

Effect of gradient of temperature upon flows in the whole maize plant

J. MICHALOV

*Institute of Ecobiology of the Slovak Academy of Sciences,
Štefánikova 3, 814 34 Bratislava, Slovakia*

Abstract

Transport of ions in young maize plants was affected by the temperature gradient (gradT). This influence was dependent on the age of plants and the solute concentrations in compartments at the two sides of plants. When gradT was increased, current, volume and heat flows rose during 20 min and then declined. On the other hand, the diffusive flow only declined. The character of the flow changes was given by the changes in permeability and reflection coefficients. In young plants under low solute concentration on both sides of plants, the permeability of the plant tissues shifted from positive to negative values. Under higher solute concentrations on both sides of the plants such phenomenon was not observed. At high gradT the reflection coefficients of the plant tissues were low, but they rose during levelling the temperature in the two compartments.

Introduction

Long distance transport induced by gradT through the primary root and through nodal roots was studied previously (Michalov 1986, 1989a, b, c). Since the plant transports substances from the root to the above ground parts and conversely, the aim of this work was to examine the transports induced by gradT through the entire undamaged plant and with the same method (1) to identify the conductive, permeable and reflection capabilities of tissues in dependence on plant age, (2) to ascertain the differences between the transports in root from which the above ground part was cut off, and in the whole plant and to explain them by establishing the permeability and reflection coefficients and (3) to determine the influence of transport by immersion of plant into KCl solution of different concentration.

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Present address: Astrová 50, 821 01 Bratislava, Slovakia*

Material and methods

Measurements of flows (current, volume, heat and diffusion) were made on the thermoosmometer illustrated in Fig. 1.

For measurements 3-, 4-, 5- and 6-d old maize plants (hybrid C-330) cultivated in distilled water on filter paper, at temperature of 20 °C and relative humidity 75 % were used. The plant was placed in the sample holder inside the thermoosmometer in the way that the coleoptile was in the solution in the first compartment in which temperature varied from 20 to 30 °C.

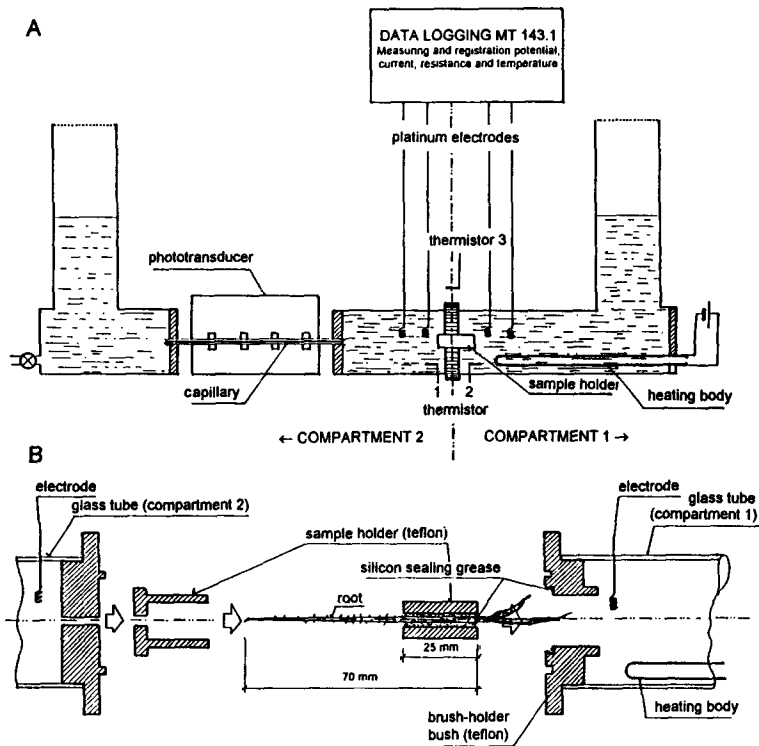


Fig. 1. A diagram of the device used to measure flows induced by action of gradT between compartments I and II. Part A: Total view of the arrangement of the device. Part B: A diagram of sample location. The position of the whole maize plant is shown. Vertical glass tubes in the right and left parts serve for the achievement of an equilibrium pressure state (hydrostatic and atmospheric). Different parts of the device are described in the diagram.

The tip of the root and the root segments that exceeded the length of the holder were in the second compartment in which temperature changed only as a result of

solution and heat transport through the plant. At the measurement 0.5 % and 1 % aqueous KCl solutions were used. Solutions and heat transport outside of the transport routes through the plant tissues was ruled out by a perfect isolation of the whole plant in the holder as well as of the holder proper placed between two compartments. Difference of temperatures between compartments varied from 0 up to 9 °C. The root tip was in a cooler environment, that is in compartment II. The effect of the gradT on flows was synchronously identified and registered by the variation of electric voltage (E), of temperatures T_1 and T_2 in the compartments, of ohmic resistance (R) and of the solution column height in the levelling tubes.

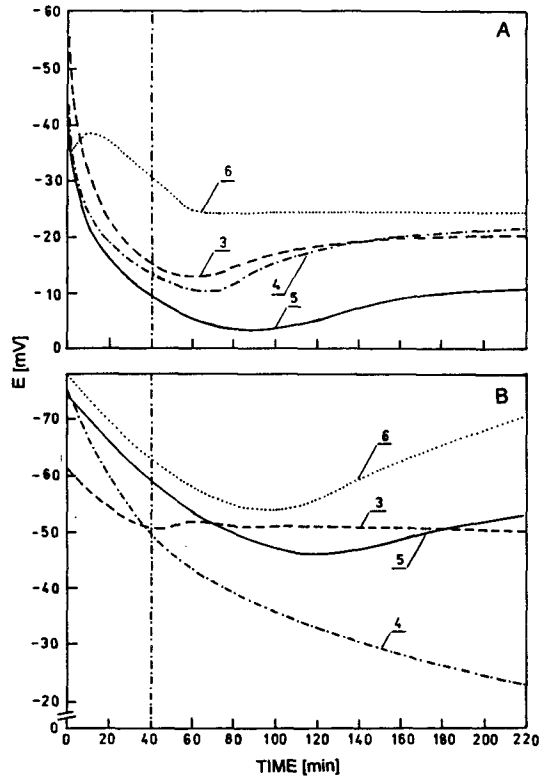


Fig. 2. Changes of voltage (E) in the whole maize plants after the grandT was established. A - 0.5 % KCl solution; B - 1 % KCl solution. Numbers at the curves indicate plant age (d), the perpendicular dot and dash line indicates time (40 min) in which the gradT °C reaches maximum value. It concurrently indicates the onset of the gradual levelling of the temperature between two compartments.

In spite of the relatively long duration of one measurement (*ca.* 3 h), measurements were made in sufficient numbers for the statistic evaluation of the measured quantities. With the help of the measured values and the mathematical model presented in previous paper (Michalov 1989), the particular flows as well as the permeability and reflection coefficients have been determined.

Results and discussion

Variations of the voltage caused by the temperature gradient: The nonlinear variations of the voltage caused by grad T through the whole plant depend on the plant age and the concentration of the surroundings KCl solution (Fig. 2).

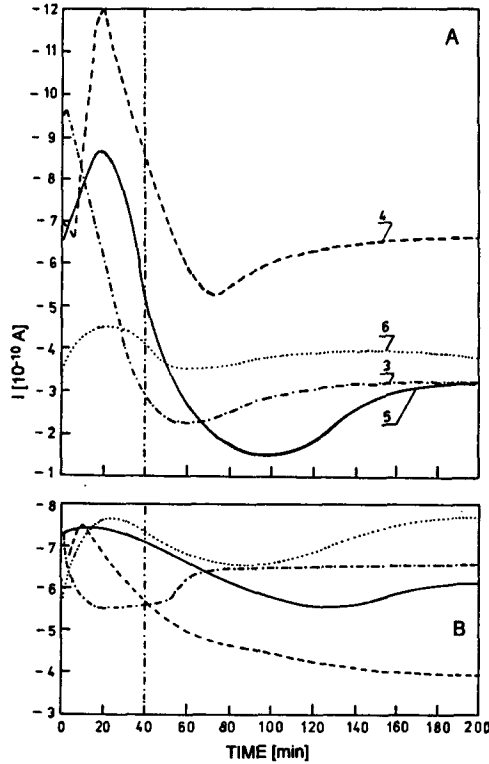


Fig. 3. Changes in current flow (I) in the whole maize plants caused by gradT. The symbols are the same as in Fig. 2.

Electric voltage attained highest values through the tissues of 6-d old plants with both concentrations of surroundings solutions (Fig. 2). On contrary, the maximum voltage during rising the grad T was in roots of 4-d old plants, but during the levelling temperatures it was also in roots of 6 d old plants (Michalov 1992).

Electric voltage variations through tissues of 3- and 4-d old plants were the same in the case of the 0.5 % solution. Only in 3-d old plants the voltage values were higher than in 4-d old plants (Fig. 2A). The voltage variations through tissues of 3-d old plants were different, when the surrounding solution was 1 %. During rising gradT the voltage declined and reached the lowest value when gradT was at maximum. When the gradT dropped electric voltage slightly rose and after 60 min dropped until levelling.

Electric voltage variations were passing off within an approximately 10 mV range. On the whole, electric voltage rose with the increasing concentration of KCl solution. When gradT rose the voltage continually declined and this continued during the temperature levelling in 4 d old plants. In the comparison in 5- and 6-d old plants the character of changes was opposite (Fig. 2B).

Effect of gradT upon current flow: As a result of the rising gradT the current flow through the tissues of the entire plant attained the maximum about 20 min earlier than the gradT in the 4-, 5- and 6-d old plants. At the 3-d old plants it was already during the first 5 min. The current flow declined with rising KCl concentration in the surrounding solutions (Fig. 3).

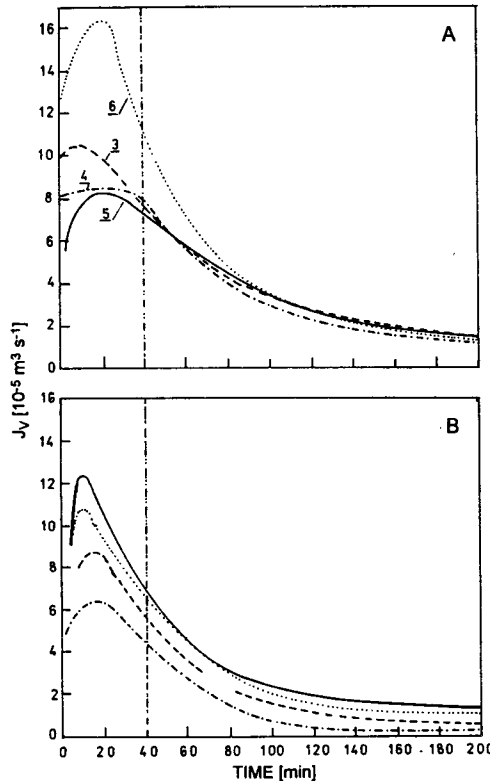


Fig. 4. Changes of volume flow (J_v) through tissues of the whole maize plants due to the acting gradT. The symbols are the same as in Fig. 2.

In the case of the 0.5 % KCl solution the maximum current flow through plant tissues was reached firstly in 3-d old plants followed by 6-, 5- and 4-d old plants (Fig. 3A). In the case of 1 % KCl solution, the sequence of plants reaching the maximum current flow values was 3-, 4-, 5- and 6-d old plants (Fig. 3B). When temperatures were levelling in the two compartments the sequence of plants with different age was similar.

Effect of gradT upon volume flow: With the rising gradT between two compartments the volume flow rose vigorously for *ca.* 15 to 20 min. The time in which it attained maximum depended on the concentration of the surrounding solution (Fig. 4.). With a more concentrated solution maximum is attained more quickly, within *ca.* 15 min., with a solution of lower concentration within *ca.* 20 min. (Fig. 4).

In course of the further rise of the gradT, the volume flow declined, and when the gradT declining to zero, volume flow also dropped. Both decline and rise depended on plant age as well as on the concentration of the surrounding solution. In the case of 0.5 % KCl solution the flow was the largest through tissues of the 6-d old plant and lowest through tissues of the 5 d-old plant. In the case of 1 KCl % solution the highest volume flow was through tissues of 5-d old plants and the lowest through tissues of 4-d old plants. These differences disappeared during the levelling temperatures between compartments.

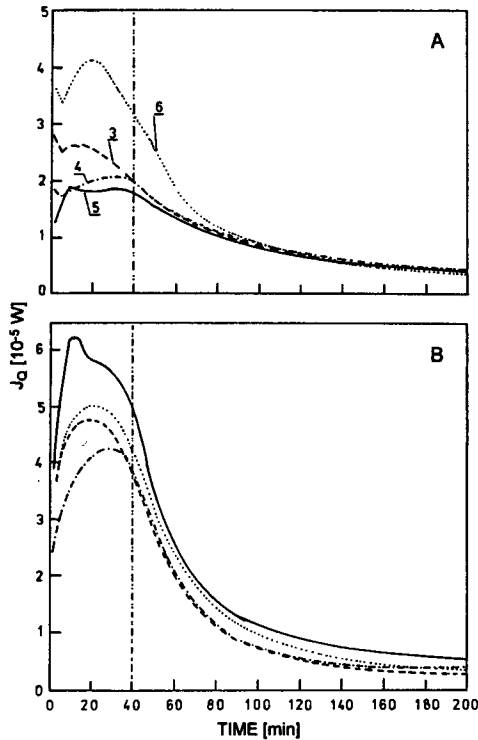


Fig. 5. Changes of heat flow (J_Q) through tissues of the whole maize plants, as a result of the acting gradT. The symbols are the same as in Fig. 2.

Effect of gradT upon heat flow: The heat flow under the influence of the gradT was rather similar to the volume flow under the same conditions. Differences were in the shape of the maximum and in the time of holding out at the maximum value. Differences were in the decline rate of the heat flow in course of the temperatures levelling between compartments. Similarly obvious was the dependence on the concentration of the washing solution. Using 1 % KCl solution the heat flow also

rose during the rising gradT, but with the temperatures levelling between compartments it quickly declined (Fig. 5).

Effect of the temperature gradient upon the diffusion flow: When using 1 % KCl solution the rate of diffusion was the highest in tissues of 5-d old plants, and when using 0.5 % KCl solution in tissues of 6-d old plants. Minimum values were attained in both cases in 3-d old plants (Fig. 6). The decline was faster through tissues of 3-d old plants and slower through those of 5- or 6-d old plants.

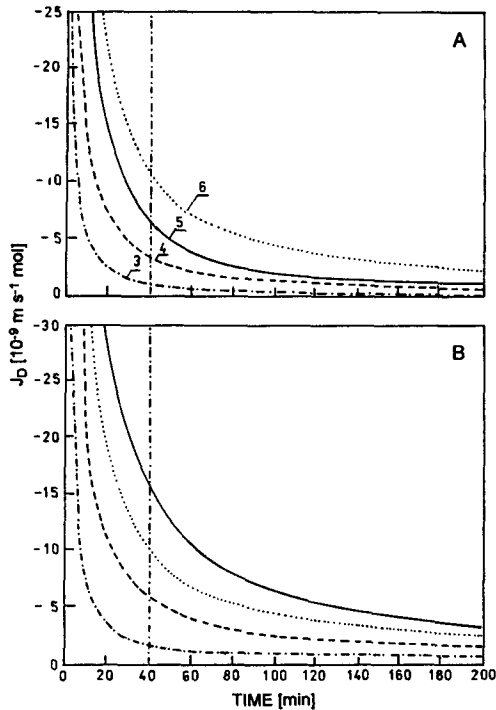


Fig. 6. Changes of diffusion flow (J_D) through tissues of the whole maize plants caused by gradT. The symbols are the same as in Fig. 2.

Effect of the gradT upon variations of the permeability of plant tissues: In 3-d old plants the permeability coefficient attained relatively high positive values immediately at the onset and then dropped (within 30 min) into negative values. In the subsequent 10 min it again rose into positive values where it attained approximately 2/3 of the initial value. In the following 10 min, the permeability coefficient declined into negative values and gradually, as temperatures between compartments levelled, they approached the value of *ca.* -1.5 cm s^{-1} . Similarly altered the permeability of tissues of 4-d old plants. There was a difference in the size of negative and positive maxima and a certain time delay. When using 5-d old plants permeability passed (within 20 min) quickly from high negative into high

positive values and it continuously declined to approximately $0.5 \times 10^{-4} \text{ cm s}^{-1}$ and subsequently slowly rose to the *ca.* $2 \times 10^{-4} \text{ cm s}^{-1}$.

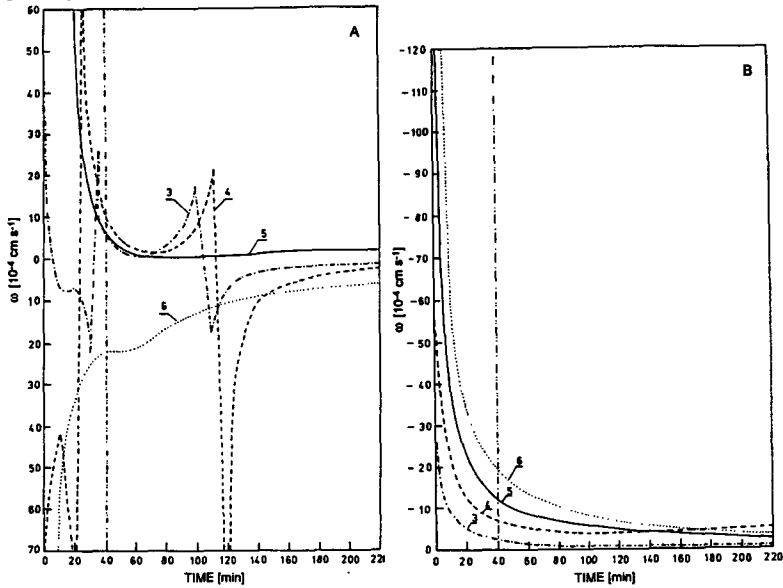


Fig. 7. Changes of the permeability coefficient (ω) of the whole maize plants tissues due to the action of gradT. The symbols are the same as in Fig.2.

The tissues permeability of 6-d old plants varied, on the contrary, only in negative values and it slowly approached *ca.* $-5 \times 10^{-4} \text{ cm s}^{-1}$.

When using 1 % KCl solution (Fig. 7B) the permeability coefficients similarly as in roots (Michalov 1992) were negative by dropping to values *ca.* -0.5 to $-5.5 \times 10^{-4} \text{ cm s}^{-1}$. Permeability was the lowest in tissues of 3-d old plants and highest in 6-d old plants. In 4-d old plants permeability started to rise again after approximately 120 min and exhibited high values after 240 min (more than $-7 \times 10^{-4} \text{ cm s}^{-1}$)

Effect of the gradT upon reflexive coefficients of plant tissues: With rising gradT the reflection coefficient of 3-, 4-, 5- and 6-d old plants declined differently according to plant age and concentration of surrounding solution. The reflection coefficient of plant tissues was closely tied up with their permeable capabilities. The quickly declining permeability was connected with the increase in the reflection coefficient. At the time in which gradT attained maximum, the reflection coefficient of plant tissues was the lowest and the most of the solute components passed through plant tissues. When the temperatures levelled, the reflection coefficient in the case of the 0.5 % KCl solution rose and so less of the solute passed through plant tissues. The lowest reflection coefficient was in the youngest plants, the highest in 5- and 6-d old plants (Fig. 8A). In the case of 1 % KCl solution the reflection coefficient rose with declining gradT the most quickly in 4-d old plants and the most slowly in 3-d old plants (Fig. 8).

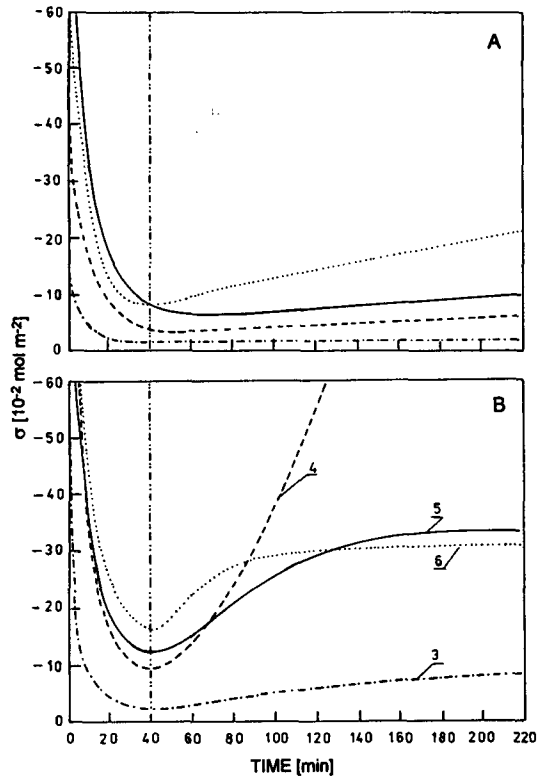


Fig. 8. Changes of the reflection coefficient (δ) of the whole maize plants tissues caused by gradT. The symbols are the same as in Fig. 2.

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