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Relations Between Solar Irradiation, Temperature and the Photochemical Activity of Chloroplasts Isolated from the Bark and Leaves of Lilac *(Syringa vulgaris* L.)

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Abstract

It has been found that under solar irradiation the temperature of the insolated side of stems may be up to 12°C higher than that of the air. The temperature of the shaded side of the stems is 2 - 3 °C lower than that of the insolated side. The temperature of the leaves exposed to sun may be up to 8°C higher than the open air temperature, while that of the shaded leaves is up to 5°C lower.

Investigations on the effect of temperature on the photochemical activity of chloroplasts have shown that in April and June the optimal temperature for photochemical activity of chloroplasts isolated from bark falls within the range 25-35 °C, and in November - in the range 25-30°C . The optimal temperature for the activity of chloroplasts isolated from leaves is 35°C.

Solar irradiation when warming the stems and leaves also increases the activity of chloroplasts. Only on hot summer days at noon is temperature of the insolated bark higher than the optimal one, resulting in a decrease in chloroplasts activity.

Keywords: bark; stem; leaves; temperature; chloroplast activity.

Introduction

The factor limiting the development of plants in spring is low temperature. Investigations of the photochemical activity of chloroplasts isolated from lilac bark have shown that the chloroplasts are active throughout the year and that in the period between the end of winter and the beginning of spring their activity is similar to that in summer [15]. The stems of lilac demonstrate photosynthetic activity, measured by CO_2 exchange also throughout the year, although in winter it is rather low when compared with that in summer [14].

In winter (already in January), on stems brought to the laboratory the development of buds takes place. Low temperature limits their development under natural conditions, where lilac buds begin to break in March, though their full development does not occur until the second half of April. In the leafless period the bark containing active chloroplasts is the only possible source of assimilates from the current production, which may be of great importance in the beginning of vegetation in spring.

The activity of the metabolic processes is limited by low temperature. Nicolai [10] showed that warming of the stems by solar irradiation depends to a great extent on the plant species, and the temperature of the bark may be up to a dozen or so degrees higher than that of the air. At the end of winter, in cloudless weather, often after a fall of below 0oC at night, the air temperature at mid-day is considerably above 0oC. Solar irradiation in that period, when warming the stems, raises their temperature and creates favourable thermal conditions for the process of photosynthesis. Again, in summer, on very hot days, by warming the stems and leaves solar irradiation increases their temperature still further, which may reduce their activity.

The aim of this study was to demonstrate to what extent the warming of the bark and leaves by solar irradiation is coursing an advantageous effect on the potential photochemical activity of chloroplasts in the various vegetation periods of the lilac. This aim was realized by determining the daily course of temperature of shoots and leaves depending on solar irradiation and by examining the effect of temperature on the photochemical activity of chloroplasts isolated from both the bark and the leaves.

Material and Methods

The investigations were conducted on lilac (*Syringa vulgaris* L.) growing in a field in a well insolated stand.

The photochemical activity of chloroplasts was determined by means of Hill's reaction, measuring the change of absorption from DCPIP (2,6-dichlorophenol indophenol) at 590 nm as a result of 1 minute irradiation (500 μmol m^{-2} s^{-1}), using a halogen lamp. The measurements of the photochemical activity were performed (15 repetitions) on chloroplasts isolated from bark and from leaves as described in detail by Pilarski [15].

The temperature of the bark and leaves was measured using a thermistor meter. The temperature of the bark was measured at a height of 1.5 m above the ground, on root suckers of current year stems, and 1-3 year-old ones growing vertically. The temperature of the insolated stem was measured on two oposite sides: the isolated side, and on the opposite one which was then in shadow. The temperature of the leaves was measured on insolated leaves on the boundary of the crown, 1.5 - 2 m above the ground, and on the leaves shaded by the crown.

The intensity of solar irradiation in the photosynthetically active range (PAR) was measured by means of a Li-COR quantum sensor above the ground.

Results

Beginning with sunrise, the increase in irradiation intensity is accompanied by the increase in air temperature and the temperature of the stems and leaves. In the afternoon hours the direction of the changes is reversed. The solar energy absorbed by the stems and leaves is responsible for their warming. The daily changes in solar irradiation, air temperature, and temperature of the leaves and stems on a sunny day in July are shown in Fig. 1. The maximum solar irradiation on that day was 1750 mmol m^{-2} h^{-1}, the maximum air temperature 32°C, maximum temperature of insolated stems 41°C, of insolated leaves 37°C, and that of shaded leaves 29°C. The temperature of shaded leaves was lower than that of the air. The temperature of shaded stems was similar to the air temperature, differing ±1°C. Fig. 2 lists the daily differences between air temperature and that of the leaves or bark (ΔT) for data given in Fig. 1. The temperature of leaves shaded throughout the day was lower than the air temperature and the highest ΔT value was 4.5°C. The temperature of insolated leaves throughout the day was higher than that of the air and the highest ΔT for insolated leaves was 8°C. The temperature of insolated stems, both on the side exposed to the sun and on the shaded side, was higher than that of the air. ΔT of the insolated side of stems reached as much as 12°C, on the shaded side of the stems being 2 - 3 °C lower than that of the insolated side of the stem. The temperature of the shaded side of the stem was higher than the temperature of insolated leaves.

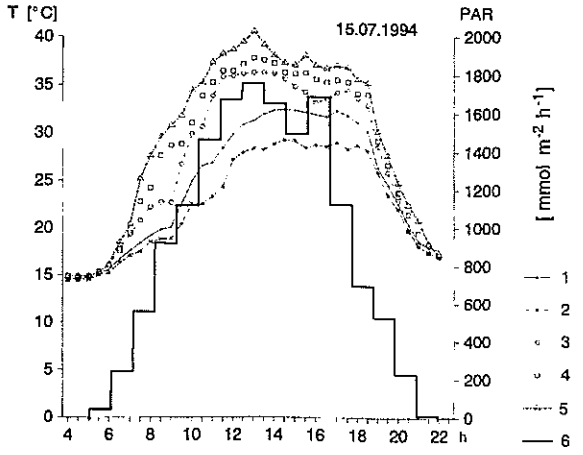


Fig. 1. Daily course of solar irradiation and of the temperature of the air, stems and leaves of lilac in summer. 1 - air temperature, 2 - temperature of shaded leaves; 3 - temperature of insolated leaves; 4 - temperature of the bark - insolated side of the stem; 5 - temperature of the bark - shaded side of insolated stem; 6 - PAR.

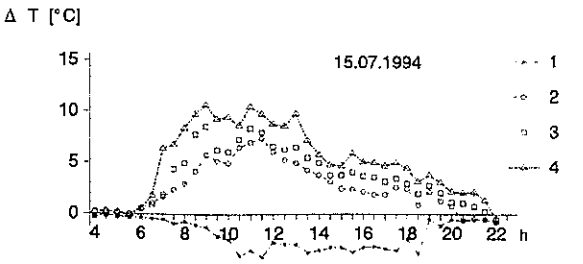


Fig. 2. Daily course of the differences between air temperature and the temperature of the bark and leaves (ΔT) in summer. 1 - shaded leaves, 2 - insolated leaves; 3 - bark - insolated side of stem; 4 - bark - shaded side of insolated stem.

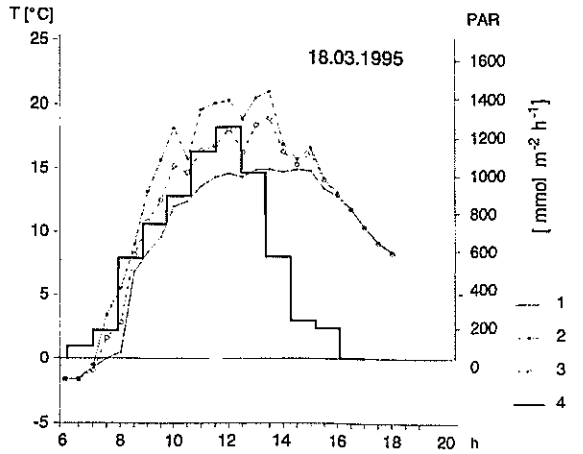


Fig. 3. Daily course of solar irradiation and of the temperature of air, and stems of lilac at the end of winter. 1 - air temperature; 2 - temperature of the bark - insolated side of the stem; 3 - temperature of the bark - shaded side of insolated stem; 4 - PAR.

Table 1. Comparison of the temperature of stems of different thickness; s - insolated side of the stem; c - shaded side of insolated stem.

Air temperature	PAR	Diameter of stem									
		1.0		1.5		1.8		2.6		3.0	
[°C]	[mmol m^{-2} h^{-1}]	s	c	s	c	s	c	s	c	s	c
8.8	1324	15.2	12.6	15.1	12.1	15.1	13.5	14.2	11.8	14	12.7
9.3	905	14.4	14.1	14.4	13.4	13.2	12.6	13.7	12.8	16	13.1
18.2	1615	25.7	24.5	25.8	24.3	26.1	24.7	26.7	24.5	28	24.1
32.1	1620	36.4	35.8	36.3	35.8	36.9	35.5	36.1	35.6	38	36.5

Illustrative results obtained at the end of winter are shown in Figs. 3 and 4, and those obtained early in the spring, in the initial period of development of the buds, are presented in Figs. 5 and 6. In March, the temperature below zero of the stems early in the morning (as a result of solar irradiation in the mid-day hours) reached 22.5°C on the insolated side and 19° C on the shaded side at the air temperature of 15°C. In April the temperature of the insolated side of the stems reached 32°C, and that of the shaded side 30°C in air temperature of 22.5°C. Temporary drops in intensity of irradiation caused by transient cloudiness were manifested by a temperature drop in the stems. Cold wind in March and April accelerated the cooling of the bark. On the insolated side of the stem the temperature variations were greater than on the shaded side. The higher temperature of the bark on the shaded side of the stem than that of the air is an indication that solar irradiation warms up the whole stem. The shaded side of the stem undergoes smaller temperature changes than the insolated side.

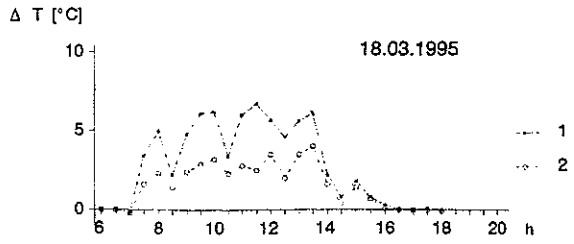


Fig. 4. Daily course of the differences between air temperature and the temperature of the bark (ΔT) at the end of winter. 1 - bark - insolated side of stem; 2 - bark - shaded side of insolated stem.

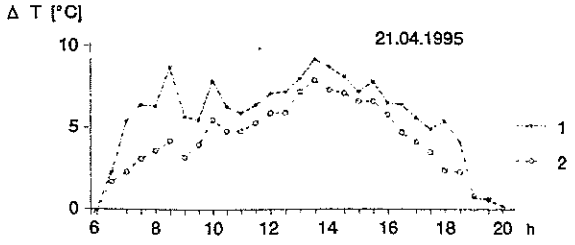


Fig. 6. Daily course of the differences between air temperature and the temperature of the bark (ΔT) in early spring. 1 - bark - insolated side of stem; 2 - bark - shaded side of insolated stem.

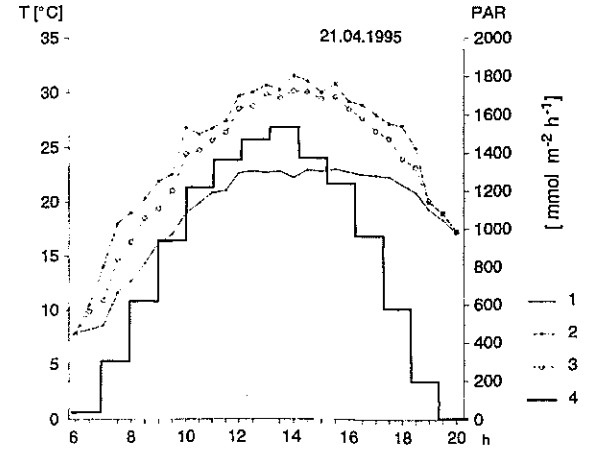


Fig. 5. Daily course of solar irradiation and of the temperature of air, and stems of lilac in early spring. 1 - air temperature; 2 - temperature of the bark - insolated side of the stem; 3 - temperature of the bark - shaded side of insolated stem; 4 - PAR.

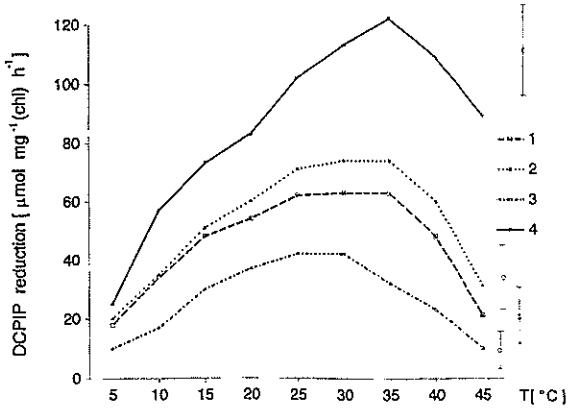


Fig. 7. The influence of temperature on photochemical activity of chloroplasts from the bark of current-year stems (1 - 3) and from leaves (4). 1, 4 -in June; 2 - in November, 3 - in April. Vertical bar indicates SE - standard mean error.

The above data have been obtained on current-year stems, growing vertically. Table 1 lists the results obtained on stems of various diameter, also growing vertically. They illustrate a tendency towards greater warming of thicker stems.

The presented results show that the temperature of insolated stems and insolated leaves is much higher than that of the air. In summer the temperature of the stems may exceed 40°C and that of the leaves 35°C. In spring the temperature of the bark may exceed 30°C.

The question arises to what extent the temperature determines the photochemical activity of the chloroplasts and whether or not the temperatures of the stems and leaves (reached as a result of the absorption of solar irradiation) limit the photosynthetic activity of chloroplasts.

The effect of temperature on the photochemical activity of isolated chloroplasts was determined in the range 5 - 45 °C by measuring the intensity of DCPIP reduction. The investigations were performed on chloroplasts isolated from current-year stems at various stages of the photochemical activity of the plant: in June, November, and in April, and on chloroplasts isolated from the leaves in June (Fig. 7). The results reveal a great dependence of the photochemical activity of chloroplasts on temperature. Those from the bark demonstrated the highest activity in the temperature range 25 - 35°C in June and in April, and in a narrower range, 25 - 30°C, in November. At 45°C the activity of chloroplasts from the bark was similar to that at 5°C. In June and in April, at low temperatures of 5 - 15°C the activity of chloroplasts from the bark was similar. At higher temperatures it was higher in June than in April. In November, in the entire examined temperature range, the activity of chloroplasts from the bark was 40 - 50% lower than in June. The chloroplasts from leaves showed the highest activity at 35°C. At higher temperatures it decreased, but less than that of chloroplasts from the stems, and at the temperature of 45°C their activity was close to that at 20°C.

The photochemical activity of chloroplasts from the bark was lower than from the leaves. With increasing temperature the differences between the activity of chloroplast from the leaves and from the bark increased. In June the activity of chloroplasts from the bark at 5°C was 20% lower than that of chloroplasts from the leaves, at 35°C 40%, and at 45°C 66% lower.

The presented results show that during the winter—spring period solar irradiation warming up the stems optimizes the thermal conditions for the activity of chloroplasts. In summer the stems and leaves reach temperatures which inhibit the photochemical activity of chloroplasts. In the case of leaves the optimal temperature for the activity of chloroplasts is slightly exceeded (1 - 1.5°C), which does not cause any great decrease in their activity. On the other hand, in the case of stems, as a result of solar irradiation the temperature of the bark of insolated stems may exceed 40°C, and at this temperature the activity of chloroplasts is almost 20% reduced. However, a bark temperature of 40°C and higher occurs only on very hot days at mid-day.

Discussion

Warming of the stems is due to the absorption of solar irradiation in infrared (700 - 1600 nm), and to a large extent depends on the optical properties of the bark [10]. In the tree species in which takes place a strong reflection of solar irradiation from the bark, the warming of the bark and cambium is rather slight. An example here may be *Betula penduloza,* in which the bark absorbs only about 6.9% of infrared irradiation and the bark temperature is up to 5°C higher than that of the air. On the other hand, species with thin and smooth bark, e.g. *Fagus sylvatica*, absorbed 80% irradiation in the range 700 - 1600 nm, the temperature of the bark and cambium may be up to 15°C higher than that of the air. Scaly bark *(Pinus silvestris*) prevents excessive warming while fissured bark (*Quercus robur*) undergoes strong warming and its temperature may be up to 30°C higher than that of the air. The optical properties of the bark have an effect on the distribution of species and, for example, trees with white bark reflecting solar irradiation (*Betula sp.*) are pioneer species in open areas.

Investigations conducted on other tree species have revealed a 10 - 20% increase in bark temperature as an effect of solar irradiation [4, 8, 17]. These investigations carried out on trunks showed a temperature increase of the insolated side of the trunk in comparison with the temperature of the air. The temperature of the shaded side was similar to that of the air, while inside the trunk, in the northern part, the temperature was lower than the air temperature [4]. The inside of trunk was not warmed uniformly throughout.

The investigations on lilac were performed on thin stems with a diameter up to 3 cm. The obtained results for the insolated side are similar to those cited above. The temperature of the shaded side of a lilac stem only slightly lower than that of the insolated side, is an indication that the stem is warmed throughout. Temporary cloudiness did not cause any great temperature variations on the shaded side, which is also evidence that the whole stem was warmed.

Thanks to the efficient operation of the stomatal apparatus, the transpiration of the leaves is responsible for the fact that insolated leaves do not become warmed up as much as the stems, and that the temperature of the shaded leaves is lower than that of the open air. Under the influence of solar irradiation the temperature of the insolated leaves reaches the optimal level for the photochemical activity of the chloroplasts. In lilac stems the very high diffusive resistance of the cork to water vapour [16] in practice makes transpira-

tion impossible, and the temperature of the stems is a few degrees higher than that of the leaves.

In the course of temperature measurements in lilac no external symptoms of water deficiency in the leaves, leading to closure of stomata and limitation of CO_2 uptake from the atmosphere, were observed [13]. The optimal temperature for CO_2 assimilation in the leaves of various plant species is 25 - 30°C [1, 3, 5, 7, 9]. The optimal temperature for the leaves of the desert plant *Larrea divaricata* is 35°C [9]. According to the author's knowledge no investigations on the effect of temperature on CO_2 assimilation by the leaves and stems of lilac have been reported.

Several data are available on the effect of temperature on photosynthesis of the stem of other species. In *Fagus cremata* an increase in photosynthesis was observed in the whole examined range 5 - 45°C [6]. In *Cercidium floridum* [1], *Spartium junceum* and *Cytisus scoparium* [11[the optimal temperature for photosynthesis of young stems was 30°C, in *Psorothamnus spinosus* 40°C [12]. A slight reduction in CO_2 assimilation with temperature increase from 20 to 40°C was observed in *Eriogonum inflantum* [13].

In an investigation on the effect of temperature on the electron transport in chloroplasts isolated from leaves of *Larrea divaricata* the optimal temperature was found to be in the range 42 - 50°C [2]. Thus it was still higher than that obtained by the author on chloroplasts from the leaves of lilac, which amounted to 35°C. At 45°C the activity of chloroplasts from lilac leaves is still very high and similar to that at 20°C.

While supplying energy for the process of photosynthesis solar irradiation simultaneously warms up the stems and leaves. This considerably improves the thermal conditions for the process of photosynthesis, increasing the photochemical activity of chloroplasts and on sunny days at 15°C the bark attains optimal temperature. In March the warming up of the bark by 10°C, at an air temperature of 5°C, increases the activity of chloroplasts to 167%, at 10 C - to 60%, and at 15°C - to 30%. In June the increase in photochemical activity of the chloroplasts amounts to: 71%, 40% and 23%. Warming up of the leaves by 10°C has a smaller effect than in the bark, and at air temperature of 10°C it amounts to 46%, at 15°C - 39%, at 20°C - 36%, and at 25°C - 20%.

In summer, the temperature of the bark may rise above the optimal one, reducing the photochemical activity of chloroplasts. However, by shading, the foliage parts protect the stems against solar irradiation.

References

1. ADAMS M. S., STRAIN B. R., Photosynthesis in stems and leaves of *Cercidium floridum*: spring and summer diurnal field response and relation to temperature. Oecol. Plant., **3**, 285-297, **1968.**
2. ARMOND P. A., SCHREIBER U., BJÖRKMAN O., Photosynthetic acclimation to temperature in the dessert shrub, *Larrea divaricata*. II. Light-harvesting efficiency and electron transport. Plant Physiol. **61**, 411-415, **1978.**
3. DE PUIT E. J., CALDWELL M. M., Stem and leaf gas exchange of two aird land shrubs. Amer. J. Bot. **62**, 954-961, **1975.**
4. DERBY R. W., GATES D. M., The temperature of tree trunks - calculated and observed. Amer. J. Bot. **53**, 580-587, **1966.**
5. HAN S. S., Studies on the productivity of korean white pine forest. I. Efect of temperature, light and water stress on photosynthesis and dark respiration rates of leaves. J. Korean For. Soc. **55**, 55-58, **1982.**
6. HAN S. S., SUZAKI T., Studies on the production and consumption of assymilates by trees (IX) Bark photosynthesis and dark respiration of young green stems and branches of *Fagus crenata* and *Quercus acutissima*. J. Jap. For. Soc. **63**, 242-244, **1981.**
7. HARI P., LUUKKANEN O., Field studies of photosynthesis as affected by water stres, temperature, and light in birch. Physiol. Plant. **32**, 97-102, **1974.**
8. JENSEN R. E., SAVAGE E. F., HAYDEN R. A., The effect of certain environmental factor on cambium temperatures of peach trees. J. Amer. Soc. Sci. **95**, 286-292, **1970.**
9. MOONEY H. A., BJÖRKMAN O., COLLATZ G. J., Photosynthetic acclimation to temperature in the desert shrub, *Larrea divaricata*. I. Carbon dioxide exchange characteristicts of intact leaves. Plant Physiol. **61**, 406-410, **1978.**
10. NICOLAI V. , The bark of trees: thermal properties, microclimate and fauna. Oecologia **69**, 148-160, **1986.**
11. NILSEN E.T., KARPA D., Seasonal acclimation of stem photosynthesis in two invasive, naturalized legume species from coastal habitats of California. Photosynthetica **30**, 77-90, **1994.**
12. NILSEN E. T., MEINZER F. C., RUNDEL P. W., Stem photosynthesis in *Psorothamnus spinosun* (smoke tree) in the Sonoran desert of California. Oecologia **79**, 193- 197, **1989.**
13. OSMOND C. B., SMITH S. D., GUI-YING B., SHARKEY T. D., Stem photosynthesis in a desert ephemeral, *Eriogonum inflatum*. Characterization of leaf and stem CO_2 fixation and H_2O vapor exchange under controlled conditions. Oecologia **72**, 542-549, **1987.**
14. PILARSKI J., Photosynthesis in shoots and leaves of lilac *(Syringa vulgaris* L.). Bul. Pol. Acad. Sci. Biol. Sci. **37**, 261-269, **1989.**
15. PILARSKI J., Photochemical activity of isolated chloroplasts from bark and leaves of the lilac (*Syringa vulgaris* L.). Photosynthetica **24**, 186-189, **1990.**
16. PILARSKI J., Diffusion of carbon dioxide through the cork and stomata in lilac. Acta Physiol. Plant. **16**, 137-140, **1994.**
17. SAKAI A., Temperature fluctuation in wintering trees. Physiol. Plant. **19**, 104-114, **1966.**