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STUDIES OF METEOROLOGICAL FACTORS INFLUENCE UPON AIR AGROPHYSICAL CHARACTERISTICS IN CANOPY ON THE BASE OF PHYSICAL AND MATHEMATICAL SIMULATION

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A b s t r a c t. Energy- and mass transfer processes in the 'soil-plant-air' system determine in great degree agrocenosis functioning and agricultural crop yields formation. Theoretical and experimental investigations of these processes are rather difficult, since their intensity and characteristics depend on the motion of energy- and mass carriers. Carrying out natural full factorial experiments, based on theoretical investigations, is laborious and practically non-reproducible because of sporadic character of the weather conditions. Laboratory physical methods of simulation energy- and mass transfer processes in 'soil -plant-air' system permits to repeat experiments many times with high degree of reproduction and visualization. Such methods give the possibility to verify and identify mathematical models, to obtain for their structure a priori information on whirlwinds formation, regular structures existence, motion kinds, space arrangement of boundaries of media and motion bifurcal values of parameters, determining the energy-mass streams structure.

The report also concerns the problems of the applications of the hydraulic analogy, based on magnetohydrodynamic effects generation in water solution electrolytes, for the purposes of simulation of wind interaction process in floral zones. The report contains the description of the mathematical model under discussion, numeric analysis, the laboratory experiment technique and physical simulation results.

K e y w o r d s: physical-mathematical simulation, agrophysical characteristics, air, canopy, magnetohydrodynamic effects

INTRODUCTION

This report presents the laboratory-scale method of physical modelling of interaction between surface layer of air and vegetation - such hydraulic analogy permits to study influence of the wind on the air properties in the near-ground layer of plants. The distinguishing feature of the above method is the excitation of plane parallel flow of thin aqueous electrolyte layer by magnetohydrodynamic method [1], which allows fine controlling of velocity magnitude and distribution in the horisontal layer of the fluid and comprehensive study of its interaction with obstacles, consequently, simulation of the mass-transfer process in the vegetation cover [2].

Two examples are viewed to confirm the correlation between theoretical predictions and experimental data, measured on the base of above technique:

- interaction between wind and homogeneous non-limited-extent floral vertical layer;
- interaction between horizontal layer of air and finite-size obstacles of given permeability, modelling forest belts of various types, e.g., shelter belts, lines of trees, wings, espaliers.

MATHEMATICAL MODEL OF INTERACTION BETWEEN WIND AND HOMOGENEOUS VEGETATION

The horizontal homogeneous structure is one of the most popular among floral zones and field crops. As a horizontal size of the crops of above structure is significantly larger compared to height of individual plants and inherent spatial pattern of wind velocity and its fluctuation in the surface air layer, turbulent air flows are usually adopted as steady and isotropic in the horizontal plane. To investigate the phenomena, characterizing such system, the mathematical model (Fig. 1a), simulating steady air flow above and inside the vegetation layer has been developed by one of the authors [4,5].

Numeric solution of the derived set of equations has been found, which in conditions of homogeneous crop allowed to study the behaviour of the lower boundary of turbulence, thus revealing the relation between wind-carrying capacity and geometric parameters of vegetation (density *S* (*z*), height of the plant *h*, plant aerodynamic drag coefficient *Cf*, wind velocity *V* (*z*) at different levels above vegetation cover, intensity of air flow turbulization, etc.). To illustrate the calculations, we represent the curves of wind-carrying capacity and the average flow velocity at the upper boundary of the floral layer versus various geometrical and dynamic floral properties (refer to Fig. 1b and 1c, respectively).

On the base of theoretical study and numeric estimation [4,5] the decision has been made about formation of three zones, which featured different kinds of air movement. Analysis of the formulae confirms the suggestion that for homogeneous vegetation of any given geometric and aerodynamic characteristics the wind flow parameters may be specified that provide the condition of full wind-carrying capacity through the height of the vegetation from the ground to the top. The floral cover, just mentioned, which is permeable to wind penetration within and inside, depending on its parameters and wind velocity, in terms of hydrodynamics may be adopted as 'permeable roughness'.

To prove the obtained results in laboratory experiment as well as to verify the correct definition of the model (with or without modifications) the following technique of physical simulation has been developed.

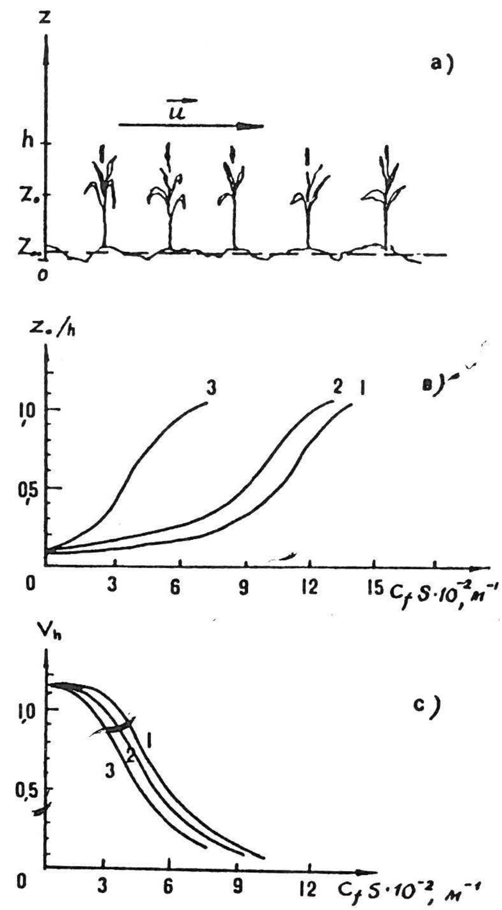

Fig. 1. Results of calculation of mathematical model for aerodynamical process within the homogeneous floral layer. a) Diagram for model calculation; b) Wind-carrying capacity for floral layer related to geometric and dynamic factors $z_0/h=f(Cf\ S)$; c) Average wind velocity at level of plants height Vh for different plant characteristics Vh = f(Cf S); z_0- lower boundary of ventilation-ability in the floral layer; z_{av} - upper boundary of soil roughness; h - plants' height, V - velocity of wind, blowing above vegetation; Cf - aerodynamic drag coefficient for the vegetation; S - its density; 1. h=0.5 m; 2. h=1.0 m; 3. h= 2.0 m.

Experimental technique

Fig. 2 shows the scheme of the experiment. The set of cylindrical elastic needles has been used to simulate the permeable roughness (vegetation layer). The aqueous electrolyte N 1.5 $CuSO_4$ has been chosen as a solution (energy-carrier medium). The plate included the set of cylindrical needles (length 15 mm, diameter 1-2 mm, bifurcate tips) was mounted on the side wall of the cell (diameter 300 mm, depth 20 mm). Needles gathered in

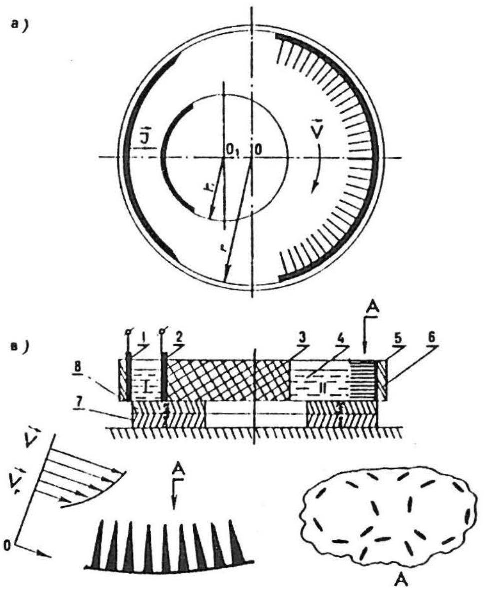

Fig. 2. Experimental instrumentation for simulation of the wind flow above the floral layer (a) and structure of permeable roughness (b); 1, 2 - copper electrodes; 3 - insert (acrylic plastic); 4 - electrolyte; 5 - cell; 6 - structure of polyethylene needles, forming permeable roughness; 7 - ferrite rings; 8 - bottom of the cell. Velocity diagram (b): Vh - flow velocity at the boundary between fluid and roughness; V - flow velocity in the middle part of channel II; A - needles at the cell wall; I - area of flow generation; II - flow area under investigation.

circular cells units (by 6 needles in each unit) were staggered with 10 mm and 6 mm steps in longitudinal and lateral planes, respectively. In the central part of the cell, the cylindrical insert was mounted in off-centre position to form two parts I, II of curved channel structure and to generate the flat parallel flow incoming over needles. Attached to the side walls of the channel I, the copper electrodes were connected to the source of stabilized direct current I varied in range from 0 to 10 A. To generate constant magnetic field with vertical component B Ij, where j - current density in channel I, two ferrite rings of 180 mm diameter chosen for this experiment were magnetized (Fig. 3), B=0.8 Tl. Due to the influence of crossed electrical and magnetic fields, magnetohydrodynamical flow generated in the part I of the channel, activates the process of fluid circulation in the channel. The experimental set-up provides shift flows of velocities 0 to 35 cm/s in the space II. This allows to simulate generation and supporting by the average movement of turbulence in the permeable roughness, as well as the disturbance which permeable roughness brings into the upper boundary layer.

Moreover, the present system may be used to simulate non-homogeneous obstacles, forming the flows in front or behind the roughness. In this case, the particular interesting are the structures of boundary eddies and processes of transfer along and around the obstacles, as these may be used in modelling and studying of behaviour of forest belts and other lines of plantations [3-7]. In this case the model of permeable roughness is located in the part II of the channel across the flow. Because of the low velocities of the electrolyte movement and chosen dimensions of part II of the channel, curvature of the latter is unsufficient to enforce the generated flow parameters. It may be accepted that this flow is very close to flat parallel one.

To visualize the flow structure and further to simulate the process of impurities transfer by the wind the aluminium powder was chosen, the picture was taken on the MIKRAT-300 film with exposures of 1-4 s. Knowledge of the exposure is necessary to determine the velocity of flow in the chosen spot of the space.

Simultaneously with photographing, the visual measurements of the velocity has been provided, which demanded to determine the time of running of the given distance by the indicator particles.

RESULTS OF THE LABORATORY EXPERIMENT

Figure 3 illustrates the qualitative picture of interaction of quasi-flat-parallel steady flow and underlaying troughness of above mentioned type in relation to different flow velocities. It may be seen in Fig. 3a, that in

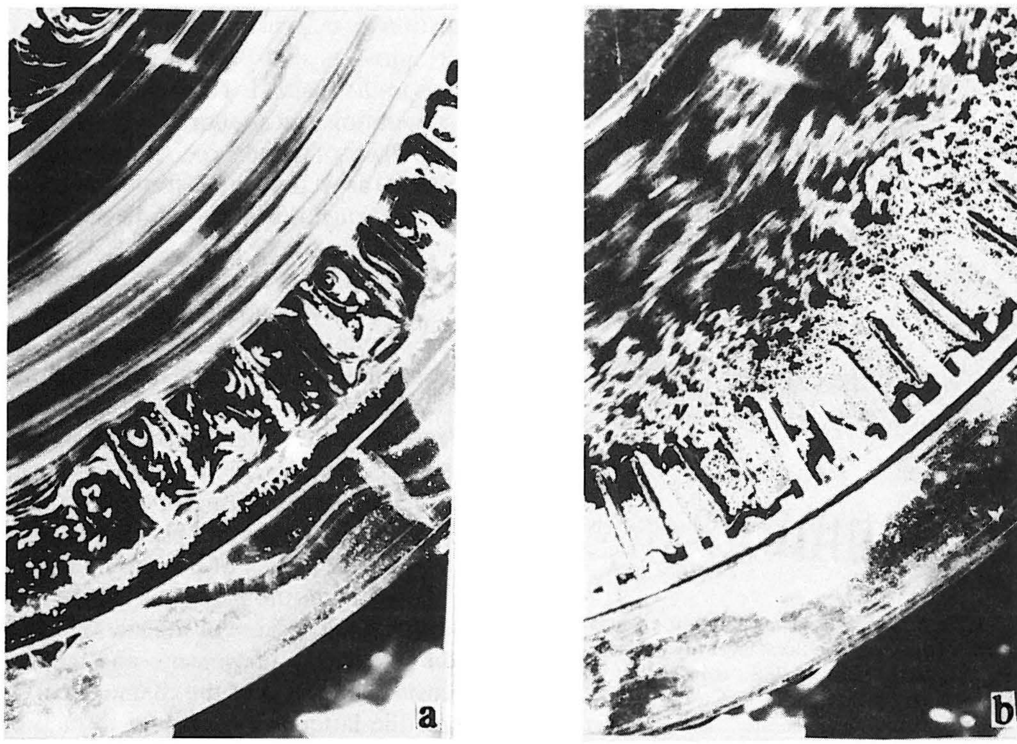

Fig. 3. Photo of interaction area wherein fluid interacts with model of homogeneous vegetation at different currents in channel I. Camera: ZENIT; Film - MIKRAT-300. a) I=0.2 A; Vh=0.6 cm/s; b) I=6 A. Vh=(7-8) cm/s.

condition of velocities *Vh* approx. 0.6 cm/s, I=0.2 A, the flow is not yet over the roughness area, i.e., z_0 is approx. *h* (Fig. 1a), but with enlarging the electrolyte velocity value, inside the set of the needles the generation of the eddy structures may be noted which have the scale close to the distance between needles and velocities of order 0.2 *Vh* (Fig. 3b). The average velocity of the flow at the middle line of the channel in the area II reaches *Vav*=(15-20) cm/s at current I=(8-10) A.

Figure 4a shows the velocity variation in the central part of the channel (curve 1) and at the level equal to the height of the needles (curve 2) relative to the current.

Figure 4b cumulated the data, which illustrate the broadening of the permeable roughness limits versus velocity raise of the flow above it, i.e., z_0 changes from $z_0=h(Vn=0)$ to $z_0=0$.

Comparison of above results and actual practical data, gathered along the vertical profile of maize plants in field conditions, demonstrates that all of the parameters of the production process, particularly photosynthesis, are directly related to the illumination and the wind-carrying capacity of the crops [6].

Minimum velocity of the change processes is provided at the lower tier of leaves despite highly developed foliage surface.

The technique described in this paper allows to simulate the interaction of the wind and floral horizontal permeable breaks. In this case quasi-two-dimensional permeable roughness is used instead of one-dimensional one. The phenomena were studied in the horizontal layer instead of vertical (Fig. 5). This approach allows to vary the velocity of incoming flow from 0 to 30-40 cm/s. The density may be also varied. The space localization

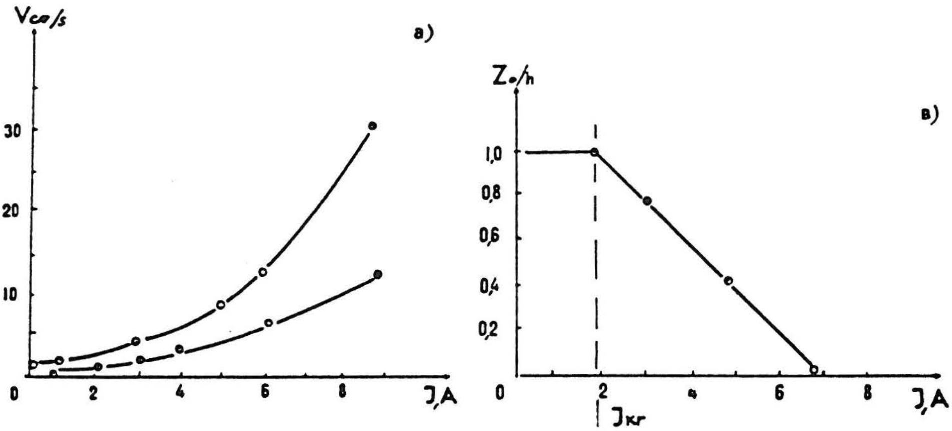

Fig. 4. Relation between flow velocities (a) and level of turbulent flow permeability in the model of vegetation z_0/h (b) and current I. 1. V=f(I) at $z=r_{av}+h$. 2. V-f(I) at z=h.

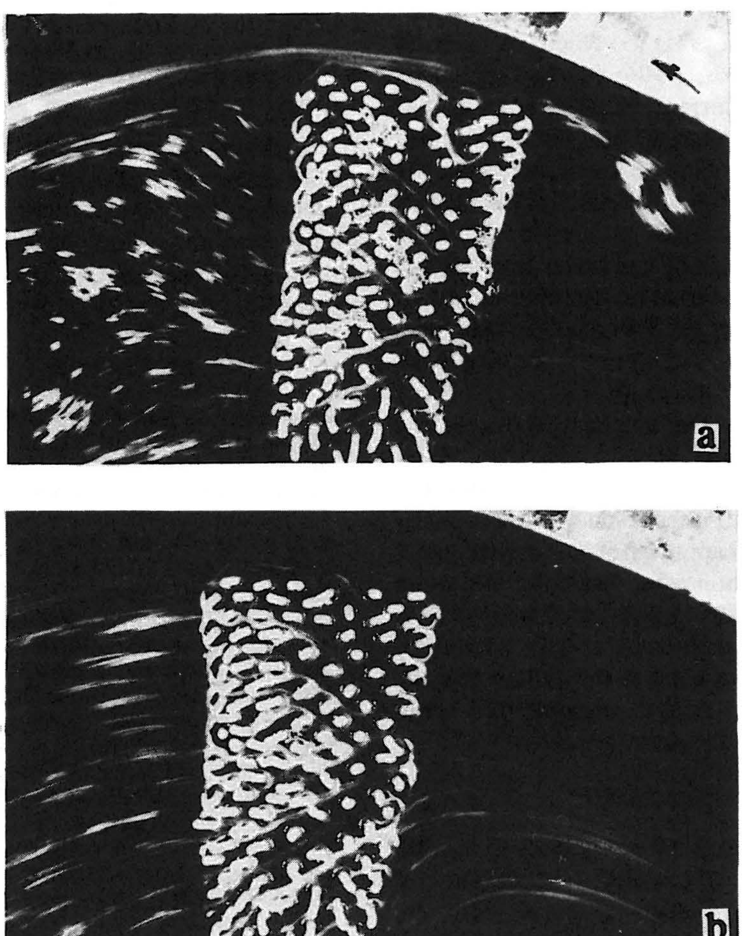

Fig. 5. Photos of electrolyte flow structure formed as a result of its interaction with limited-size model of homogeneous vegetation. Diaphragm 5.6; exposure time 4 s; film MIKRAT-300. a) I=100 mA b) I=400 mA. The model of roughness is located in channel II (see Fig.2).

of forest lines may be simulated by changing the distance between them.

Comparing previous theoretical developments in field of mathematical models of processes in similar structures and in the boundary layers [7], it may be noted:

This approach applied to simulation problem is apparently useful and can be implemented and improved upon in the development of the vegetation breaks, choice of their parameters, e.g., it allows to determine the areas of the whole impenetrability for wind at relatively low velocities of incoming flows, which corresponds to threshold velocity magnitudes. Figure 6 shows the flow velocity ratio received in the experimental set-up, where the velocity in front of permeable roughness *Va* to velocity at the back of roughness *Vb* (*Vb*/*Va*<1) was measured in relation to current. It may be noted that at currents lower than 50 mA, *Va* (1-5) mm/s, whereas after going through the break the flow disappears (*Vb*=0). With the current raise, the obstacle becomes permeable, moreover this dependence is of non-linear type. So, this approach may be used to determine the extent of disturbance of the flow after the roughness has been passed, and to reveal the eddy areas and their characteristics.

Changing of the roughness width, density or its transparence allows to design the adequate models to reveal the optimum structures of vegetation belts. Further evolution and improvement of present approach should evidently provide the transition from qualitative evaluation to full-scale simulation and to development of necessary basic criteria and specific recommendations. It is the hope of the authors that the method applied could be encountered in urban building as well as in training process.

CONCLUSION

The synthesis of mathematical and laboratory physical methods of modelling and simulation of interaction plants with the near the ground layer of atmosphere is comfortable, economic and perspective.

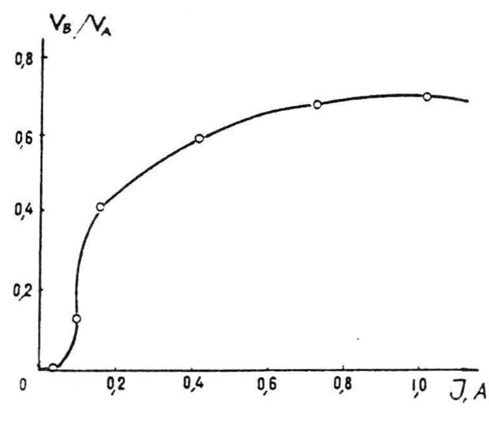

Fig. 6. Relation between attenuation of incoming flow velocity in the roughness edge centre (point A) and current in channel I (experimental data). Vb/Va=f(I), where Va - flow velocity in point A, Vb - flow velocity in point B, located on the 'roughness stern', i.e., after flow has passed the roughness. The instrumentation equipment - see Fig. 5.

The hydraulic analogy permits to receive quality estimations of dynamic energy-mass trasfer in various plant structures in case of wide spectra of agrometeorological factors, verify and indentify mathematical models of permeable roughness hydrodynamics.

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