A NOTE ON VEGETATION TEMPERATURES ABOVE THE TIMBER LINE IN SOUTHERN NORWAY

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SUMMARY

Surface temperatures of dwarf shrubs and other components of Norwegian fjell vegetation were measured with an infrared thermometer of simple construction.

With strong solar radiation, temperatures varied between 2°C (cold spring) and 63°C (ant hill). Dwarf shrubs like *Loiseleuria* had temperatures up to 20°C above air temperature.

From heat budget considerations the conclusion is drawn that the fjell vegetation transpires rather slowly and transforms most of the absorbed energy into heat.

The possible importance of the high vegetation temperatures is discussed.

1. INTRODUCTION

In an earlier paper (STOUTJESDIJK 1966) it was shown that in a low mosaic vegetation like a dune grassland, surface temperatures of soil and vegetation can differ greatly from one point to another, or, in other words, that the mosaic-like diversity shown by the vegetation cover is reflected in the temperature pattern. These differences are due to differences in vegetation structure, water economy, and small-scale exposure effects of the patches.

From visual observations it was concluded that the vegetation of the Norwegian fjells would form a very interesting subject for this kind of studies. The fjells are extensive plains or slopes above the timber line. Important elements of the vegetation are small shrubs like *Betula nana* and *Juniperus communis*, "cushion" plants like *Loiseleuria procumbens* which as it were form part of the surface, and patches of lichens and mosses. In depressions there is peat formation resulting in a surface structure of tussocks and crevices, presenting on a small scale all kinds of extreme exposures.

Furthermore under the prevailing climatic conditions it may be expected that temperature is often in the minimum for plant development, and the actual temperatures that can be reached by plants become of great interest (*cf.* WARREN WILSON 1957).

The measurements were made in July 1966 at Høvringen at an altitude of 1200 m and at 62° N. Lat. DAHL (1956) has given an extensive description of the vegetation in this area and its ecological aspects.

2. METHOD

The measurements were made with a radiometer measuring the heat radiation emitted by a surface, and thus indirectly the surface temperature (STOUTJESDIJK 1966). The instrument measures the mean temperature of a surface. At a distance of 20 cm the field of view has a diameter of 10 cm.

3. DISCUSSION OF MEASUREMENTS

In *fig. 1* the structure of the main components (from our point of view) of the vegetation is given in a semi-schematic way. The horizontal lines indicate the ambient air temperature. The length of the vertical lines gives the difference between vegetation temperature and ambient temperature which is called Δt. The measurements were all made with a high sun (50°).

A characteristic feature of the area are the cold springs (2 °C), as described by Dahl, with their bright green vegetation of *Philonotis fontana.*

The first scheme shows the temperatures of such a spring and its surroundings. At the foot of the moss stems the temperature is 3 °C. Yet the surface temperature of the moss is up to 23 °C, *i.e.*, 6 °C above air temperature. It is remarkable that the moss is dry at its surface but not desiccated .This means that through the stems of the moss, about 4 cm high, the water is transported at a sufficient rate to keep pace with transpiration. The water transport seems to be less primitive than in most other mosses which are either wet at the surface or desiccated.

The second scheme of *fig. 1* represents a small bog with tussocks and crevices with differences in height of a few decimeters. The humid *Sphagnum* at the South side of the tussock has a temperature of 14 °C above air temperature. Where the *Sphagnum* is somewhat less South-exposed, Δt is only 10 °C. On the top of the tussock the dry lichens have a temperature of 40 °C, that is, Δt is 22 °C. The North side of the tussock is damp and receives no direct solar radiation; Δt is negative here. At the bottom of the crevice the surface temperature is nearly 10 °C below air temperature. This may be partly due to thermal inertia of the soil. Furthermore the radiation energy budget at the bottom of the crevice is probably negative. The sky was clear and cloudless and, as shown by measurements, it behaved thermally like a dome with a temperature of —21 °C. Moreover, under these conditions diffuse solar radiation is weak. It is therefore very probable that the heat radiation from the bottom of the crevice was not compensated by heat radiation from the sky plus diffuse solar radiation. That indeed a negative radiation balance may exist under similar conditions in full summer was confirmed by measurements in the Netherlands, where the diffuse light is still stronger than at higher altitudes in Norway.

An excessively high temperature is reached on the South slope of an ant-hill which is exposed at a steep angle to the sun's rays. The favourable exposure combined with the strongly isolating material of dry plant remains makes a Δt of 45 °C possible. The ant-hills in the area are usually built as sketched. The North slope is uninhabited and covered with vegetation. The South slope is covered in the usual way with dry leaf fragments etc. It must be mentioned that at the time of measurements the surface was deserted by the ants.

For comparison we mention measurements by Turner (*cf.* AULITZKY 1960) who measured at the timberline in the Austrian Alps a surface temperature of 80 °C with an air temperature of 27 °C. The measurements were made on a steep SW slope covered with raw humus. VAARTAJA (1949) measured 63 °C on raw humus in southern Finland.

WARREN WILSON (1957) cites Sørensen who measured a surface temperature of 49 °C at a latitude of 73 °NL, the air temperature was 16 °C. The measurements of Turner and Sørensen were taken slightly below the surface, so the true surface temperatures must have been somewhat higher still.

Very important elements of the vegetation are the dwarf shrubs and the lichens. The temperatures are all considerably above air temperature, especially of the lichens and of those dwarf shrubs which are pressed against the surface. A *Loiseleuria* cushion reaches a temperature of 30 °C with an air temperature of 10 °C. A patch of lichen has a temperature of 25 °C above air temperature. The dwarf shrub cushions are so dense that the temperatures given are actual plant temperatures and not a mean value between soil surface temperature and plant temperature proper.

Temperature measurements of cushion plants were also made by BIEBL (1968) in W. Greenland (68 °N.). By means of a contact temperature probe he measured temperatures between 12 °C (*Silene acaulis*) and 17 °C (*Dryas integrifolia*) above air temperature.

These rather high temperatures must be partly due to the compressed growth form which makes heat transfer to the air more difficult, partly to a low transpiration. An impression of the low transpiration intensity of the dwarf shrubs can be obtained by comparing their temperatures with those of a dry lichen mat. When the latter is dried out down to the raw humus layer it may be assumed that the evaporation is very small indeed and we may put:

$$R_{net} = \alpha \, \Delta t$$

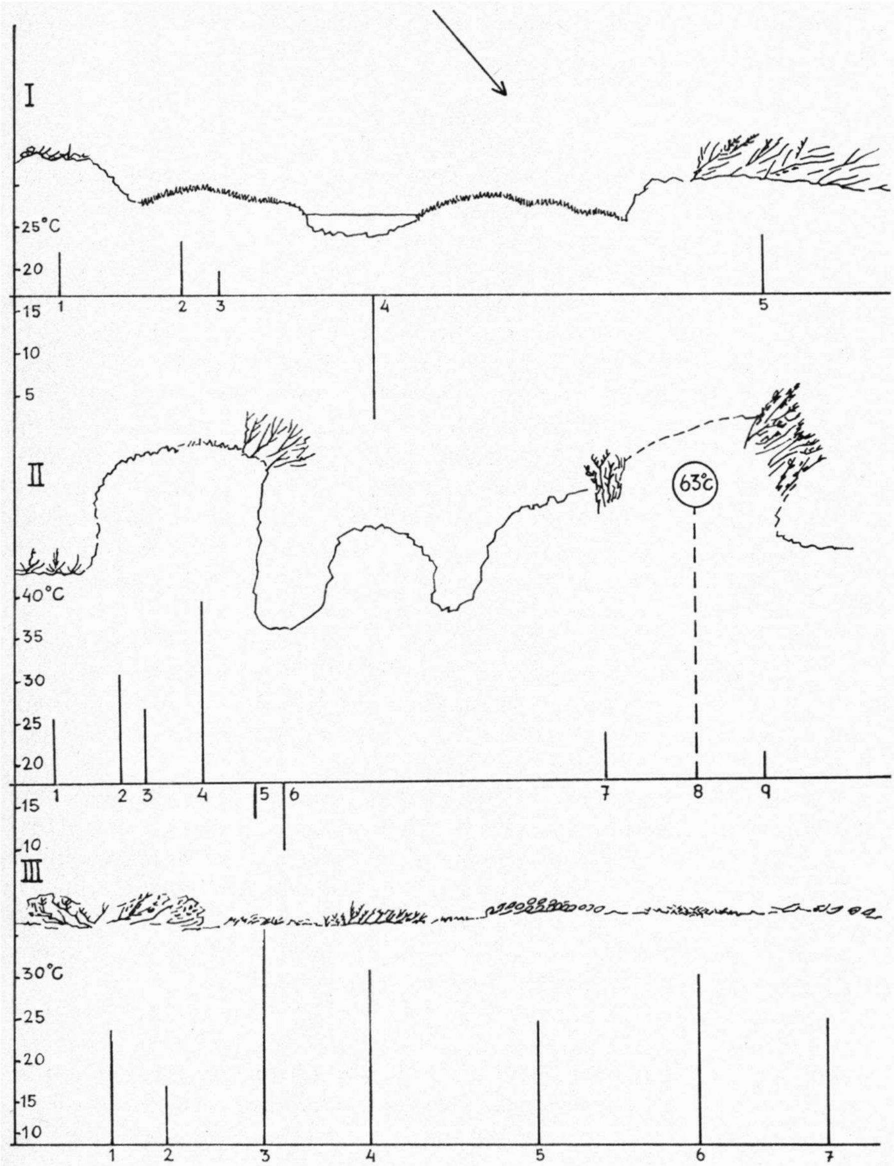
R_{net} being the net amount of radiation absorbed by the surface and α the heat transfer number (STOUTJESDIJK 1966). When the heat transfer number and R_{net}

Fig. 1. Semischematic profiles of the vegetation elements studied. Length of vertical lines indicates temperature difference vegetation-air. Horizontal lines represent air temperature at 1 m height. The arrow gives the angle of incidence of the solar radiation. The measurements of each series (I, II, III) were taken simultaneously. All measurements were made under comparable conditions: nearly cloudless, low wind velocity, high altitude of sun.

I 1. Carices and Gramineae, 2. and 3. *Philonotis fontana*, 4. Cold spring, 5. *Juniperus communis*.

II 1. *Nardus stricta*, 2. and 3. *Sphagnum* spec. (damp), 4. Lichens (dry), 5. shadow-side of tussock, 6. Crevice, 7. and 9. *Vaccinium uliginosum*, 8. Ant-hill.

III 1. Dead centre of *Betula nana* patch with lichens and mosses, 2. Living *Betula nana*, 3. Lichens: *Cetraria islandica*, *Stereocaulon alpinum*, and *Cladonia* cf. *rangiferina*, 4. *Empetrum hermaphroditum*, 5. *Arctostaphylos uva-ursi*, 6. *Loiseleuria procumbens*, 7. *Arctostaphylos alpina*.


I
25°C
20
15
10
5
1
2
3
4
5
II
63°C
40°C
35
30
25
20
15
10
1
2
3
4
5
6
7
8
9
III
30°C
25
20
15
10
1
2
3
4
5
6
7

are the same for the lichens and the dwarf shrubs we can write for the dwarf shrubs

$$R_{net} = \alpha \Delta t + E$$

in which E is the energy used in evapotranspiration.

Comparing the *Loiseleuria* patch with a Δt of 20 °C with the lichens with a Δt of 25 °C we can estimate in this way that the dwarf shrub gives 20/25 of the net absorbed energy as heat to the air and uses the rest, 20%, for transpiration.

In the same way we estimate for patches of *Arctostaphylos uva-ursi* (III 5) and *A. alpina* (III 7) that about 60% of R_{net} is given to the air and 40% is used in transpiration. A comparison of dead, hence non-transpiring patches of dwarf shrub with living ones gave similar results. A short grass vegetation with a Δt of 5 °C (not shown in the scheme) by the same reasoning uses about 80% of R_{net} for transpiration. Of course the values given leave some doubt. R_{net} may differ owing to differences in reflectivity for solar radiation. The structure of the surface which absorbs the solar radiation is also of importance. This is doubtless the main reason why a dry loose lichen mat does not reach a Δt which is as high as that of a compact raw humus layer. Furthermore α depends upon surface properties. Still we think the values given are acceptable as first approximations, the more so as a comparison of dead (non-transpiring) patches of dwarf shrub with living ones gave similar results.

The vegetation temperatures of *Juniperus communis* and *Betula nana* are not as high as those of the lower dwarf shrubs. This does not necessarily mean that they transpire more strongly. The smaller Δt is probably mainly due to the greater height and the looser growth form of the vegetation, which make heat transfer easier, i.e.: α is higher and Δt lower.

Estimates of transpiration intensities of alpine dwarfshrub communities were made by PISEK & CARTELLIERI (1941). They calculated that an alpine dwarf heath uses 30–52 mm water in a summer month as compared with 101 mm for grassland and 376 mm for wet grassland. The estimates are based on transpiration of cut shoots. The figure for wet grassland seems too high to be energetically possible, but we may safely conclude that alpine dwarf shrub is a weakly transpiring vegetation in relation to the energy absorbed.

In Alaska, BLISS (1960) measured the transpiration of shoots of *Betula nana* and other small shrubs by means of potometers. The measurements indicate that only a small fraction of the solar radiation absorbed is used for evaporation.

In a few plants with sufficiently large leaves, leaf temperatures were measured. The results show that the leaves can reach a considerable difference with the air temperature.

Plant species	Δt leaf-air
Caltha palustris	8.8 (dry leaf: 10.5 °C)
Aconitum alpinum	11.7 leaves slightly S-exposed
Rubus chamaemorus	14.7 leaves slightly S-exposed
Salix glauca	9.4 leaves slightly S-exposed
Geum rivale	13.7 leaves slightly S-exposed

For the *Caltha* leaf the comparison of a dry leaf with a transpiring leaf shows that transpiration uses only a small part of R_{net}. For *Rubus, Salix,* and *Geum* the temperatures of the transpiring leaves could not be compared with non-transpiring leaves owing to the strongly changing conditions but the high Δt values measured indicate that transpiration must have been weak.

Wilson found that leaf temperatures of *Salix arctica* were up to 6.5 °C above air temperature, but usually Δt was less. The leaves were placed at right angles to the sun's rays. Wilson stated that the thermocouples used by him are likely to underestimate Δt.

Biebl measured a Δt of 4 °C on *Salix glauca* leaves.

4. ENERGY BALANCE OF THE FJELL VEGETATION

From the measurements on the different components of the vegetation and an estimate of the relative surfaces taken in by them we can construct a rough picture of the heat- and water-economy of the fjell vegetation as a whole.

Vegetation component	Coverage	Part of R_{net} given to air as heat
Lichens (when dry)	50%	90%
Dwarf shrubs	25%	60%
More strongly transpiring vegetation (swampy spots etc.)	25%	20%
	Weighted mean	65%

Of course this picture is only valid when the lichens are dry since by the large surface they occupy they have such a dominant influence on the mean. When they are wet a high evaporation can be expected and much less than 65% of R_{net} is given to the air as heat.

For the dry vegetation we assume the estimated 65% to be rather too low than too high. When we take into account that it is considered as normal that 15–25% of R_{net} is given to the air as heat by a "closed green crop never short of water" (PENMAN 1963), the fjell has a very unusual heat- and water-economy. Compared with the "normal" vegetation three to four times more heat is given to the air. In spite of the fact that there is no shortage of water only a rather small fraction of the available energy is used in evaporation.

When a vegetation uses a large part of the energy budget for heating the air, higher air temperatures can be expected than over a "normal" vegetation. How much higher is difficult to estimate. Over Dutch heaths we found that at 2 m height the air temperature was about 2 °C higher than over grassland in the neighbourhood (STOUTJESDIJK 1959). An upper limit of the effect on the fjell is probably given by the observation that when a cloud shades the surface the air temperature suddenly drops by about 5 °C. Overheating of the lower layers of the air also results in a great instability of the air, a strong exchange of hot air with cool air from higher layers. This process limits the amount of overheating that can occur.

The strong unrest of the air near the surface can be visually observed by the shimmering of the air and the frequent occurrence of small whirlwinds. These effects are also observed on Dutch heathlands, and Warren Wilson reported the eddies for Jan Mayen.

5. BIOLOGICAL SIGNIFICANCE OF HIGH PLANT TEMPERATURES

It has been proposed that by the cooling effect of transpiration plants can keep their temperatures below the lethal level in warm climates. On the other hand one might regard the rather high plant temperatures on the fjell, especially of the cushion plants, as an adaptation to low air temperatures.

In this connection it is interesting to compare the present measurements with those of LANGE (1959) in the Sahara. Lange found that leaves of a Cucurbitaceae (*Citrullus colocynthis*) in full sunlight had a temperature of 37 °C with an ambient air temperature of 50 °C. On the fjell a patch of *Loiseleuria* can have a temperature of 30 °C with an air temperature of 10 °C.

Of course under warmer conditions high temperatures are also reached by plants that grow appressed to the surface and have a low transpiration. But what is inevitable in one case is a necessity in the other.

The high Δt's of the fjell vegetation should not be considered in relation to conditions in full summer only. Shortly after the snow has molten the air temperature is only a few degrees above zero, while solar radiation is already strong and cloudless periods are longer than later in the year. The overheating may be of vital importance at this time of the year.

Furthermore it seems possible that even short periods of a higher temperature may be of importance in certain phases of development, be it true that in botanical literature only the effect of daily temperature changes is discussed. (KNAPP 1956). RICHARDS (1957) mentions experiments in insect development where a few hours daily at a higher temperature are required and sufficient for normal development.

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