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The Cybernetics of Hydroamelioration Processes and Simulation Models

1. INTRODUCTION

Usually, we mean by hydromelioration work a heterogeneous group of preoccupations aiming to settle vegetation factors, such as: humidity in the soil and/or chemical compounds to be found in the radicular zone of the plants for creating favourable conditions for the growing of agricultural crops. This work consists of irrigation, draining to which might be added the refertilization of the agricultural soils degraded by rains, floods, polluted waters, industrial-mining work, etc.

The finding of most reasonable ways for the technical-economic solving of these hydroamelioration problems under the present conditions of reducing the consumption of energy incorporated into the agricultural product, of combatting the pollution of environment, of decreasing the water resources usable by man and of vertiginously increasing the demand for agricultural products requires the more careful examination of the way in which the processes of water migration into the soil are taking place, eventually by using, on a large scale, the modern methods of mathematical modelling.

Theoretical preoccupations in this respect are to be found in the literature of speciality [7], and the publications of some organizations of prestige, such as ASAE (American Society for Agricultural Engineering) or A.G.U. (American Geophysical Union through the publication Water Resources Research), etc. have already published several mathematical models meant to solve such problems.

The aim of this study is to establish a methodology of modelling the evolution in time of the complicated hydroamelioration phenomena which by rapidly and precisely investigating the physical and economic implications, should be able, in the end, to substantiate one technical decision or another. *Two distinct parts can thus be distinguished in the proposed methodology:*

the simulation model of the physical phenomenon and the optimization economic calculus.

The simulation model is based on the fact that each process is conceived as being a cybernetic system with selfadjustment and which has as an expression a ratio which is solved through finite differences.

The choosing of the most adequate technical method out of a suite of proposals for the adjustment of a vegetation factor is made by taking into consideration not only its economic efficiency (investment, annual expenditure and/or profits) but also the functionality of the method, its reliability synthetically expressed by productivity.

2. THE FUNDAMENTAL LAW OF HYDROAMELIORATION CYBERNETIC PROCESSES

[1], [7], [8] consider that the evolution of vegetation factors (water and salts and the organic substances in the soil, etc.) in time and space can be represented in its transient plenitude, in the form:

$$\delta U/\delta t = \delta(D\delta U/\delta z)/\delta z \qquad (1)$$

where:

U = the vegetation factor: water, mineral salts nourishing or inhibitive to the process of vegetal synthesis, eventually chemical substances brought into the soil by the polluted waters, etc. (cm^3/cm^3);

D = complex factor describing the space diffusiveness of factor U (between the soil layers) (cm^2/s);

t = time;

z = space.

Equation (1) is valid for the unidimensional systems, in which gravitation has a decisive role.

Ample reference to eq. (1) is to be found in the literature of speciality and which derives from the well known Darcy's theory of circulation of water into the soil, adapted to the unsaturated mediums.

Having been used at the beginning for establishing the laws of water, infiltration into the soil, it was gradually extended for calculating the suction of the soil which is closely linked to the share of soil humidity. In this way new relations have come to be validated for the calculus of the water consumption on the agricultural soils which, in contradiction to the previous formulations take into account, in the first place, its momentary humidity. It was thus proved that the more water the soil has lost, the more it is slackening its drying process in accordance with the well known process characteristic of the cybernetic systems of selfadjustment.

We shall consider another case where U expresses the quantity of salts in the soil (transitivity in the form of solution). In this way, a law on the salination of soil and /or of its washing, can be established. Bressler gives an equation for the migration of salts in this direction by simultaneously taking into account both the momentary humidity of the soil and its content in salts.

Considering that U represents the quantity of organic substances brought by the polluted waters on the irrigated agricultural lands, a law can define on their decomposition and redistribution into the soil.

Finally — without being the last possible case — U may be considered to represent the quantity of nitrogen in the soil resulting from natural and /or artificial sources and the way in which it is stored or washed by irrigation waters in the unexplored layers.

The solving of equation (1) by finite differences, on time steps, leads after some simplifications to ratios of the type:

$$(U_z^{t+1} - U_z^t)/\Delta t = [\bar{D}^t_{(z+1;z)}\ U^t_{z+1} - U^t_z) - \bar{D}^t_{(z,z-1)}(U^t_z - U^t_{z-1})]/\Delta z^2 \quad (2)$$

or, in the form which may be used in calculating the simulation of the time process for layer Z at time $t+1$:

$$U_z^{t+1} = \Phi(U^t_{z+1}\ ;\ U^t_z;\ U^t_{z-1}) \quad (3)$$

where Φ represents a transformation which takes into account both the technical method applied and the natural conditions (rains, temperature, etc.).

This equation may often be found in the literature of speciality and we shall call it the pilot equation of the model because it expresses the evolution of factor U in the period of time from t to $t + 1$ and for the Z soil layer in keeping with the condition of the same factor U at the previous time in the surrounding space (layers $z + 1$, $z - 1$ and, of course, z too).

The graphic expression of ratio (3) is presented in Fig. 1.

The idea is inferred from Figure 4 that to calculate the recurrent value U_z^{t+2} it is necessary to know conditions U_z^{t+1} and U_{z-1}^{t+1}. It is possible by using

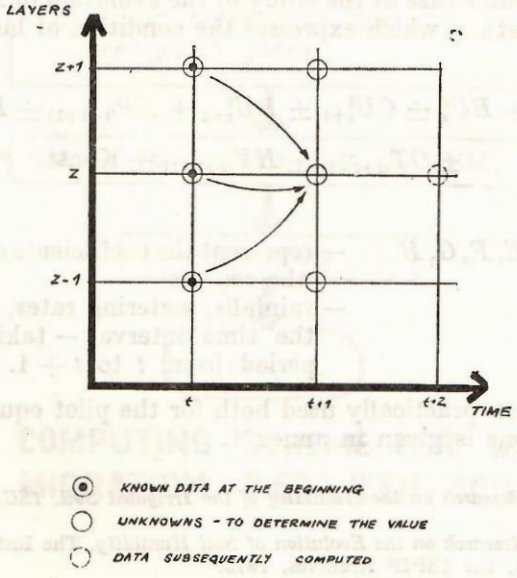


fig. 1: COMPUTING SCHEME

equations called recurrence equations. These equations have forms similar to those for the forecast of hydrological elements, namely the average value of quantity U in the evolution of the process is also taken into consideration.

Equation (3) is brought to a calculable form through the processing of experimental data from the soil with the aid of multiple correlations. For this, the authors have used a routine (REMUS) drawn up by the researchers of the Laboratories of the Department of Economic Cybernetics of the Academy of Economic Studies.

3. SIMULATION MODEL

The general logical scheme used for the study of water migration between the soil layers looks like in Fig. 2, where the place of the pilot equation (A) is indicated as expressed in equation (3) and of the recurrence equations (B).

The analysed model has referred to the establishment of a method which should allow the observation of the evolution in time and space of the humidity of the irrigated and non-irrigated soils.

To this purpose, the studies made by Rasucean E. *(1969—1974) on the evolution on the humidity of irrigated soils in the Bărăgan and Dobrudja as well as the works of professor Andrei S**. on the suction of soils have been used.

The experimental data consisting of observations on the humidity of five soil layers (table 1) for a one year period (the vegetation period) but, under various irrigation regimes (without irrigations with various irrigation rates applied at various intervals, etc.) have been processed in the form of equations of multiple correlation with the aid of the REMUS routine and the results are presented in annex 1.

In the particular case of the study of the evolution of humidity U of the soil, the pilot equation, which expresses the condition of humidity of a layer z, will be:

$$U_z^{t+1} = \pm A U_{z+1}^t + B U_z^t \pm C U_{z+1}^t \pm D U_{z+2}^t + E P_{(t \div t+1)} \pm F M_{(t \div t+1)} \pm \quad (4)$$
$$\pm G T_{(t \div t+1)} \pm H V_{(t \div t+1)} \pm \text{Konst}$$

where:

A, B, C, D, E, F, G, H	— represent the coefficients calculated through the routine
P, M, T, V	— rainfalls, watering rates, temperature and the time interval — taking place in the period from t to $t+1$.

The expression practically used both for the pilot equation and for the recurrence equations is given in annex 1.

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* *Studies and Research on the Humidity of the Irrigated Soil. ISCIF* 1972 (Manuscript) ISPIF.

** *Studies and Research on the Evolution of Soil Humidity.* The Institute of Engineering, Bucharest, Manuscript, the ISPIF Archives, 1973.

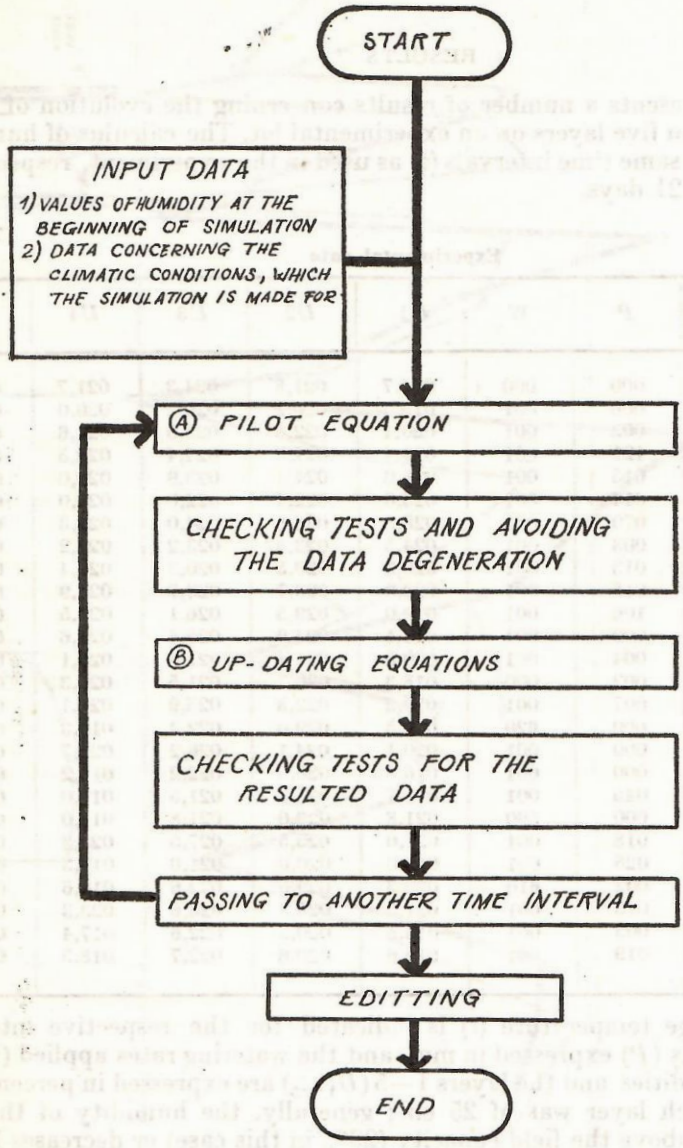


fig. 2: **COMPUTING SCHEME FOR WATER MIGRATION BETWEEN SOIL LAYERS**

The simulation model envisages a number of tests having the preventive role of maintaining the values resulting in the explored field of experience and of practice in general, preventing the degeneration of the calculated data. The control computation and standardization of the model represented a separate preoccupation.

4. RESULTS

Table 1 presents a number of results concerning the evolution of humidity of the soil on five layers on an experimental lot. The calculus of humidity was made at the same time intervals (z) as used in the experiment, respectively from two up to 21 days.

Table 1

Experimental data

t	T	P	W	$U1$	$U2$	$U3$	$U4$	$U5$
00		000	000	024,7	021,8	024,3	021,7	023,9
21	09,0	006	001	019,5	020,2	020,2	020,0	020,6
06	13,0	003	001	020,4	022,8	023,5	021,6	020,1
12	15,0	121	001	029,4	027,8	024,4	022,5	019,8
08	17,0	015	001	026,0	024,4	023,9	022,0	020,9
09	19,0	014	001	023,0	022,4	022,0	021,0	021,1
07	17,0	070	001	028,3	026,6	024,0	022,8	022,1
07	19,0	003	001	024,5	023,5	023,2	022,2	021,3
13	21,0	013	001	020,3	020,5	020,3	020,4	019,8
05	15,0	015	001	022,0	023,7	023,7	021,9	020,2
04	16,0	106	001	029,0	029,5	026,1	023,5	021,6
03	19,0	000	001	025,1	024,9	025,4	022,6	020,0
07	21,0	004	001	020,8	021,4	021,8	020,1	019,9
07	22,0	002	000	018,3	020,7	021,5	020,3	019,1
03	17,0	007	001	019,3	022,8	023,9	021,1	018,4
02	23,0	000	620	023,5	029,0	022,4	019,3	019,2
02	27,0	000	001	020,1	024,1	026,2	022,7	014,9
02	23,0	000	001	016,6	020,5	022,2	018,2	016,4
07	26,0	045	001	017,7	021,3	021,5	019,0	016,8
03	25,0	000	590	021,8	029,0	021,8	019,0	018,4
02	25,0	018	001	021,0	025,5	027,5	023,3	013,7
09	23,0	028	001	017,0	020,0	021,0	017,3	015,1
04	19,0	002	610	022,3	029,0	022,6	018,6	018,7
04	18,0	013	001	021,3	025,8	028,6	023,3	013,9
06	18,0	005	001	016,5	020,3	022,6	017,4	015,3
09	17,0	019	001	015,6	020,6	022,7	018,5	015,8

The average temperature (t) is indicated for the respective interval, the precipitations (P) expressed in mm. and the watering rates applied (W) in m^3/ha. The humidities and the layers $1-5$ ($U_{1...5}$) are expressed in percentage; the depth of each layer was of 25 cm; generally, the humidity of the soil cannot increase above the field capacity (29% in this case) or decreases below 19% without the plants suffer. Comparing the resulting data to the experimental ones a good concordance is noticed, differences also existing, which are explainable by the experimental errors, of approximation through the method of correlations used, etc.

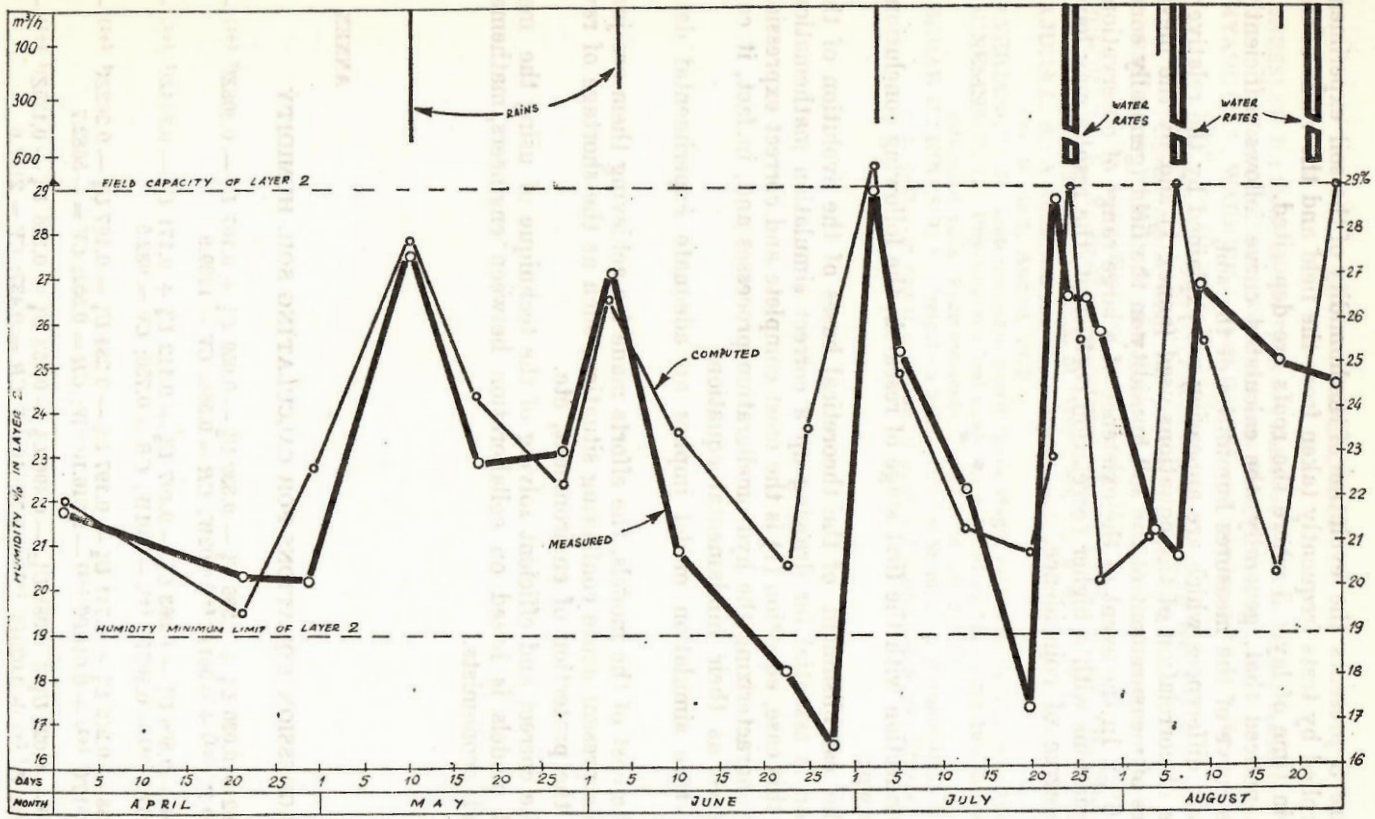


fig.3: EVOLUTION OF HUMIDITY IN TIME AND IN THE SOIL LAYER NUMBER 2 AFTER EXPERIENCES AND COMPUTED WITH THE SIMULATION MODELS

Figure 3 presents the evolution of the humidity of the soil experimentally controlled by tests frequently taken from the field and the value of the humidity in time of layer 3 where the roots are deposited.

It is noticed that, generally, the calculated curve follows sufficiently closely the curve of the measures humidities of the soil.

Certain differences which are appearing are explained by the relatively low degree of correlation of the equations used (annex 1) and by the inevitable errors of measurement of the soil humidity in the field (generally comprised 4—6%). In the event of the existence of a large range of observations also for equations with a higher correlation coefficient, the results may have a higher degree of coincidence.

* * *

In connection with the first stage of research, the following conclusions can be drawn:

1. The establishment of the theoretical bases of the evolution of the phenomenon is essential for drawing up a correct simulation mathematical model. In this case, equation (1) is the most complete and correct expression known for characterizing the hydromelioration processes and, in fact, it can be considered as their fundamental equation.

2. A true simulation model implies an adequate experimental data base.

3. The cost of the models, the efforts made for achieving them are justified in the present acute conflicting situation, such as the shortage of raw materials, the protection of environment, etc.

4. The correct and efficient solving of the technique of using the mathematical models is based on collaboration between engineers, mathematicians and economists.

ANNEX 1

REGRESSION EQUATIONS FOR CALCULATING SOIL HUMIDITY

$$U_2^{t+1} = 22.562 + 0.080\,U_1^t + 0.386\,U_2^t - 0.339\,U_3^t - 0.059\,U_4^t + 0.167\,U_5^t - 0.308Z^{(t\ t+1)} - \\ - 0.20\,T^{(t\ t+1)} + 0.061P^{(t\ t+1)}\,0.02W;\ CR = 0.568;\ CV = 1739.9$$

$$U_1^{t+1} = 12.76 + 0.806\,U_1^t - 0.063\,U_2^t - 0.407\,U_3^t + 0.112\,U_4^t + 0.171\,U_5^t - 0.344Z^{(t\ t+1)} - \\ - 0.20T^{(t\ t+1)} + 0.103P^{(t\ t+1)} - 0.01W;\ CR = 0.756;\ CV = 982.5$$

$$U_3^{t+1} = 25.588 - 0.252\,U_1^t + 0.711\,U_2^t - 0.197\,U_3^t - 0.284\,U_4^t = 0.167\,U_5^t - 0.262Z^{(t\ t+1)} - \\ - 0.251T^{(t\ t+1)} + 0.018P^{(t\ t+1)} - 9.316.10^{-4}W;\ CR = 0.552;\ CV = -5682.7$$

$$U_4^{t+1} = 18.39 - 0{,}022\,U_1^t + 0{,}388\,U_{22}^t - 0{,}496\,U_3^t - 0{,}053\,U_4^t + 0{,}326\,U_5^t - 0{,}135Z^{(t\ t+1)} - \\ - 0.100\,T^{(t\ t+)} + 0.020P^{(t\ t+1)} - 9.770.10^{-4}W\ CR = 0.437;\ CV = 2157.6$$

$$U_5^{t+1} = 17.583 + 0.872\,U_1^t - 0.961\,U_2^t + 0{,}099\,U_3^t + 0{,}004\,U_4^t\,0.172\,U_5^t - 0.197Z^{(t\ t+1)} - \\ - 0.016\,T^{(t\ t+1)} + 0.026P^{(t\ t+1)} + 0.003W;\ CR = 0.527\ CV\ 1978{,}1$$

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