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Temperature of Norway spruce and Scots pine buds*

INTRODUCTION

Effect of solar radiation on the thermal conditions of various plant organs is of considerable importance in the physiology of plants. Majority of papers on this subject concern studies on the energy balance of leaves (Gates, 1968; Perttu, 1971). Much less information is available about the thermal changes taking place in buds of woody plants (Landsberg et al., 1974).

According to many authors the generative development of coniferous trees is to a large extent dependent on temperature (Tiren, 1935; Baxter, 1972; Giertych and Królikowski, 1978). In order better to know the mechanism in which temperature acts on the process of flower formation it is necessary to know the thermal conditions occurring in buds.

In natural conditions the temperature of buds will depend on such factors as the magnitude of absorption of solar radiation, and the magnitude of heat emission by radiation, convection, conduction and transpiration. Only black objects absorb all the incident solar radiation. It was shown that plant organs are capable of absorbing only a certain range of solar radiation while the remainder is reflected or passes through (Larcher, 1975). Emission of radiant energy concerns the exchange of heat with the nearest surrounding as well as with distant objects and the stratosphere. Amount of heat emitted by buds will be proportional to their temperature and their emissive capacity. For leaves the emissive capacity is given as being arround 0.95. Further loss of heat by buds may occur through convection and conduction. A bud in contact with air is surrounded by a zone it can influence thermally by convection. This closest zone of thermal exchange is referred to as the boundary layer (Salisbury and Ross, 1969). Magnitude of the

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boundary layer will decline with a decrease in the size of the object and with an increase in the rate of air movement. Loss of heat by conduction is likely to be small since plant tissues are poor conductors.

The role of transpiration in the regulation of air temperature is well known (P a l l a s et al., 1967) but we know little about the role of this factor in regulating the temperature of buds. One can suspect that the cooling effects of transpiration will also occur in buds but to a lesser degree than in leaves.

Temperature of buds, leaves and other plant organs is rarely the same as that of the surrounding air. L a r c h e r (1975) reports that during strong radiation on a tropical day the temperature of a leaf may be 26.4°C higher than that of the air. At the time transpiration cooled by 3.0°C. On a more moderate day when the temperature difference was 15.9°C the transpiration cooling amounted to 1.3°C.

MATERIALS AND METHODS

Measurements of temperature in the buds of Norway spruce (*Picea abies* (L.) Karst) were conducted in two 7 year old grafts growing 20 m away from the Institute of Dendrology building and on a 100 years old tree growing in the Kórnik Arboretum. The temperature of Scots pine (*Pinus sylvestris* L.) was measured on an 18 years old individual growing in conditions of limited insolation since south of it there grew trees of similar dimentions as the measured tree.

Temperature was measured with the help of miniature copper-constantan thermocouples 0.2 mm in diameter. Always one thermocouple

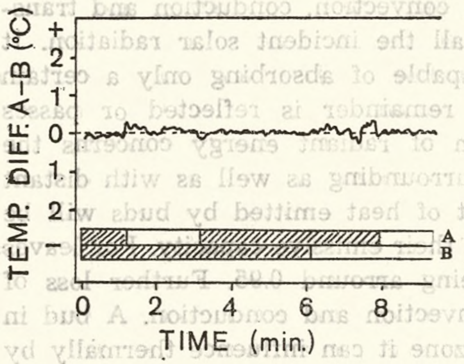

Fig. 1. Measurement of temperature difference between two linked thermocouples. Tips of the thermocouples A and B were in the sun of shaded under a minute umbrella as indicated below

was placed delicately into a bud and the second control one was positioned in air about 1.0 to 1.5 cm from the measured bud. In this way the thermocouples were localized in various parts of the crown relative to cardinal directions and tree height.

The temperature was recorded automatically using a 12 channel registrator (eKNT-12) and a continuous recorder (TZ 21S). Studies were conducted in the summer months of 1977 and 1978.

The method of measurement of air temperature employed is sufficiently accurate. Error in the measurement under direct insolation was of the order of ± 0.2°C (Fig. 1), and placing one thermocouple under shade relative to the other by using a minute umbrella has had practically no effect on the temperature difference. On the other hand placing the thermocouple tip in a shaded box (comparable to meteorological records) created a zone of cooled air that did not correspond to the conditions existing in the direct proximity of an insolated bud.

RESULTS

During a sunny day bud temperature in Norway spruce and Scots pine is higher than that of the air around it. On the other hand during a cloudless night the temperature in the buds is frequently lower than that of the air (Fig. 2). Southern buds attain during sunny days a higher temperature, by up to 6.0°C while in the night they may have a lower one by about 1.0°C (Fig. 3). Measurements conducted over many months have shown that the magnitude of the temperature in the buds depends primarily on insolation. The correlation coefficient between temperature

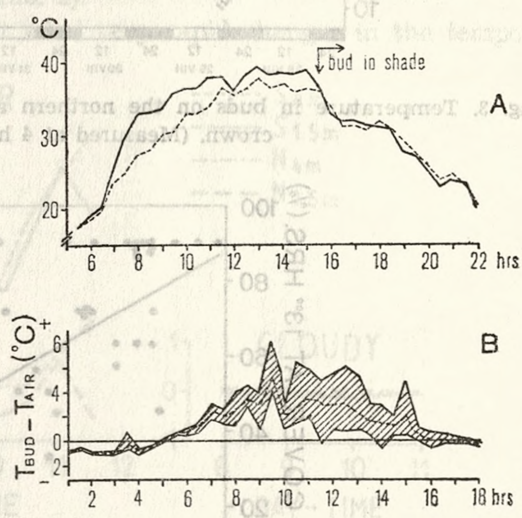

Fig. 2. A. Mean daily temperature fluctuations in a spruce bud ——— and air — — — and B hourly fluctuations in the magnitude of temperature difference between a spruce bud and the air around it

differences (T_{bud} — T_{air}) in spruce and the percentage cloudiness as estimated at the nearest meteorological station (100 m away) was highly significant, $r = -0.51$ (Fig. 4).

The greatest temperature difference recorded between a bud and a surrounding air occurred for the spruce graft and it was 7.5°C (Tab. 1). A similar value was recorded for Scots pine. In August in a pine

Table 1

Highest bud temperatures observed in natural conditions in °C

Plant and crown position	Maximal noon temperature in bud	Air temperature at the time	$T_{buds} - T_{air}$
Spruce graft			
$S_{exp.}$	31.0	23.5	+7.5
Spruce mature tree			
$S_{exp.}$	31.2	26.0	+5.2
$N_{exp.}$	25.9	24.3	+1.6
Pine mature tree			
$S_{exp.}$ 4.0 m	35.0	29.5	+5.5
S_{exp} 1.5 m	35.5	28.5	+7.0
$N_{exp.}$ 4.0 m	33.5	28.5	+5.0
$N_{exp.}$ 1.5 m	29.5	25.0	+4.5

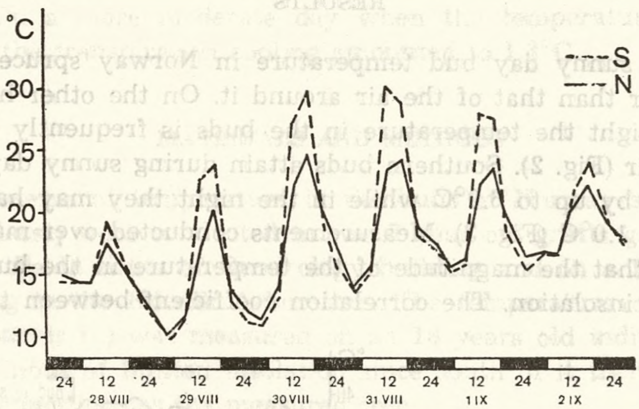

Fig. 3. Temperature in buds on the northern and southern side of a spruce tree crown. (Measured at 4 hr. intervals)

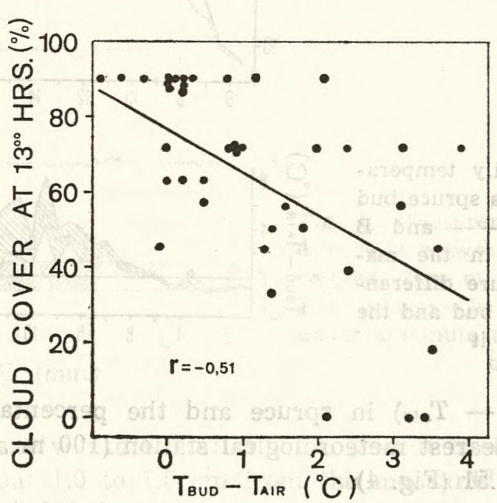

Fig. 4. Relationship between percentage cloud cover at 1300 hrs and the value of temperature difference between bud and air in the southern part of the crown in August and September

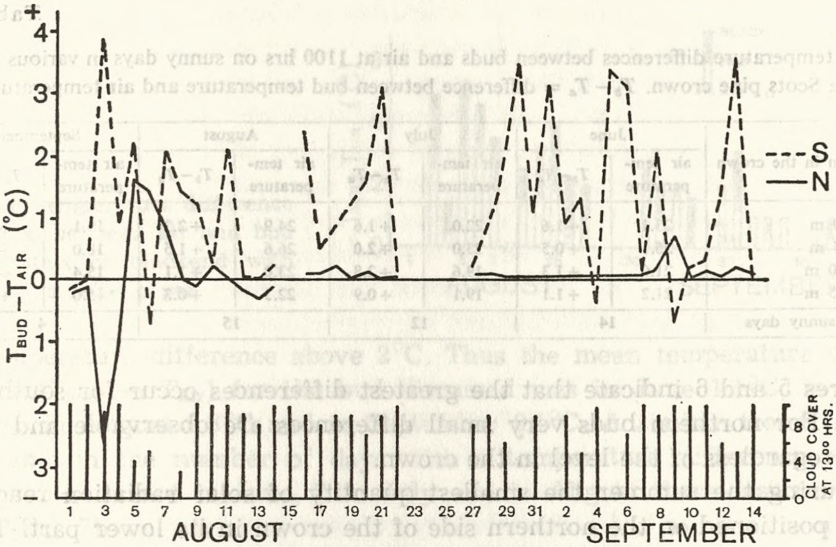

Fig. 5. Difference in temperature between bud and air at 1300 hrs on the southern and northern side of a spruce tree crown

bud located on the southern side of a tree crown the highest temperature recorded was 35.5°C, while air temperature at the time was 28.5°C thus the difference was 7.0°C (Tab. 2).

On sunny days, with a slight wind very rapid changes in the tempe-

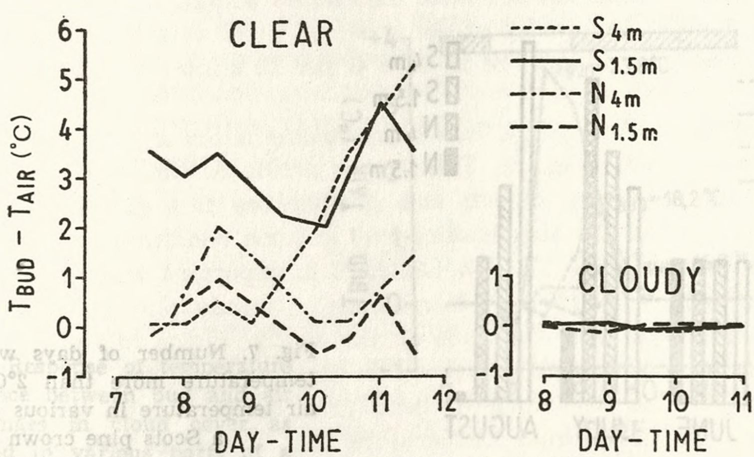

Fig. 6. Difference in temperature between bud and air in various positions of a Scots pine crown under a clear or cloundy sky

rature differences are observable, sometimes of the order of 5.0°C within the space of 20 s.

The magnitude of the difference in temperature between bud and air is much affected by the position of the bud in the crown of the tree.

Table 2

Mean temperature differences between buds and air at 1100 hrs on sunny days in various parts of a Scots pine crown. $T_b - T_a$ = difference between bud temperature and air temperature

Position in the crown	June		July		August		September	
	air temperature	$T_b - T_a$	air temperature	$T_b - T_a$	air temperature	$T_b - T_a$	air temperature	$T_b - T_a$
$S_{exp.}$ 4.0 m	23.1	+1.6	22.0	+1.6	24.9	+2.3	19.1	+1.4
$S_{exp.}$ 1.5 m	25.1	+0.5	23.0	+2.0	26.6	+1.5	18.0	+2.1
$N_{exp.}$ 4.0 m	21.0	+1.3	19.6	+2.8	23.0	+1.1	15.4	+1.1
$N_{exp.}$ 1.5 m	21.2	+1.1	19.1	+0.9	22.3	+0.3	15.0	+0.1
No. of sunny days	14		12		15		4	

Figures 5 and 6 indicate that the greatest differences occur for southern buds. For northern buds very small differences are observable and this is so regardless of the level in the crown.

During the summer the smallest quantity of solar radiation reaches buds positioned on the northern side of the crown in its lower part. This is indicated both by the low mean air temperature near these buds and the low temperature differences between bud and air in various months (Tab. 2).

In June a similar number of days was observed with a temperature difference above 2°C in all parts of the crown (Fig. 7). In that month also the mean values of the temperature differences are similar, except for the bud located on the southern side in the lower crown, for which

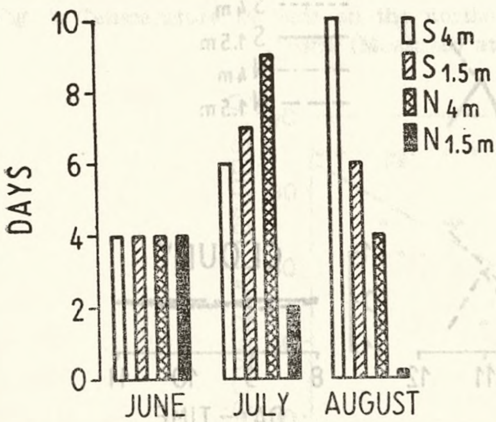

Fig. 7. Number of days with bud temperature more than 2°C above air temperature in various parts of a Scots pine crown

the temperature difference is 1.0°C lower than in remaining buds (Tab. 2). This is probably associated with the angle at which sun rays fall on the whole tree, in June parallel with its axis and in later months at some greater angle. On the example of the northern bud located at the bottom it can be clearly seen how the changing angle of sun rays falling on the tree affects the temperature of buds and the mean number of days with

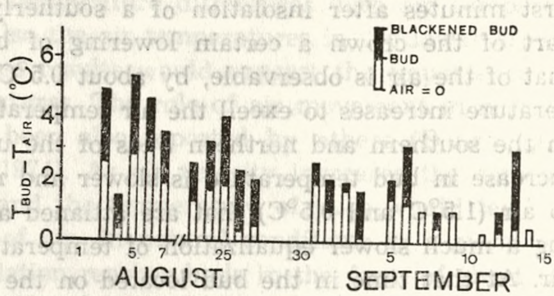

Fig. 8. Temperature difference at noon between air and bud left intact or blackend with a felt-tip pen

a temperature difference above 2°C. Thus the mean temperature difference (T_{bud} — T_{air}) for the bud discussed was in June 1.1°C, in July 0.9°C, in August 0.3°C and in September 0.1°C. A similar trend is observable in the number of days with a temperature difference above 2°C which was 4 in June, 2 in July and in August there was no such day (Fig. 7).

The thermal balance in the buds is no doubt affected by the colour of the buds that cover them and which changes with the vegetative season.

In order to demonstrate how one can artificially alter the temperature of buds by changing their colour a study was made of temperatures in buds following painting them black. It turned out that on a sunny day the temperature in blackened buds is increased relative to con-

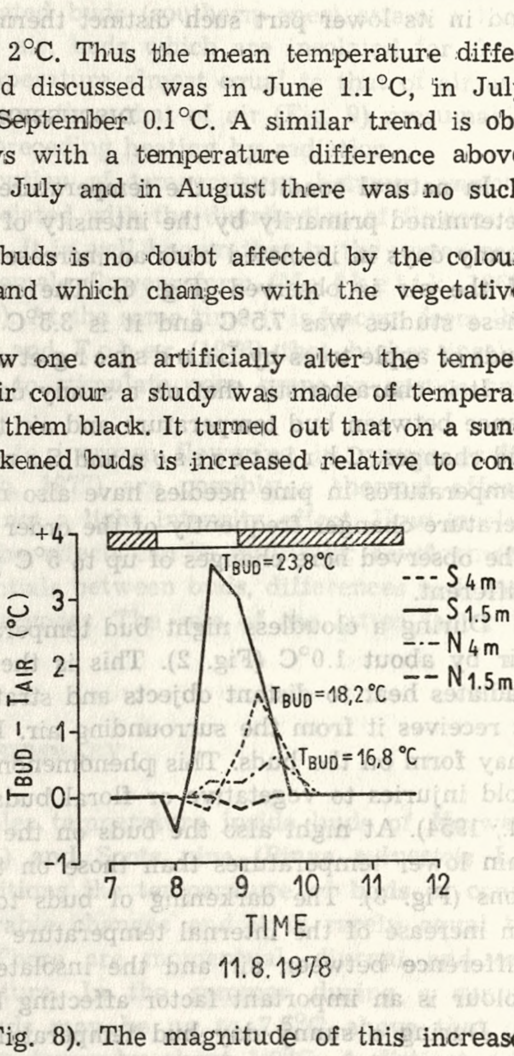

Fig. 9. Response of temperature difference between bud and air to changes in cloud cover as recorded in various parts of a Scots pine crown

trols by an additional 2.0°C (Fig. 8). The magnitude of this increase does not appear to be correlated with the values of temperature differences with air for the non blackened buds.

An important factor to consider concerning bud temperatures is the magnitude and rapidity of changes occurring in these organs. In the first minutes after insolation of a southerly located bud in the lower part of the crown a certain lowering of bud temperature relative to that of the air is observable, by about 0.5°C, but then quickly the temperature increases to excell the air temperature by about 3.5°C (Fig. 9). In the southern and northern buds of the upper part of the crown the increase in bud temperature is slower and maximal differences relative to air (1.5°C and 0.5°C) that are attianed are much lower. After shading a much slower equalization of temperature is obtained with that of air. At that time in the bud located on the northern part of the crown and in its lower part such distinct thermal changes are not observable.

DISCUSSION

In natural conditions the temperature of buds of coniferous trees is determined primarily by the intensity of solar radiation. Always during sunny days in insolated buds an increase of temperature relative to that of the air is observed (Fig. 6). The maximal difference observed in these studies was 7.5°C and it is 3.5°C higher than that reported for buds of apple trees by Landsberg et al. (1974).

It is characteristic that on a sunny day with a slight wind the difference between bud temperature and air temperature undergoes very rapid changes. Christersson and Sandstedt (1978) who registered temperatures in pine needles have also noted a high frequency of temperature changes frequently of the order of 7.0°C over a period of 5.7 s. The observed here changes of up to 5°C per 20 s intervals are not much different.

During a cloudless night bud temperature is lower than that of the air by about 1.0°C (Fig. 2). This is the result of the fact that a bud radiates heat to distant objects and stratosphere at a greater rate than it receives it from the surrounding air. In such conditions dew or frost may form on the buds. This phenomenon is important when considering cold injuries to vegetative or floral buds of woody plants (Rogers et al., 1954). At night also the buds on the southern side of the crown attain lower temperatures than those on the northern, for the same reasons (Fig. 3). The darkening of buds towards the winter may lead to an increase of the internal temperature (Fig. 3) and of the temperature difference between air and the insolated bud (Fig. 5 and 7), because colour is an important factor affecting bud temperature (Fig. 8).

During a sunny day bud temperature is strongly dependent on its location within the tree crown (Fig. 6). Differences between individual buds may be of the order of 5.5°C. Generally for most of the day higher temperatures occur in buds located on the southern side of a tree (Fig. 3). At the same time on the southern side buds located in the lower crown when insolated have higher temperature differences with air compared to the upper ones (Fig. 6). Also the air temperatures in the lower crown can be higher (Tab. 2). These results would suggest the importance of wind velocity on air temperatures. The role of air movement in regulating bud temperatures has been also reported by others (Burrage, 1971; Landsberg et al., 1974). As air velocity increases the convection losses of heat increase and the temperature of buds would tend to become more equal to that of air. In natural conditions in a stand we often observe that solar radiation reaches buds in the form of short lasting flashes. Thus while insolated buds (southern ones) attain a high temperature relative to that of air, buds which are insolated for short periods of time will have a temperature almost equal to that of air and sometimes even temporarily lower than that of air (Fig. 9) presumably due to increased transpiration preceding heating by radiation.

This zonality in the distribution of temperatures between various parts of the crown may be associated with the distribution of flowers in the crowns of spruces and pines. It is well known that in the upper part of the crown generally more female flowers form (Muśketik, 1960; Fraser and McGuire, 1969). At the same time it is known from the studies of Chałupka (1975) and Fober (1976) that higher insolations and temperatures appear to stimulate cone crops in spruce and pine.

Polyethylene covers known to increase flowering in spruce grafts (Chałupka and Giertych, 1977) are possibly a thermal effect, may be a humidity effect, but not a light intensity effect. How insolation acts we do not know and the effects can be multifold: development of differences in electrical potentials between buds, differences in transpiration rates and thermal differences. The role of the latter factor is probably most important here.

SUMMARY

Using miniature thermocouples temperature inside buds of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) was measured. In natural conditions the temperature of buds of coniferous trees undergoes considerable changes and it is rarely equal to that of the surrounding air. There are momentual, diurnal and seasonal fluctuations of temperature. In the summer during a sunny day the temperature in the buds may be up to 7.5°C above that of the air, while at night in can be lower by about 1.0°C. A distinct differentiation occurs also within various zones of the tree crown. On sunny days as well as throughout the season most energy reaches the southern buds and least reaches the lower crown. The differences be-

tween temperature of southern buds and air increase towards the autumn, possibly as a result of the bud scales becoming darker. The relation between bud temperatures and their development into flower buds in pine and spruce is discussed.

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Temperatura pąków świerka pospolitego i sosny zwyczajnej

Streszczenie

Stosując miniaturowe termopary rejestrowano temperaturę pąków świerka pospolitego (*Picea abies* (L.) Karst.) i sosny zwyczajnej (*Pinus silvestris* L.). W warunkach naturalnych temperatura pąków drzew iglastych ulega ciągłym zmianom i rzadko jest równa temperaturze otaczającego powietrza. Temperatura pąków ulega zmianom sekundowym, dobowym i sezonowym. Latem, w czasie dnia słonecznego, jest wyższa od temperatury powietrza nieraz o 7,5°C, natomiast w nocy często niższa o 1,0°C. Wyraźne zróżnicowanie występuje również w temperaturze pąków w obrębie korony drzew. W dniach słonecznych, jak również w całym okresie wegetacyjnym najwięcej energii słonecznej dociera do pąków południowych, a najmniej do północnych u dołu korony drzewa. Różnice między temperaturą pąka południowego a powietrzem rosną im bliżej jesieni. Prawdopodobnie jest to wynikiem ciemnienia łusek pąków. Związek między temperaturą pąków a kwitnieniem świerków i sosen jest dyskutowany.

ПАВЕЛ ПУКАЦКИ

Температура почек ели обыкновенной и сосны обыкновенной

Резюме

Применяя миниатюрные термопары регистрировали температуру почек ели обыкновенной (*Picea abies* (L.) Karst.) и сосны обыкновенной (*Pinus sylvestris* L.). В естественных условиях температура почек хвойных постоянно изменяется. Она редко равна температуре окружающего воздуха. Температура почек изменяется посекундно, поминутно, в течение суток и сезона. Летом, во время солнечных дней, температура почек неоднократно превышает температуру воздуха даже на 7,5°C, а ночью она часто ниже на 1°C. Существуют четкие различия между температурами почек в кронах деревьев. В течение солнечных дней в период всего вегетационного сезона больше всего солнечной энергии доходит до южных почек, а меньше всего к почкам северным в нижних частях кроны. Разницы между температурами южных почек и окружающим воздухом возрастают к осени. По всей вероятности причиной является потемнение чешуек почек. Дискутируется связь между температурой почек и цветением сосны и ели.