phenological occurrences and experimental results. A few examples are given in the following.

One of the factors affecting the soil temperature is the quality of the plant cover. In the summertime the effect of the plant cover is to prevent the soil from being warmed up (PESSI 1957); it is readily obvious that this effect is more pronounced accordingly as the plant cover is denser and more luxuriant. Thus it can be assumed that the soil temperature is lower under denser than under more sparse vegetation, with correspondingly slower development as a consequence. Let us consider two barley varieties, Pirkka and Tammi, having different stalk characteristics. Pirkka barley grows a long, luxuriant stalk, producing a dense and bushy vegetation, whereas Tammi barley has a short stalk and its vegetation has a distinctly less distinctive appearance. Table 14 shows the observations relating to the stages of development of both varieties, made in connection with the sowing time test carried out at the Frost Research Station in 1953. In the case of each sowing time the tillering occurred in both varieties after the same period of time, but differences are observable between the dates when the cereals began to bear heads. It can be seen from the times of complete ripeness that the growing time of Pirkka barley was longer than that of Tammi barley by 12 days in the test with the earliest seeding, and in the subsequent tests by 10, 4, 5 and 2 days respectively. As a rule, the growing time of Pirkka barley is considered to exceed that of Tammi barley by 2—4 days (SIEMENJULKAISU 1955). The considerably greater differences in connection with the earliest seedings can be given, for instance, the following explanation:

When the sowing is done early, tillering, too, will occur at an early date. The plants thus commence at an early date to shade the soil and to hinder it from being warmed up. Consequently, the soil temperature cannot rise to a similar level before tillering on areas sown at an early date as on those where the seeding has been done later. It can be said that the different effect of the vegetation of different varieties in preventing the heating of the soil is most distinctly evident in connection with early sowing.

It has also been established at the Frost Research Station that the most advantageous seed quantities under the conditions prevailing at the Research Station and presupposing proper growing power of the fields, are 140 and 120 kg of one-hundred-percent germinating oats and barley per hectare respectively. The advantageousness of such small seed quantities may be partly due to the effect of the quality of the vegetation upon the soil temperature.

Nitrogen fertilization has been found to have the effect of prolonging the growing time of cereals. This phenomenon, too, may be partly attributable to the influence of nitrogen fertilization upon the luxuriance of the vegetation, which, in turn, affects the soil temperature.

It is worth while in this connection to mention an observation made by AGERBERG (1954, p. 26) concerning the correlation between grass crops and the depth to which the ground freezes. He has noticed that grass crops decrease with increasing depth of the frozen ground layer. On the other hand, it is known that the depth of the frozen ground layer affects the soil temperature. One possible cause of the said correlation between the grass crop yield and the depth of the frozen ground might thus be found in the different soil temperature at the different depths of frozen ground.

Table 14. Stages of development of barley crops sown at different times at Pelsonsuo, 1953. Varieties: Pirkka and Tammi.

Taulukko 14. Eri aikoina kylvetyn ohran kehitysvaiheet Pelsonsuolla 1953. Lajikkeet: Pirkka ja Tammi.

Variety *Lajike*	Sown on *Kylvetty*	Tillered on *Orastanut*	Panicles appeared on *Tuli tähkälle*	Completely ripened on *Täystuleentunut*
Pirkka	2. V	19. V	28. VI	19. VIII
Tammi		19. V	25. VI	7. VIII
Pirkka	9. V	22. V	1. VII	21. VIII
Tammi		22. V	27. VI	11. VIII
Pirkka	16. V	27. V	2. VII	21. VIII
Tammi		27. V	30. VI	17. VIII
Pirkka	23. V	5. VI	8. VII	27. VIII
Tammi		5. VI	4. VII	22. VIII
Pirkka	30. V	7. VI	10. VII	29. VIII
Tammi		7. VI	8. VII	27. VIII

Summary

In the investigation the kind of plant cultivating tests arranged at the Frost Research Station at Pelsonsuo are described, from which observations can be made and inferences can be drawn with regard to the significance of the soil temperature in respect to the rate of development of barley and oat plants and their crop yield. The discussion is based on soil improving tests and on tests in which soil temperature differences have been produced by means of artificially induced differences in the colour of the soil surface. In the first-mentioned tests coarse sand has been used as a soil improving agent in admixture to cultivated bog soil, while in the latter tests the soil surface has been whitened by spreading barium sulphate powder.

It was found in the investigation that the rate of development of the plants can be accelerated merely by raising the soil temperature. Since the tests were performed under the usual agricultural conditions, this also proves the thermal conditions of the cultivated bog areas of the Research Station to be so scantily sufficient that the said measure has a practical effect in the prevailing circumstances. Consequently, this factor possesses significance with regard to the grain yield of cereals, at least in cases where night frosts occur at such an early date that the plants are damaged.

Since the density and luxuriance of the vegetation affects the soil temperature, consideration is made of the significance possibly attached to knowledge of the thermal conditions in the soil in an interpretation of phenological phenomena and test results, for instance, when inferences are drawn from these with regard to factors influencing the growing time of cereal plants.

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Selostus

Maan lämpötilan merkityksestä kasvinviljelyssä

Yrjö Pessi

Maatalouden tutkimuskeskus
Hallakoeasema, Pelsonsuo

Tutkimuksessa on selostettu sellaisia hallakoeasemalla Pelsonsuolla järjestettyjä kasvinviljelyskokeita, joiden perusteella voidaan tehdä havaintoja ja päätelmiä maan lämpötilan merkityksestä ohran ja kauran kehityksen nopeudessa ja sadossa. Tarkastelu on suoritettu maanparannuskokeiden sekä sellaisten kenttäkokeiden perusteella, joissa maan lämpötilaerot on aikaansaatu maan pinnan värieroilla. Ensin mainituissa kokeissa on käytetty suoviljelyksen maanparannusaineena karkeata hietaa, jälkimmäisissä kokeissa maan pinnan valkaisemiseen bariumsulfaatti-jauhetta ($BaSO_4$).

Tutkimusten perusteella todettiin, että yksinomaan maan lämpötilaa kohottamalla voidaan jouduttaa kasvien kehitystä. Kun kokeet suoritettiin tavanomaisissa viljelysolosuhteissa, merkitsee se samalla sitä, että koeaseman suoviljelyksillä on maan lämpötila siksi alhainen, että toimenpiteellä on vaikutusta näissä olosuhteissa. Seikalla on vaikutusta näin ollen viljojen jyväsatoihin ainakin silloin, kun halloja esiintyy siksi varhain, että kasvit vaurioituvat.

Kun kasvuston tiheydellä ja rehevyydellä on vaikutusta maan lämpötilaan, tarkasteltiin tutkimuksessa, mikä merkitys maan lämpöolojen tuntemisella saattaa olla fenologisten ilmiöiden ja koetulosten tulkinnassa esim. silloin, kun tehdään päätelmiä kasvuaikaan vaikuttavista tekijöistä.