PAPER • **OPEN ACCESS**

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To cite this article: A P Grishin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **274** 012127

IOP Conf. Series: Earth and Environmental Science **274** (2019) 012127 doi:10.1088/1755-1315/274/1/012127

The uniformity of a random process structure of plants transpiration

A P Grishin[1]*, A A Grishin[1] and V A Grishin[1]

[1] Federal Scientific Agroengineering Center VIM, 5 1st Institutsky proezd, Moscow 109428 Russia

E-mail: 5145411@mail.ru

Abstract. It is noted that the process of transpiration in plants is characterized by randomness and determinism, which co-exist with the Random processes. Their properties are well described by methods of probability theory. Fractal structures having a total intra-group determinism and randomness is described by fractal analysis methods. The results of studies on fractal dimensions of seedling samples have similar values, indicating that homogeneity of the structure of the process of transpiration do not depend on the plant species. Selected deterministic component has a fractal dimension close to unity, which allows to ensure a high degree of determination of the obtained number. And close values of the variances of the centered random components of each process of the studied cultures refer to together with the same value, which is confirmed by a test of this hypothesis using the criterion Cochran. It is shown that the regularity of the homogeneity of the structure of a random process of transpiration for all studied plants allows to simplify the set of hardware requirements transpiration irrigation.

1. Introduction

The process of transpiration, i.e. the evaporation of water from the surface of a leaf of a plant in order to cool it, is an energy-information process in the physiology of plants. It is based on the principle of energy extremality of self-organization (PEES), which is a generalization of the second law of thermodynamics (SLT), according to which the utilization of objects of nature that cease self-organized existence and the law of survival (LS) formulated by I. I. Sventitsky. LS is that the plant for its development and growth makes maximum use of the free available part of the energy of solar radiation, called photosynthesis exergy [1].

This principle reflects the progressive direction of the evolution of the entire self-organizing nature, including human society as its part. Such systems selectively consume free energy from the environment, accumulate, and use it economically through various energy efficiency mechanisms.

The most prominent LS, PEES and PE, material and energy-information economy are reflected in the fractal manifestation of self-organizing nature. The fractal structures created by nature are more stable and adapted to survival. For example, a leaf of a plant has a central stem with branches that, in turn, continue to branch. In each group of branches, the average diameter decreases according to the power dependence, and so that the diameter of each group depends on the diameters of the previous group. In each group there is a range of diameters that can only be described in a probabilistic sense. That is, there is general determinism, expressed by average diameters with a power dependence on the group number and intragroup randomness characterized by a dispersion of diameters. A fractal structure that has common determinism and intragroup randomness is more stable and resistant to errors than other structures, since the error decreases with fractal scaling due to power dependence and probability structure. Each group has a range of diameters in which one malformed branch has less influence on the formation of other.

Self-organizing systems are characterized by randomness and determinism, which simultaneously coexist. Determinism gives us the law of nature. Chance introduces innovation and diversity. A self-developing system is one that not only can survive random shocks, but can also absorb them in order to improve the entire system in accordance with the LS.

Traditionally, processes over time are considered either as random or deterministic. The latter are determined from the moment of their appearance; therefore, in most cases, preference is given to the deterministic notion of time. However, we can observe random deviations from a predetermined process flow.

At the beginning of the article, we mentioned the energy-informational essence of the transpiration process. Explain its meaning.

Since any energy-information system or structure in its development seeks to maximize the use of free available energy and move to a more ordered level with less entropy and more information, the plants can be attributed to energy-information systems or structures that meet the following conditions of energy information unity:

- The energy and informational mechanisms are complementary, i.e. they have mutual conformity and complement in the formation of a whole unified hierarchical mechanism that meets the principle of synergetics;
- The functioning of this mechanism is aimed at maximizing the use of the free available energy of its trophic level in accordance with the principle of extreme energy focus in the process of self-organization.
- In the energy-information system, the efficiency of information and the efficiency of its carrier (operator efficiency) are mutually determined by the optimal amount of information. The energy efficiency of progressively evolving natural systems is enhanced by increasing the value of the information contained in them and reducing the energy intensity of its content and functioning, as well as improving the reception of information from the external environment.

Indeed, the rate of photosynthesis depends on the surface temperature of the sheet and has a maximum value at a certain value of temperature, which is provided by the self-organizing process of transpiration. Up to 95% of all consumed water is spent on transpiration in plants.

Consider the process of transpiration from the standpoint of self-organization, for which we present the basic principles of self-organization of thermodynamic systems. Hereinafter, we use the terms, definitions, and terminology used in [2, 3, 4].

The system of transpiration cooling meets these conditions of the process of self-organization:

1. The system is *open* and is in a highly *nonequilibrium* state;
2. The cooperative nature of the action of the elements of the system is carried out according to *the principle of subordination of synergetics*, in which the *control parameters* of the system are subordinate to *the order* variable [5];
3. The system has a fairly high level of *fluctuation, prone to overgrowth and bifurcation*.
4. *The influx of energy* to the system ensures the achievement of *a critical state* (bifurcation point) with a subsequent *exit* from this state *abruptly* according to the type of phase transition.

The jump characterizes the formation of a new dissipative structure. Dissipative structures are complex space-time structures that arise under the action of thermodynamic forces in a system that is far from the thermodynamic equilibrium and that exist only in the mode of constant make-up. Dissipative self-organization is a phase transition of irreversible structures far from equilibrium.

Therefore, the first sign of evolving self-organizing systems is ***dissipativity in an open system***.

The lifetime, localization area, and fractal dimension are the most important characteristics of dissipative structures.

Phase transitions in relation to self-organization differ in type: the 1st kind is typical for conservative processes, and the 2nd kind for dissipative processes. The relation of the process to the 2 kind confirms its ***fractality***.

V. N. Zholkevich notes, that the transpiration process is oscillatory in nature, i.e. it is a time series with a fractional topographic dimension, and gives its graphic representation for the *Erythrina Variegata* sheet [6]. We have investigated this time series for its fractal character. The fractal dimension of the series was determined using the method of *normalized span* or (***R / S***) analysis. The fractal dimension of the time series is a function of the zoom scale over a period of time. For the case under consideration, a minute time scale was chosen in which the fractal dimension ***D*** is equal to ***1.31***.

Fractal dimension, is an indicator of the complexity of the curve. Analyzing the alternation of areas with different fractal dimensions and how external and internal factors affect the system, one can learn to predict the behavior of the system. And most importantly is to diagnose and predict unstable conditions. The fractal dimension characterizes the occupancy of space and describes the structure during fractal scaling. For physical fractals, this transformation takes place in space. For a time series, the scale changes over time.

Also, the value of the fractal dimension can serve as an indicator of the number of factors affecting the system. When the fractal dimension is less than 1.4, the system is affected by one or several forces moving the system in one direction. If the dimension is about 1.5, then the forces acting on the system are multidirectional, but more or less compensate each other. The behavior of the system in this case is stochastic and is well described by classical statistical methods. If the fractal dimension is significantly more than 1.6, the system becomes unstable and is ready to move to a new state.

In addition, the fractal dimension close to unity indicates a combination of deterministic behavior and statistical properties of the process, which is typical of non-linear phenomena between the order (structure) and disorder (chaos). This is the second sign of evolving self-organizing systems — ***nonlinearity*** that ensures the complementarity of opposites.

An open thermal control system is in a flow-equilibrium steady state. The entropy in the steady state is constant as a result of the balance of the produced entropy within the system and its outflow into the external environment. So the entropy of evaporated water is about twice the liquid phase. That is, an open system is able to give entropy and reduce it in the system, increasing order and information. This is the third sign of evolving self-organizing systems – ***negentropy***.

2. Research Method

For many time series, the observed normalized range is the ratio of the difference between the maximum and minimum transpiration values for a given time interval (lag, n), R to the standard deviation calculated for the transpiration values of the same lag, S is well described by the empirical expression:

$$R / S = c n^H , \tag{1}$$

where c is a constant, H is the Hurst index, which is associated with the fractal dimension D by the relation $D = 2 - H$.

The fractal dimension of the time series is a function of the zoom scale over a period of time. It is important because it emphasizes that the process can be between a deterministic character (a line with a fractal dimension of 1) and a random one (a fractal dimension of 1.50). In the general case, the fractal dimension of the series can be in the range from 1 to 2. The closer the dimension is to two, the more inversions the random sequence has. The closer to one, the more predictable the process becomes. The transpiration process, as shown by studies [6], has a fractal structure with the dimension

D* = *1,31, which confirms the coexistence of determinism and randomness in the fractal time series, describing the transpiration process as a self-organizing process and with long-term memory.

The Hurst index is a measure of the persistence of the tendency of the process to trends (as opposed to the usual Brownian motion). A value of H>0.5 means that the directional process directed in a certain direction in the past will most likely entail continuation of movement in the same direction. If H <0.5, it is predicted that the process will change direction. H = 0.5 means uncertainty, the Brownian motion.

The water regime of the plant provides a set of parameters and operating conditions for the production processes in the plant, ensuring its evolutionary development, as well as the preservation and current reproduction of the elements of the plant's life support. The upward flow of water in the plant goes through the xylem vessels, the flow rate ***Q***, carrying out the transport of nutrients to the growing embryonic tissues located on the stems, growth points and leaves. Leaves, participating in evaporative cooling, create a gradient of suction pressure, forming a flow ***Q.***

Transpiration, as evaporative cooling is a thermodynamic process in an open system, which is dissipative random in nature. However, solar thermal radiation, which has a known periodicity, introduces a certain determinism in this process.

3. Experimental Part

In the course of research, the process of transpiration is presented in the form of a discrete time series with a step equal to a day. This process is determined by exposure to solar thermal radiation, which affects all plants equally regardless of the type of plant. Obviously, having data on the processes of transpiration in several plant samples, one can try to reveal this determinism, but first it is necessary to substantiate its presence and its uniformity in these samples. To do this, we define the fractal dimension of the time series of transpiration for the samples, the studies of which were carried out according to the considered method [7]. The calculation results are summarized in Table 1.

Table 1. Fractal dimensions of the transpiration processes of the studied cultures.

Crop	Approximation expression	Approximation reliability	Hurst score	Fractal dimension
Tomato	$(R/S)_{av} = 0,5573n^{0,7008}$	$R^2 = 0,9803$	0,7008	1,3
Cucumber	$(R/S)_{av} = 0,5964\,n^{0,6506}$	$R^2 = 0,9902$	0,6506	1,35
Beans	$(R/S)_{av} = 0,5643n^{0,6853}$	$R^2 = 0,9971$	0,6853	1,31

4. Results and Discussion

Thus, we obtain the fractal dimensions of the seedling samples from the values close to each other and the average value $D_{av} = 1,32$, which indicates the homogeneity of the structure of the transpiration process, which does not depend on the type of plant. This value is obtained from a time series with a daily scale of fixation of transpiration values. Earlier studies of the time series of transpiration of the plant *Erythrina Variegata* [6], by definition, show the fractal dimension with the minute fixation scale resulted in the fractal dimension ***D*** equal to ***1.31***. This is a very close dimension to the dimensions obtained in these studies, but on a different minute scale, which confirms the fractal nature of the time series, and describing the transpiration process as a dissipative self-organizing process. The dimension is close to unity, which indicates the presence of a deterministic component in the structure of the process. It is necessary to select it. To do this, taking into account the homogeneity of the structure of the transpiration process for all three samples, we define the expectation of time series of the studied processes, presenting them as separate implementations of one process. Calculate the fractal dimension of the calculated series and get ***D* = *1, 12***. This allows you to verify the high degree of determination of the series. We approximate this series with a polynomial function of the second degree with a reliability of $R^2 = 0.9966$; we obtain the initial formula for further study of the required transpiration consumption for artificial irrigation in greenhouse seedling growing systems:

$$\Delta M_u = 0{,}01\, t^2 - 0{,}33\, t + 3{,}38$$

Knowing the deterministic component, we can distinguish random components of the transpiration process by a mathematical centering operation and determine the variance of the process for each culture, the results are summarized in Table 2.

Table 2. Dispersions of centered components of the time series of transpiration.

Seedling culture	Cucumber	Tomato	Beans
Dispersion of centered components of the transpiration time series	0.87	1.14	0.69

The results obtained are quite similar values. Let us check with the help of a statistical hypothesis about the relation of the calculated variances to the aggregate with the same value. For this we apply the Cochran's Q test.

The Cochran's Q test (q) is the ratio of the maximum of the variances compared to the sum of all variances. For our case, we have $k = 1$ sections (samples) with the number of observations $n_1 = n_2 = ... = n_{24} = 15$, in which variances are calculated. The sum of the variances is equal to $\sum_{k=1} \sigma^2_{qk} = 2{,}71$, the greatest value of the variance is $\sigma^2_{q2\max} = 1{,}14$.

The value of the criterion for a set of variances in the processes under consideration is equal to:

$$q = \frac{\sigma^2_{q2\max}}{\sum_{k=1} \sigma^2_{qk}} = \frac{1{,}14}{2{,}71} = 0{,}42$$

Using the table, we reliably determine the smallest critical value of the criterion that corresponds to higher values of the number of variances (samples) and the number of degrees of freedom $z = n_k - 1$, than in the considered variant: $q_{p;k;z} = q_{0,95;1;15} = 0{,}4709$. Since the calculated value of the criterion is less than the smallest of the theoretical tabular ones, we can assume that the assumption that the calculated dispersions are related to different flows is incorrect. All calculated variances refer to the aggregate with the same value, which confirms the homogeneity of the structure of transpiration processes in the cultures under consideration. This fact allows us to simplify the requirements for numerical characteristics for the development of technical means of transpiration irrigation, such as the delivery of a fine-dispersed pump, temporary delivery modes, and other.

5. Conclusions

The homogeneity pattern is revealed in the structure of the time series of a dissipative random transpiration process for seedlings of tomato, cucumber, beans in the daily time scale and the adult plant *Erythrina Variegata* in the minute time scale. For all studied plant samples and time scales, the fractal dimensions have close values (1.3; 1.35, 1.31 and 1.31, respectively), which confirms the dissipation, fractality and homogeneity of the structure of the random transpiration process for all studied plants and allows us to simplify the set of requirements for transpiration irrigation hardware.

The homogeneity of the structure of the transpiration process is confirmed by the close values of the variances of the centered random components of each process of the studied cultures. All calculated variances relate to the aggregate with the same value of 1.14, which is confirmed by testing this hypothesis using the Cochran's Q test.

The selected deterministic component has a fractal dimension of $\boldsymbol{D = 1.12}$ and an analytical expression, which allows to make sure that the obtained series is highly determined.

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