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The possible mechanism for the water transport in the tree trunks in early spring

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Abstract. Modern technologies in the field of forest restoration require the creation of an integrated approach for systematizations all the developed methods and theories. The main difficulty in the concept creating may be an insufficient number of formalized models of processes that ensure the vital cycle of woody plants. The paper suggests a physical model of transport of salt solutions in the xylem of tree trunks in early spring. The flow of mineral ions is carried out in the porous wood of the trunk during this period by the principle of a molecular vacuum pump in which the energy for the movement of the salt solution is consumed from the thermopolarization field of the xylem arising by the change in the ambient temperature. The results of measurements of the potential difference along the tree trunk of the families Betula pendula and Populus tremula were used for interpretation the model. Measurements of the potential difference along the tree trunk were made under natural conditions and the ambient temperature was measured. Analysis of the results showed that the thermopolarization phenomena in the xylem of the trunks can be the basis of the mechanism of sap movement in early spring. Therefore the hydraulic ratios known for ion pumps can be used for the formalized simulation of the process under investigation.

1. Introduction
The conceptual approach plays an important role in modern science. This approach systematizes all known theories into a hierarchical structure. Forest scientists from different countries are looking for integrated approaches to solving the problem of protection and restoration of forests [1–2]. It is necessary to develop formalized models of processes ensuring the life cycle of woody plants for this purpose. For example, physical models of water transport mechanisms in tree trunks can serve as a basis for a conceptual approach to forecast, evaluate and study the state of trees. Consequently such models can be part of the systemic analysis of the ecological state of the environment.

Many works describe the mechanisms and models of water transport in the trunks of woody plants at the present time [3–6]. The basic mechanisms of transport of salt solutions along the tree trunk are transpiration and root pressure according to these works and textbooks on plant physiology [7–8]. However the nature of the mechanism of root pressure has not been fully understood to the present. The phenomenon of transpiration can be formally described using physical models. But the phenomenon of transpiration does not explain the mechanism of sap movement in the early spring, when the trees stand without foliage yet. We investigated the thermopolarization phenomena in wood in an inhomogeneous temperature field [9] and proposed a thermopolarization mechanism for explaining sap flow in the trunks of woody plants in early spring [10]. Thus, the analysis of various literary sources [3–8] has shown that the possibility of the presence of an electric mechanism for the water transport in the tree trunks has not yet been considered. This approach to the problem of water transport may be interesting for a wide range of scientists.

The purpose of this work is to find out how the ambient temperature changes during the day in the early spring, to investigate how the state of the xylem of tree trunks changes at this time, and to evaluate the effectiveness of the thermopolarization mechanism of sap movement.

2. Experimental part

Studies took place on the territory of the Pravoberezhnoye forestry of the training and experimental forestry enterprise of Voronezh State University of Forestry and Technologies named after G.F. Morozov (Russian Federation) in March from 2014 till 2018. The subjects of study were 34 – 50 years old trees of deciduous breeds of the families Betula pendula and Populus tremula of different vital state. Monitoring of the environment state was conducted by measuring the temperature of the air near the trees. An analysis of changes in the mean daily and evening air temperatures in March was made.

Monitoring of the potential difference along the tree trunk was carried out by estimating of the xylem state with changing ambient temperature during the day under natural conditions. The electrodes were implanted into the wood at the center of the trunk and along the trunk radius at equal distances from the center at heights of h = 1.3 m and h = 3 m to measuring the potential difference and providing a relatively stable result in time. Shafts for electrodes with a diameter of 5 mm were drilled in the test samples for this purpose (Figure 1). The electrodes were steel rods insulated to the contact surface (4-5 mm). The electrodes were connected to a portable measuring instrument – the Mastech MY62 digital multimeter (Precision Mastech Enterprises Co., Ltd., Hong Kong) by means of a flexible wire.

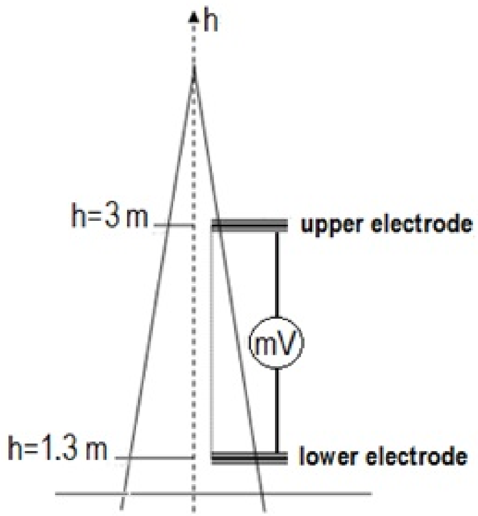

Figure 1. Scheme of measuring the potential difference along the tree trunk.

Investigations of the phenomena of thermal polarization of wood in an inhomogeneous temperature field underlie the methodology for studying the response of xylem tree trunks to changes in ambient temperature [9]. Partially crystalline fiber-forming cellulose and amorphous lignin (high molecular substances) are the main components of the cell walls of wood. This allows us to simulate the xylem of the trunk as a polymer composite with a reinforcing component – cellulose and filler – lignin. The coefficient of thermal expansion of lignin is much higher than the same coefficient for cellulose. Therefore a change of the external environment temperature leads to the expansion or contraction of lignin. It causes deformation of cellulose crystallites. It is known that cellulose has pyroelectric and piezoelectric properties. Therefore the deformation of its piezocrystals in the field of spontaneous polarization will cause the appearance of an electric field of thermal origin. The magnitude of the field potential difference is directly proportional to the temperature inhomogeneity and depends on the moisture content and structural features of the xylem wood [9]. An inhomogeneous temperature field arises along the radius of the tree trunk at the ambient temperature changes. It leads to the electric field appearance. The characteristics of the electric field depend on the structure of the xylem, its humidity and the radius of the trunk. The radius of the tree trunk decreases with height. Therefore, the potential difference arises along the trunk also. The potential difference can stimulate the movement of salt solutions in the xylem along the tree trunk theoretically [10].

3. Results and discussion

It is known that a gradual increase of temperature occurs in the early spring (in March). The temperature difference between night and day begins to increase at the same time. The results of the statistical distribution analysis of the difference of daily and evening temperatures in March are shown in figure 2: N(%) is the probability of hitting the temperature difference into the interval ΔT(°C) in the figure. The daily temperature was measured near 15.00 hours. The evening temperature was measured after sunset between 9 pm and 10 pm. Observations of the last five years confirm the typical nature of this distribution.

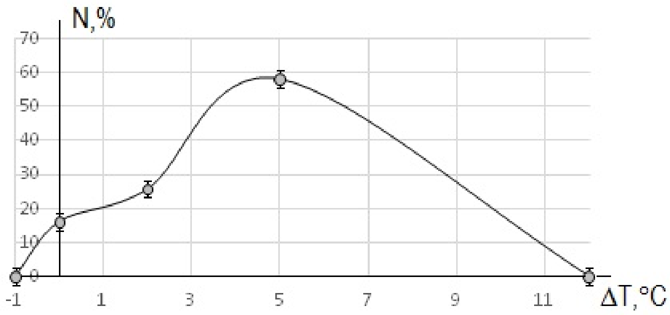

Figure 2. The distribution of the probability of the difference in temperature of day and night in March.

The given data show that a change of the ambient temperature by 5 degrees at the change of day and night has the greatest probability (about 60%) during the active spring sap movement. The T/T_{max} value is 90-95% for this temperature change.

Experimental studies have confirmed that the potential difference arises along the trunk when the ambient temperature changes. This potential difference depends on the time little and depends on the changes in the ambient temperature substantially. The daily dynamics of the relative ambient temperature (T/T_{max}) and the relative potential difference (U/U_{max}) along the tree trunk between points at heights of 1.3 and 3 m located at a distance from the trunk axis of 0.25*R* (*R* is the trunk radius at height *h* = 1.3 m) in the live (Birch tree1 and Birch tree 2) and the dead (Birch tree D1, Birch tree D2) birches are shown in Figure 3.

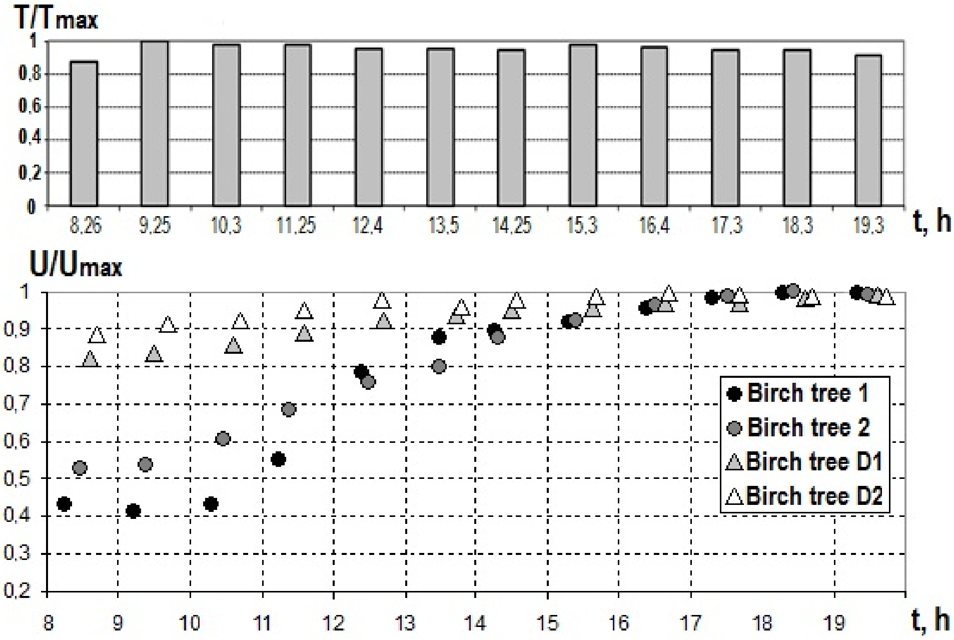

Figure 3. The daily dynamics of the relative ambient temperature (T/T_{max}) and the relative potential difference (U/U_{max}) along the tree trunk.

These results allow us to make an assumption explaining the intense sap flow in the absence of transpiration currents in the early spring. It is easy to imagine that the flow of mineral ions is carried out in the porous wood of the trunk by the principle of a molecular vacuum pump. The energy for the motion of the salt solution is consumed from the thermopolarization field of the xylem when the ambient temperature changes at this time. It is necessary to estimate the potential difference needed to raise the salt solution in the tree trunk to the required height h to check the assumption. The excess pressure required to transport the solution to a height h is determined from the ratio according to the basic physical laws:

$$p=\rho gh\ , \tag{1}$$

where ρ is the density of the solution, g is the acceleration due to gravity, and h is the lift height. The pressure created by a stream of salt ions in a field with a potential difference U can be estimated as the ratio of the work of the electric field A_U to the volume of the solution V. The ratio is determined by the ratio according to the laws of electrostatics as:

$$p = A_u / V = \sum_i^k n_i q_i U, \tag{2}$$

where n_i is the concentration of ions of the i-th salt, q_i is the charge of ions of the i-th salt. Suppose that the losses are unimportant when the current flows. We take into account the expression for the concentration of salt ions:

$$n_i = \frac{\rho_i}{m_i} = \frac{\rho_i}{\rho m_i}\rho = C_i \frac{\rho}{m_i}, \tag{3}$$

where C_i is the fraction of the i-th salt content in the juice solution, m_i is the mass of the i-salt molecule. The expression for the estimation of the potential difference needed for lifting the solution to the height h is obtained from the relations (1) and (2) with allowance for (3) in the form:

$$U = \frac{gh}{q_i / m_i C_i} \cdot \tag{4}$$

It is known that the concentration of nitrogen cations increases in the early spring. The using of relation (4) gives a magnitude of the order of several millivolts for the potential difference U needed to raise nitrogen cations at $C = 0.01$ to a height $h = 30$ m. The total potential difference can range from several units to several hundred millivolts, taking into account the complexity and differences in the composition of the juice of different trees. And the potential difference formed as a result of the change in the ambient temperature is 5 – 200 mV according to our measurements in tree trunks.

4. Conclusion

Our studies allow us to draw the following conclusions. Experimental studies have shown that the potential difference arises indeed along the trunk when the ambient temperature changes. The value of this potential difference depends on time weakly and correlates with changes of the ambient temperature. The results of estimating the potential difference needed for transporting the salt solution to a certain height coincide with the values of the magnitude of the potential difference measured in the trunks of the experimental trees.

Similar coincidence of the magnitudes of the potential difference suggests that the thermopolarization phenomena in the xylem of the trunks can underlie the mechanism of sap movement in the early spring. Thus, the theoretical relationships (1), (2) and (4) can be used to simulate the transport of salt solutions in the xylem of woody plants in early spring. And the measured potential difference can become a key parameter in assessing the vital condition of trees and the common ecological situation.

References

[1] Stucki V and Smith M 2011 Integrated Approaches to Natural Resources Management in Practice: The Catalyzing Role of National Adaptation Programmes for Action *Ambio* **40**(4) 351

[2] Reinecke S and Blum M 2018 Discourses across Scales on Forest Landscape Restoration. Pesticide productivity and food security *Sustainability* **10**(3) 613

[3] Kim HK, Joonghyuk K and Hwang I 2014 Investigating water transport through the xylem network in vascular plants *J. Exp. Bot.* **65**(7) 1895

[4] Meinzer FC, Clearwater M and Goldstein G 2001 Water transport in trees: current perspectives, new insights and some controversies *Environ. Exp. Bot.* **45** 239

[5] Kumar R, Shankar V and Jat MK 2014 Evaluation of root water uptake models – a review *Ish J. Hydraul. Eng.* **21**(2) 115

[6] Pfautsch S, Hölttä T and Mencuccini M 2015 Hydraulic functioning of tree stems – fusing ray anatomy, radial transfer and capacitance *Tree Physiol.* **35**(7) 706

[7] William G. Hopkins and Norman P.A. Hüner 2010 *Introduction to Plant Physiology* (John Wiley & Sons, Inc) p. 523

[8] Taiz L, Zeiger E 2002 *Plant Physiology* (Sunderland: Sinauer) p. 690

[9] Matveev NN, Sidorkin AS, Kamalova NS, Evsikova NYu and Lisitsyn VI 2016 Emergence of differences in potential in wood as a result of natural changes in temperature. *Bull. Russ. Acad. Sci. Phys.* **80**(9) 1158

[10] Matveev NN, Kamalova NS, Evsikova NYu and Lisitsyn VI 2014 Thermopolarization mechanism of sap movement during the spring equinox *Forest Engineering Journal* [in Russian – Lesotekhnichesky Zhurnal] **4**(16) 26