UDC 551.551.8

Fractal analysis of climatic parameters and productivity of cereal crops

O. Demydenko,
doctor of agricultural sciences
Cherkasy State Agricultural Research Station NSC "Institute of Agriculture of the National Academy of Sciences of Ukraine"

The purpose. To analyze long-term series of climatic parameters and series of dynamics of productivity of cereal crops (winter wheat, corn) depending on system of adaptive measures (fertilizing, machining), to determine their classification attributes according to fractal properties, to fix basic trends of further development and realization of the forecast for the future in agrocnosises of the Central Left-bank Forest-steppe. **Methods.** Field experiment and weather observation, fractal assessment of the statistical information. **Results.** Except for the annual cycle, 12-years climatic cycle caused by solar activity is precisely manifested. Cyclicity of change of productivity of cereal crops makes 4 – 5 years. **Conclusions.** Climate fluctuation, in particular, increase of temperature in conditions of central part of Left-bank Forest-steppe promotes increase of yield of new hybrids of corn and winter wheat for all period of probes.

Key words: *climatic parameters, productivity of cereal crops, fractal analysis, Hurst's index, soil cultivation, agrocenosis.*

The study of long-term rows of agro-climatic parameters and crop yields is an important and actual problem, and one of the ways of its solution is the use of statistical time series of observation data on the main climatic characteristics associated with rows of changes in the productivity of agro-crops in the forest-steppe zone of Ukraine [1]. In the ranges of the dynamics of climatic parameters and yields coded information about their past and present state, and the receipt of this information using the method of "decoding" time series is extremely important, because this information can be used to predict their further dynamics.

Numerous studies of the last decades have shown that the implementation of most of the dynamic processes in nature has fractal geometry [2-5]. Fractality means self-similarity [6-9], that is, at different scales, the time series maintains its structure. In the work of E. Peters [5], it is noted that any method of estimating the possibility of predicting the change in time of the dynamic series of parameters requires taking into account the fractal properties of the time series itself. Different kinds of fractal structures in open dynamic systems cause fractal behavior of the indices of such systems. In works [7-8,10-11], an algorithm for determining the Hurst model, which characterizes these properties, is given. Dynamics of open dynamic systems is represented in the form of time series, which serve as the basis for analysis, modeling and forecasting of their further development, and the quality of forecasting will depend on how well the system has been evaluated in terms of its determinism. Modern mathematical tools, in particular R / S analysis, proposed by Hurst [6-7], are a powerful tool that allows you to establish a "degree of chaos" of the system. If the time series reveals long-term memory, that is, the corresponding system is largely deterministic, more efficiently to apply the standardized Hurst scale. , This problem is solved using R / S analysis methods. This method allows us to investigate the effects of long-term memory in time series, both yields and climatic parameters [10-11], and, with certain modifications, predict cyclicity of yield and climatic parameters in long-term observation series [12-13].

The purpose of the article is to analyze the long-term series of climatic parameters and the dynamics of productivity of grain crops (winter wheat and maize) depending on the system of adaptation measures (fertilization, cultivation), the definition of their classification characteristics in accordance with the fractal properties, identification of the main tendencies for further development and implementation of the forecast for the future. . in agrocenoses of the Central Left-Bank Forest-steppe of Ukraine.

The method of conducting research. The research was conducted in the conditions of the central part of the left-bank forest-steppe of Ukraine in the long-term stationary experiment of the Drabovka experimental field of the Cherkasy State Research Station "NSC" Institute of Agriculture of NAAS ". Soil conditions and the scheme of long-term experiments are shown in previous publications [14-15].

Methodology of statistical calculations. The algorithm for calculating the Hurst index, based on the R / S analysis, can be carried out according to the method [10]:

Initially, deviations from the mean value are determined: where N is the length of the period, which varies from 2 to <length of the time series>; t is a variable whose value ranges from 1 to N-1; MN - average N elements; e is a specific time series element. 2. For each iteration, we obtain N-1 values of Xt, N used in formula (2): where R is the span of deviations X. 3. Further, the normalization of the magnitude is divisible by a standard deviation S, which is set to N value. 4. We logarithm R / S and N and build on the basis of the data the graph of the function of the dependence of the value of R / S on a logarithmic scale from the period in the logarithmic mass-headquarters. 5. In the graph of the function Ln (R / S) of Ln (t) we find the slope by linear approximation. The tangent of the angle of this inclination is the Hurst index. The Hurst index, in turn, is related to the fractal dimensionality of the D curve by the ratio: D = 2-H, (3); where D is the fractal dimension of the curve.

The index H, by analogy with the generalized Brownian motion, may reach values from 0 to 1: 1) (0 <H <0.5) or (1.5 <D <2) - an anti-persistent or ergodic time series ("pink noise"), there is an anti-brand, the tendency of the dynamic system to continually change the trend (growth variesdecay, but vice versa). The stability of the antiperspective behavior of a series depends on how far H is close to zero, the series is more variable or volatile. This type of system is often referred to as "return to the average"; 2) (H = 0,5) or (D = 1,5) - the numerical series is absolutely random or stochastic ("white noise"), the absence of long-term statistical dependence (random behavior of the indicator); 3) (0,5 <H <1) or (1 <D <1,5) - persistent time series ("black noise"), a trend is observed, a tendency to increase or decrease of the indicator both in the past and in the future . At the same time, the higher the value of the indicator, the more so after its rise, there is a rise, and after the downturn - a recession. Consequently, the deviation of the Hurst index from 0.5 is a peculiar reflection of the fractal properties of processes generating time series, and the Hurst index, in turn, is related to the fractal dimensionality (D) of the curve in the ratio: D = 2-H. Along with the use of the Hurst index for analyzing the trend of a number, a correlation relation is used to estimate the autocorrelation influence of the previous values of the dynamic series on its subsequent values and the determination of the future trend: C = 22n-1, where C is the measure of autocorrelation, and H is the Hurst index [6].

Research results. Dynamic rows of atmospheric precipitation over 100 years of observation had an anti-imperative character (H = 0.291-0.335, Fr = 1.67-1.71 (fractal dimension)), and the coefficient of autocorrelation of the time series was: C = -0.205-0.335. Similarly, the time series for the 20 and 40 years of the variation in the amount of atmospheric precipitation over the observation periods is estimated. During the winter period, the series acquires a random character (H> 0.354), that is, it is close to the average value. Only a dynamic number of changes in the amount of atmospheric precipitation in the year gained an anti-recurrent (growing) character. The coefficients of autocorrelation between the values of the dynamic series were: C = -0,089: -0,224). Calculation of the Hurst index (H) showed that over 100 years of observations, its value varied within the range: H = 0.280-0.335, and the coefficient of autocorrelation of the values of the series was: C = -0,021: -0.331. The ranks of the speakers have an anti-imperative character. Over 40 years of observation, the Hurst (H) index for the winter period in the whole year had an anti-recurrent character, and in the spring, summer autumn, and during the vegetation, it was a casual character. Coefficients of autocorrelation in time series have lower values in relation to observations over 100 years. The Hurst index for dynamics series over 20 years is characterized as random with a probability of 99.7%, that is, the values change with respect to the mean, and the coefficients of autocorrelation between the values of the dynamics series vary in the range of C = -0.112: -0.159.

Estimation of the dynamics of the average daily temperature of air over the observation periods showed the existing reliability of its growth. During the spring period, the average air temperature for 40, 20, 10 and 5 years was significantly higher than the average for 100 years: t> 2.00. The average daily temperature values for the shorter periods of observation relative to the average values for 100 years during the summer and autumn periods proved to be significantly higher.

Only the average over 40 years of observation did not have a significant difference in 100 years of observations. The annual average air temperature over the observation periods was significantly higher relative to the values for 100 years. Calculation of the Hirst index (H) showed that over 100 years of observations, its value varied within: H = 0.280-0.335, and the coefficient of autocorrelation of the values of the series was: C = -0,021-0.331. The statistical parameters of the change in the sum of active temperatures (Table 1) showed that the sum of negative temperatures for short periods of observations is significantly higher with respect to observations over 100 years. During April-May, the reliability of the growth of the sum of active temperatures for short periods of time (tv.St> 2.00) was confirmed.

For June-July, only for 40 years, the amount of active temperatures is not significantly different from the full cycle of research. During the warm period of the year, the sum of active temperatures is significantly higher than the average for periods of 20, 10 and 5 years relative to 100 years, which indicates an increasing array of climate

Table 1. Statistical estimation of climate parameters for observation periods for the conditions of the Left-bank forest-steppe of Ukraine for 1913-2015 (Drabovskoye experimental field)

Periods definition	Statistical parameter	Periods of determination for:						
		winter	spring	summer	autumn	Vegetation	year	character
Atmospheric precipitation, mm								
100 years old	Hirst Index (H)	0,335	0,310	0,325	0,317	0,291	0,310	Anti-persian-tent
	Fractal dimension (FR)	1,67	1,69	1,68	1,68	1,71	1,69	
	Coefficient of autocorrelation of a series (C)	-0,205	-0,231	-0,215	-0,224	-0,332	-0,232	
40 years old	Hirst Index (H)	0,378*	0,344	0,325	0,375*	0,355	0,319	Anti-persian-tent
	Fractal Dimension (FR)	1,63	1,65	1,67	1,63	1,65	1,68	
	Coefficient of autocorrelation of a series (C)	-0,156	-0,195	-0,215	-0,159	-0,182	-0,222	
20 years	Hirst Index (H)	0,410	0,362	0,415	0,388	0,432	0,319**	Random
	Fractal Dimension (FR)	1,59	1,64	1,59	1,61	1,56	1,68	
	Coefficient of autocorrelation of a series (C)	-0,117	-0,174	-0,111	-0,156	-0,089	-0,224	
Темперeратура повітря, t^0C								
100 years old	Hirst Index (H)	0,317	0,290	0,332	0,323	0,321	0,335	Anti-peaches tent
	Fractal Dimension (FR)	1,683	1,710	1,669	1,667	1,680	1,665	
	Coefficient of autocorrelation of a series (C)	-0,224	-0,331	-0,205	-0,218	-0,221	-0,205	
40 years old	Hirst Index (H)	0,353	0,395	0,372	0,386	0,371	0,353	Random
	Fractal Dimension (FR)	1,647	1,605	1,628	1,614	1,629	1,647	
	Coefficient of autocorrelation of a series (C)	-0,184	-0,135	-0,163	-0,146	-0,164	-0,184	
20 years	Hirst Index (H)	0,412	0,375	0,388	0,403	0,416	0,401	Random
	Fractal Dimension (FR)	1,558	1,625	1,612	1,597	1,584	1,591	
	Coefficient of autocorrelation of a series (C)	-0,159	-0,159	-0,156	-0,126	-0,112	-0,19	

Random; ** anti-persistent

The calculation of the Hurst index showed that a number of dynamics for 100 years was anti-imperative, and for shorter periods of time random, that is, in the latter case, the sum of active temperatures gravitated to average values of choices for 20, 10 and 5 years. The values of the coefficients of autocorrelation decrease as the observation periods are reduced (Table 1).

The average long-term value of GCP for 100 and 40 years in the period April-May corresponded to rather humid conditions, and the values of GTCS for 20 years more tended to a level of insufficient moisture. The humidity conditions for the June-July period, on average, for 100 and 40 years of observation were gravitated to slightly arid conditions (SCC = 1.04-1.05), and for 20, years of observations - to dry conditions (GTC = 2.1-2.5) By the Hurst index, the dynamic rows of GTCS in the 100 and 20 years were anti-impermeable, the fractal dimension was F = 1.65-1.75, and the autocorrelation coefficients were C = -0.189: -0.339 and C = -0.157: -0.224, respectively. A dynamic range of 40 years of observation was characterized as random, and for the period April-May the dynamic series was anti-persistent.

The yield of grain crops in dynamic ranks was determined by calculating the mean values for periods of 40, 20, 10 and 5 years. The comparison of the mean values was done by comparing the average shorter segments of the dynamics series with the average of 40 years (Table 2). On average, over 20 years, wheat yields tended to decline relative to the average for 40 years, but there remained a steady trend towards its growth in non-polar operations. According to the same principle, the coefficients of variation in yield were reduced: for the implementation of non-field cultivation to the level of 20,2-22,9%.

For shorter periods of time (10 and 5 years), there has been a significant increase in wheat grain yields in relation to non-fertilizer control and up to an average of 40 years. In crop rotation with peas, higher yield was obtained for performing plowing (5.38-5.88 t / ha) against 5.22-5.36 t / ha for deep unpolished cultivation and 5.24-5.41 t / ha - for surface cultivation.

Table 2. Productivity of different types of crop rotation and coefficients of variation of productivity for separate periods of research

Study periods	Crop rotation: up to 60% grains; up to 20% - legumes; up to 20% - sugar beets						Crop rotation: up to 60% - grains; up to 20% sugar beet; up to 20% - perennial grasses					
Winter wheat												
Control: without fertilizer												
40 years old	3,31	33,2	3,59	28,3	3,52	26,3	3,17	31,7	3,42	25,1	3,46	24,9
20 years	2,79*	33.4	3,09*	26,8	3,06*	26,4	2,71*	27,7	3,04*	24,1	3,11*	21,9
10 years	3,16*	28,8	3,38	24,5	3,33	27,9	3,13	22,0	3,27	19,6	3,33	16,0
5 years	3,49	30,0	3,64	26,3	3,68	28,5	3,37*	19,5	3,44	18,4	3,35	17,9
$N_{60}P_{60}K_{60}$												
40 years old	4,94	25,4	5,01	22,0	4,95	21,5	4,63	21,6	4,81	20,6	4,72	21,4
20 years	4,70	27,9	4,76	21,4	4,83	20,2	4,50	23,2	4,69	22,9	4,57	23,3
10 years	5,38*	24,5	5,22*	19,6	5,24*	19,4	5,05	13,5	5,37*	11,9	5,29*	11,4
5 years	5,88*	26,2	5,36*	22,7	5,41*	23,5	5,17*	17,2	5,26*	15,4	5,08*	13,3
Corn (average for crop rotation) - $N_{90}P_{60}K_{60}$												
40 years old	6,38	30,5	6,32	29,9	6,03	32,2	6,58	31,1	6,63	29,6	6,19	31,6
20 years	7,18	28,3	7,28	25,3	7,03	26,7	7,31	26,7	7,47	24,8	7,15	25,3
10 years	7,89*	21,7	7,81*	16,6	7,73*	18,6	7,98*	20,6	7,94*	21,0	7,76*	16,8
5 years	8,22*	23,6	7,79*	18,5	7,81*	21,9	8,41*	24,8	7,92*	26,3	7,77*	21,1

* tkr.Studud > 2.0; P (tkr Stu.d.) <0.005, Fr.Phys. (F)> Fr.Phis (tabl); P (Fcr)> 0.0

Table 3. Statistical estimation on the normalized Hurst scale of grain yield crops by observation periods for the conditions of the Left-bank forest-steppe of Ukraine for the years 1913-2015.

Added fertilizers	Plowing 20-22 cm			Barefoot 20-22 cm			Superficial by 10-12 cm		
	*H	**D	***C	*H	**D	***C	*H	**D	***C
up to 60% - grain; up to 20% sugar beet; up to 20% - perennial grasses									
1975-2015 pp.									
No fertilizer	0,310	1,69	0,30	0,324	1,68	0,27	0,318	1,68	0,28
A	0,401	1,59	0,15	0,404	1,59	0,14	0,418	1,58	0,12
1975-1995 pp.									
No fertilizer	0,305	1,70	0,31	0,345	1,66	0,24	0,346	1,65	0,24
A	0,392	1,61	0,16	0,410	1,59	0,33	0,412	1,59	0,35
1996-2015 pp.									
No fertilizer	0,441	1,56	0,08	0,403	1,61	0,14	0,383	1,62	0,18
A	0,432	1,57	0,09	0,491	1,51	0,014	0,475	1,53	0,04
до 60% -зернові; до 20% - зернобобові; до 20% - цукрові буряки									
1975-2015 pp.									
No fertilizer	0,362	1,64	0,21	0,334	1,67	0,26	0,379	1,62	0,21
A	0,357	1,64	0,22	0,379	1,62	0,18	0,404	1,59	0,16
1975-1995 pp.									
No fertilizer	0,368	1,63	0,21	0,374	1,63	0,19	0,451	1,55	0,07
A	0,342	1,66	0,24	0,420	1,58	0,12	0,441	1,56	0,08
1996-2015 pp.									
No fertilizer	0,465	1,54	0,05	0,467	1,54	0,05	0,455	1,56	0,07
	0,499	1,50	0,01	0,493	1,51	0,01	0,556	1,44	0,06

* H is the Hurst index; ** D-fractal dimension; *** C - measure of auto-correlation.

And - N62P62K81

The introduction of fertilizers contributed to a decrease in the coefficients of variation in wheat yield, which varied within 21,5-25,4% and 20,6-21,4% respectively, crop rotation with peas and herbs. On average, over 20 years, wheat yields tended to decline relative to the average for 40 years, but there remained a steady tendency for its growth in non-polar operations.

For shorter periods of time (10 and 5 years), there has been a significant increase in wheat grain yield as regards non-fertilizer control and an average of 40 years. In crop rotation with peas, the average yield of maize for 40 years was the highest in plowing and field-free cultivation (6.32-6.38 t / ha), and yields for 20 and 10 years increased by 0.80-1.50 t / ha crop rotation with peas and 0.79-1.36 t / ha in crop rotation with herbs for deep work. A significant increase in the yield of corn grain has been obtained during the last 5 years for plowing: 8.22-8.41 t / ha, whereas for non-field cultivation the yield has stabilized at 7.79-7.81 t / ha. The coefficients of variation (Cu) of corn yields for 40 years were at 30.5-31.0% for plowing; 29.6-29.9% for non-field cultivation and over 30% for surface cultivation. Over the past 20 years, Cr has a tendency to decrease, which was more pronounced in non-field cultivation: 24.8-25.3% against 26.7-28.9% for plowing. Over the 10 years of observation, Cv had a significant decrease in non-field cultivation (16.6-21.0%) against 20.6-21.7% for plowing. Over the past 5 years, Qv has grown somewhat over 10 years of observation but has not exceeded the permissible values (Qv = 30.0%).

Estimation of the dynamics of grain crops for 1975-2015 according to the normalized Hurst (H) index for non-fertilizer control showed an anti-persistence of dynamics in the studied crop rotation for fieldless cultivation (H <0.354), while the rows of dynamics were random in nature for the plowing and surface cultivation (H> 0.354). For the introduction of fertilizers, the ranks of grain yield crop dynamics were steady random (H = 0.354-0.649). For 1975-1995 The rows of grain dynamics dynamics were anti-subsistent (H <0,337) on non-fertilized variants, with their introduction random (H = 0,337-0,663). For 1995-2015 rows of dynamics of grain crops were random (H> 0.337) (Table 3).

Conclusions

1. The assertion of global climate change in the left-bank part of the Central Forest-steppe of Ukraine is not correct. The R / S analysis carried out has revealed time intervals of the anti-continuity behavior of the

series of climatic parameters and existing cycles: in addition to the annual cycle, a 12-year climatic cycle, which can be due to solar activity, can clearly be manifested.

2. In modern conditions of management, climate change, in particular temperature rise, in the conditions of the central part of the Left Bank Forest-steppe of Ukraine, has a positive effect on the growth of crop yields over the entire period of research. Cyclic changes in crop yields are 4-5 years old.

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