THE LESSER MAXIMUM OF EVENING TEMPERATURE

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Zusammenfassung. In Pflanzenbeständen — besonders bei heiterem windstillem Wetter — setzt nach Sonnenuntergang eine Temperaturerhöhung ein, die oft auch 5°C beträgt. Auf Grund von Modelluntersuchungen folgern die Verfasser, dass die Ursache dieser Temperaturerhöhung in erster Linie die Taubildung ist. Ihre Feststellung wird bewiesen durch die Tatsachen, dass

a) die Temperaturerhöhung und die Taubildung gleichzeitig einsetzen,

b) die Temperaturerhöhung und das Mass der Taubildung proportional veränderlich sind.

Summary. In vegetation stands — especially in clear, calm weather — a temperature rise of often as much as 5 °C occurs after sunset. On the basis of model examinations the authors come to the opinion that the cause of this rise of temperature is first of all the formation of dew. This is proved by the facts that

a) the rise of temperature and dew formation occur simultaneously,

b) the rise of temperature and the degree of dew formation are proportionately variable.

A rise of temperature of several degrees often takes place in the vegetation after sunset. This phenomenon was first found 12 years ago by R. WAGNER in the course of his microclimatological observations and has been observed many times since then. This rise in temperature after sunset has been observed in different kinds of vegetation several times also by us. According to WAGNER's and our own observations the rise of temperature differs according to the kind of vegetation and occurs especially in clear, calm weather, after high day temperatures. We have not found a description of this phenomenon in the literature and it is not mentioned in the fundamental microclimatological works of LUNDEGÅRDH (3) and GEIGER (2) either.

The problem is what causes the rise of temperature which often exceeds 5°C in certain kinds of vegetation even when the sky is not covered. According to R. WAGNER and N. G. POTAPOV (oral communications) this phenomenon is due to plant ecological and biological processes. They think that probably the plants take up warmer-than-air water from the soil and this causes the rise of temperature in the vegetation. Besides this the energy-producing metabolic processes of the plants, respiration above all, play a role.

On the basis of energetical considerations, however, we cannot accept this hypothesis, for the relatively small amount of water taken up from the soil cannot cause a rise of temperature of several degrees in the microclimatic space of the vegetation. One m^2 of compact vegetation maximally takes up 1 to 2 l of water from the soil dur.ng a few hours. Let us suppose that between the temperatures of the soil and the air there is a difference of 10 °C (maximal difference). In this case the water taken up from the soil in one hour produces 20 kcal of heat. This quantity of heat would cause a temperature rise of maximally 1°C if the air layer 1 m over the ground is taken as a basis. Many times as much is the heat loss by outgoing radiation after sunset, especially in clear, calm weather. Similarly little energy is produced by the respiration of the plants. The metabolic processes of the microorganisms in the soil which produce considerable energy must be left out of consideration, because the rise of temperature after sunset can only be observed in the upper 5 cm layer of the soil and it is of a lesser order than in the air.

How can then the rise of temperature in the vegetation after sunrise be explained? We believe that it is connected first of all with the dew formation. Our hypothesis is supported by the fact that the highest rise of temperature after sunset occurs in clear, calm weather after hot days when the weather conditions favor dew formation. Dew formation produces a considerable amount of heat. At the formation of 1000 ml of dew 537 kcal of heat is liberated. Taking into consideration the 0.241 kcal specific heat of air (weight of 1 m^3 of air: 1.293 kg) this amount of heat may cause a considerable rise of temperature in the relatively closeds ystem within the vegetation. Naturally the theoretically calculable rise of temperature is greatly reduced by the usually intensive outgoing radiation at dew formation and the movement of air L. Aujeszky also points out the considerable air temperature-rising effect of dew formation saying "... by the change of phase of vapor a quantity of heat energy becomes liberated which completely compensates the heat loss due to outgoing radiation and hinders further cooling of the air."

Material and Method

In order to test the correctness of our hypothesis we carried out microclimate model experiments in the Agrobotanical Garden of the G Ö D Ö L L Ő University of Agriculture in 1962.

For the model experiments compact vegetable stands of oat (Avena sativa), sunflower (Helianthus annuus) and buckwheat (Phagopyrum aesculentum) were laid out in 12 by 12 m plots. The observations were made in these stands on 29 June and 16 July 1962. The amount of dew formed was determined by measuring hourly an amount of about 20 g of the leaves of different plants, and determining after drying the water content of the leaves. The fresh weight measurements were made on the spot on a tare weigher and the leaves were taken off carefully so that the dew formed on them would not fall off. The calculated "water content" represents the total amount of the actual water content of the plant and the dew formed on the leaves. In the sunflower in which no visually observable dew formation was found the change of water content in the evening hours was only one per cent. The "water content" of the buckwheat leaves, however, increased by more than 10% and the most intense dew formation was observed in this tand. Therefore we think that the change in "water content" represents nearly totally the amount of dew formed; the actual water content increase of the leaves may at the most be 5 to 10% of this amount. In the evaluation the total in crease of "water content" was regarded as dew. Calculating the leaf surface on the basis of the dry weight we determined the amount of dew formed on 100 cm^2 of leaf surface. From this the actual amount of dew formed in 1 m^2 of vegetation stand can be determined if we know the total leaf surface. In the course of microclimate investigations, depending on the height of the stand, the air temperature was measured with mercury thermometers at four levels and the relative vapor content of the air was determined at two levels with an Assman aspiration psychrometer. The air thermometers were set up 10 cm high over the ground, in the middle of the stand, at the level of the stand, and 20 cm high over the same. The relative vapor content was determined in the middle and at the level of the stand. The height of the sunflower was 150 cm, that of the buckwheat 70 cm, and that of the oat 100 cm. Control measurements were made in an area with no vegetation where the air thermometers were set up 10, 50, 100 and 150 cm high. The mercury thermometers were protected from direct radiation by tinfoil sheets. The air temperature was measured every half hour, the vapor content every hour.

Results and Evaluation

Before reporting on the results of the model experiments we present by way of an example some results of our microclimatologcal observations carried out at Buzsák on June 30, July 1 and August 23, 1960 where the rise of temperature after sunset is well visible. On both occasions the air temperature was measured electric resistance thermometers at various levels depending on the height of the vegetation stand every half hour.

In the course of our observations of June 30, 1960 the microclimate was measured at three stations. The first station was set up in the fish-pond over open water, 14 m offshore. The second station was 5 m away from the shore in a 50 cm high dense stand of Ruderalia and the third 50 m from the shore in 10 cm — high Lolietum grass. The variations of the temperature at 10 cm and 150 cm, and the temperature isopleths of the air layer close over the ground, between 19 and 23 hours, are shown in Figs. 1 and 2.

At the station set up in the pond nearly even temperature sinking was observed on both days. (The slight rise of temperature observed between 21 and 23 hours on June 30 may be explained by the advection caused by the gentle west wind. In the Ruderalia on the shore after 20 hours a minor, and after 21 hours a greater (1.7°C) rise of temperature was observed. Slight dew formation in this stand began about 20 hours and there was heavy dew after 21 hours. An intense rise of temperature of more than 2°C occurred over the Lolietum after 21.30. Dew formation in this stand could be observed after 21 hours.

Microclimatological observations were again made in the same area on August 23 1960. Fig. 2 shows the data of three stations, between 19 and 23 hours.

The first station was 35 m from the shore in a 10 cm tall Lolietum stand. The second was also 35 m from the shore in a 70 cm tall dense Caricetum stand. The third station was set up 50 m offshore over open watersurface.

On this occasion, too; a fairly even sinking of the temperature over the

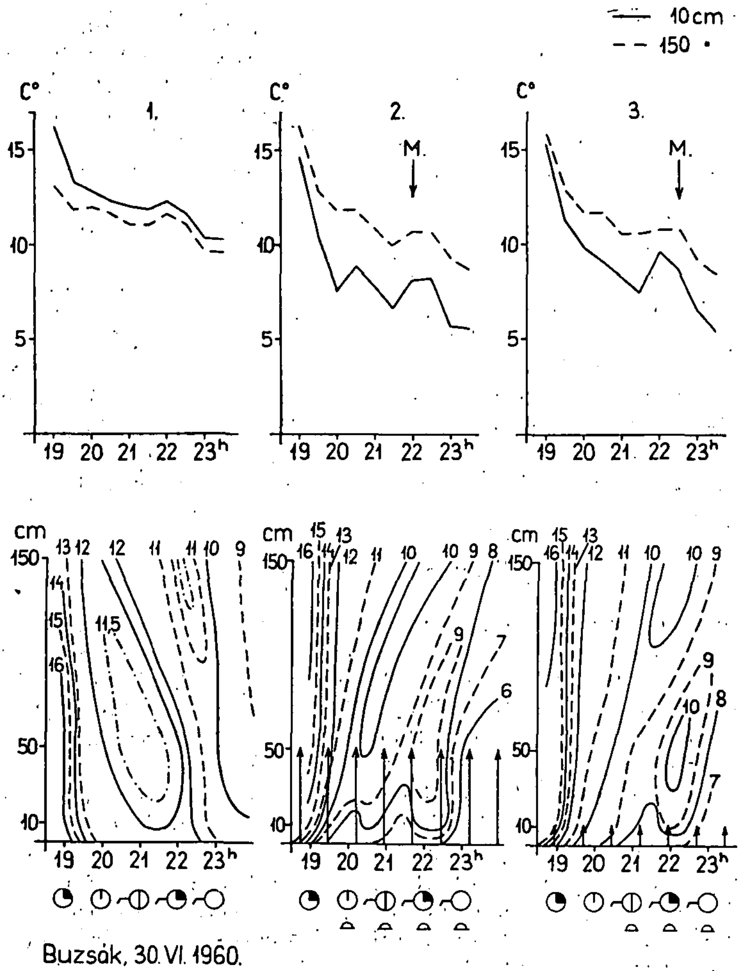

Fig. 1.

Temperature of the air over the ground. (June 30, 1960.) 1 = pond, 2 = ruderalia on the, 3 = Lolietum, M = rise of temperature ↑ = tallness of stand

pond was observed. A minor rise of temperature occurred about 20 and 23 hours. At the two other stations dew formation was observed from 21 hours on. Howerer, dew formation was much more intense in the Caricetum than in the Lolietum. Over the vegetation stand in the Lolietum a temperature rise of 1.2°C, and at the level of the vegetation stand in the Caricetum where the dew formation was the strongest, a temperature rise of 2 °C was observed.

We give the results of our model experiments according to our observations on July 16, 1962. The air temperature conditions of the different stands are shown by curve graphs and isopleths in Fig. 4.

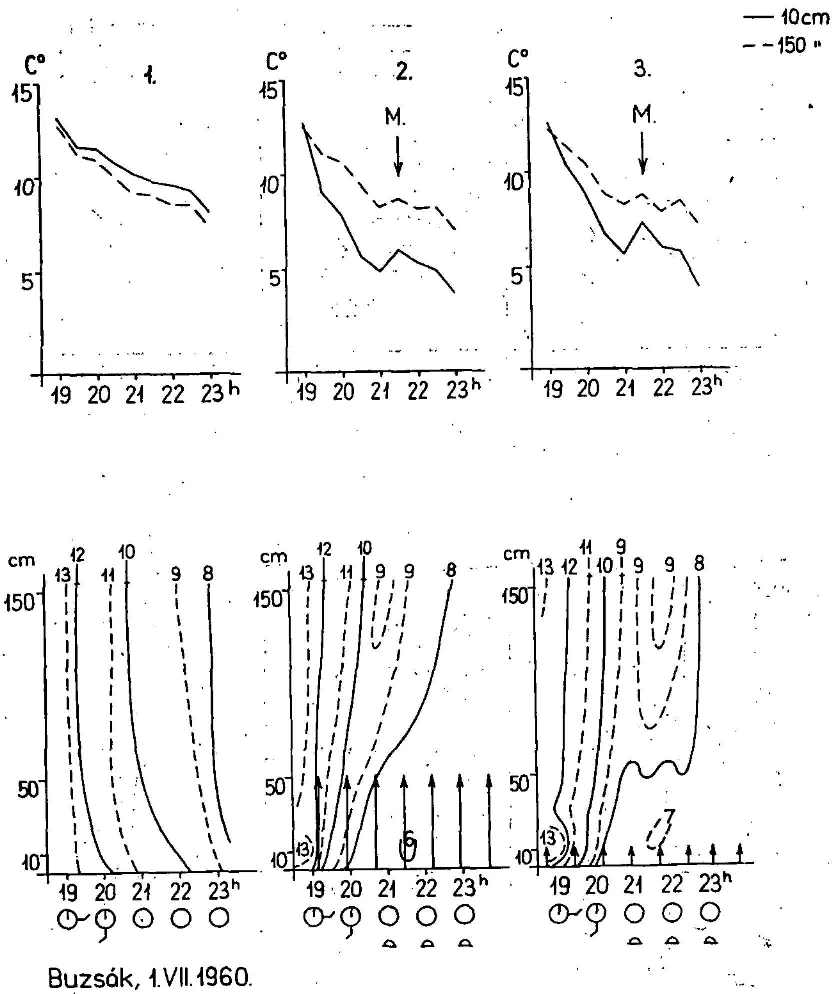

Fig. 2.

Temperature of the air over the ground (June 1, 1960.) 1 = pond, 2 = ruderalia on the shore, 3 = Lolietum, M = rise of temperature ↑ = tallness of stand.

Fig. 5 shows the amount of dew formed hourly between 19 and 22 hours in the three different vegetation stands.

An even sinking of temperature occurred after sunset in the stand of sunflowers (1) as well as in the control area (4). Only at the height of 150 cm in the control area did a slight rise of temperature (0.8°C) occur. This latter, however, may be explained by advection because at the same time the temperature was above 15°C in the vegetation stands not far from this area.

According to our observations scarcely any dew was formed in the stand

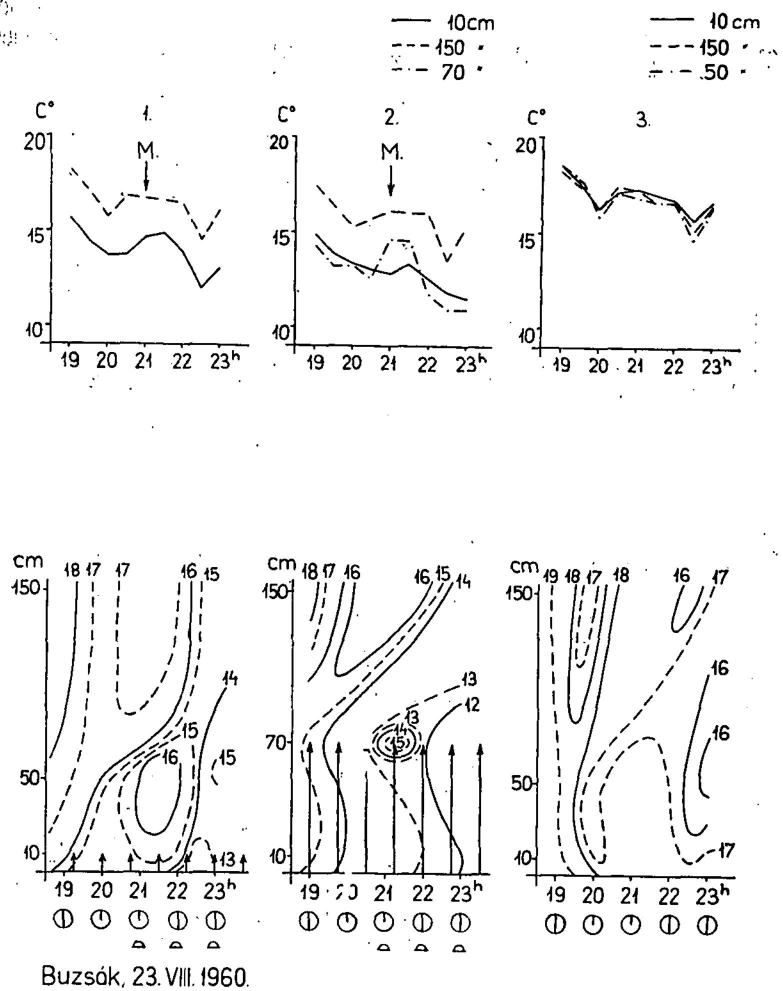

Fig. 3.

Temperature of the air over the ground (August 23, 1960). 1 = Lolietum, 2 = Caricetum, 3 = pond, M = rise of temperature, ↑ = tallness of stand.

of sunflowers; as small an amount as 0.2 ml per 100 cm^2 of leaf surface was found.

The greatest rise of temperature was observed in the stand of buckwheat between 20.30 and 21 hours. Its value at 35 cm was 1.5°C, and at 70 cm, i. e. at the height of the stand, where dew formation was the most intense, it was 2.1 °C. In the stand of buckwheat 5.4 ml of dew per 100 cm^2 of leaf surface was measured between 19 and 22 hours and 3.5 ml of this fell into the period of the greatest rise of temperature (between 20 and 21 hours).

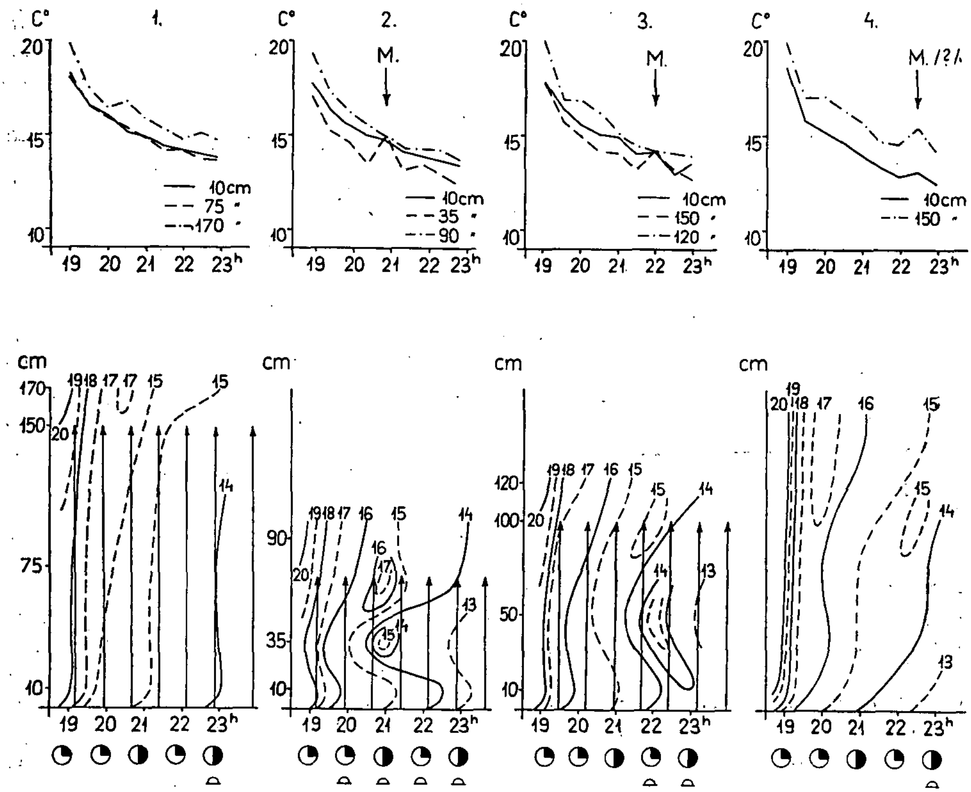

Fig. 4.

Temperature of the air over the ground (July 16, 1962). 1 = stand of sunflowers, 2 = stand of buckwheat, 3 = stand of oat, 4 = control with no vegetation, M = rise of temperature ↑ = tallness of stand.

Slight dew formation (1.3 ml per 100 cm² of leaf surface between 19 and 22 hours) and a slight rise of temperature (0.9°C at 50 cm) were observed in the oat stand. The rise of temperature manifested itself in the oat about a half hour later than in the buckwheat stand. According to our observations maximal dew formation took place simultaneously with the rise of temperature in this stand too.

According to our model experiment the 5.3 ml of dew in 1 m² of area (taking 5 m² of leaf-surface minimally as a base) formed on 100 cm² of leaf surface in the stand of buckwheat showing maximal dew formation between 19 and 22 hours means an hourly average of 900 ml of dew, 480 kcal of heat becomes liberated at the formation of this amount of dew. In our opinion it is by this amount of heat that the rise of temperature in the vegetation stand in calm weather can be explained.

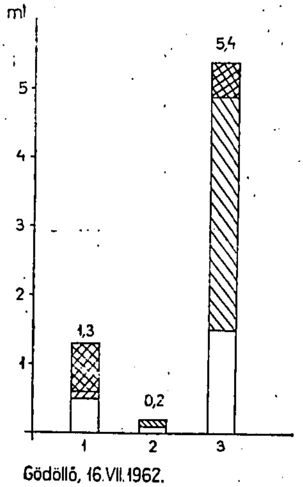

Fig. 5.

Dew: ml per 100 cm, of leaf surface 1 = oat, 2 = sunflower, 3 = buckwheat □ *= between 19 and 20 hours. Striped column = between 20 and 21 hours. Checkered column = between 21 and 22 hours*

In areas with no vegetation cover also in our model experiments a slight rise of temperature (0.4°C) was observed at 10 cm after 22 hours.

It is with this dew formation that we explain what happens on the soil surface but we could not measure it with our method. The greater rise of temperature at 150 cm in the control area (0.8 °C) may be explained by advection. (The oat stand was 10 m distant from the control station.)

The rise of temperature in the vegetation stand after sunset observed in our microclimatological investigations is a general phenomenon in calm weather. On the basis of our model experiments 1962 we think that dew formation is responsilbe for it. This view of ours is supported by the following facts:

a) the rise of temperature and the dew formation occur simultaneously,
b) the degrees of the temperature rise and of dew formation are proportionately variable,
c) at dew formation a considerable amount of heat becomes liberated which, according to theoretical computation (taking a closed system without outgoing radiation as a basis), would cause a much greater rise of temperature than that actually observed.

Summary

In vegetation stands, especially in clear, calm weather, a rise of temperature usually occurs after sunset. This rise of temperature often is as much as 5 °C. On the basis of our model experiments in 1962 we think dew formation is responsible for this rise of temperature. This opinion is supported by the following facts:

(a) the rise of temperature and the dew formation occur simultaneously,
(b) the degrees of the temperature rise and of dew formation are proportionately variable,
(c) at dew formation a considerable amount of heat becomes liberated which, according to theoretical computation (taking a closed system without outgoing radiation as a bases), would cause a much greter rise of temperature than that actually observed.

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