Phenological Computer Program Development in Mangyshlak Experimental Botanical Garden

Imanbayeva A.A, Belozerov I.F.

Abstract: ***The article presents the characteristic of the special computer program, Feno-S, created in the MEBG. The purposes of the program include: entering and keeping phytophenological data in the computer memory for its further prompt search, mathematical processing, identification of plant efficiency phenoindicators, printing, developing histograms and phenospectrums, exporting data to various text and graphic formats, compiling reports and lists on given taxonomic, bioecological, decorative and phenological parameters. The description of a simplified methodology for collection, systematizing and preparation of lengthy phenological studies outcomes to be imported into electronic databases. Information is presented on the developed database composition and structure, including 130 information fields of symbolic, numerical, logical and temporary types and 3,911 records by years for 533 taxa from 7 departments of the Botanical garden, 52 families and 108 genera.***

Keywords: phenology, computer program, databases, statistics of observation series, correlation, histograms.

I. INTRODUCTION

The phenology as a science is a system of knowledge about seasonal phenomena of nature, timing of their occurrence and their defining causes [1]. The founders of phenology were the French scientist R. Reaumur and the Swedish naturalist K. Linnae during the second half of the XVIII century. In general, there are quite a lot of phenology interpretations. One of the most objective interpretations was given during the last century by the famous Russian phenologist A.I. Rudenko at the first All-Union phenological meeting: “Phenology is the science that studies the patterns of the plant and animal world seasonal development, as well as the phenomena of inorganic nature in their interrelation and interaction” [1-2]. According to the classification by V.A. Batmanov [2], all studies related to the study of various object seasonal development are divided into theoretical and applied phenology. Depending on the objectives of research and the sector of the national economy, it includes agricultural, forestry, hunting and transport phenology. By sections of knowledge, the author identifies landscape, meteorological, zoo, hydro, and phytophenology or the phenology of plants.

Phenological observations in botanical gardens are one of introduction study priority areas, the results of which are of great scientific and practical importance in terms of economically valuable range adapted to local natural conditions, diagnostics of prospects, determination of the growing season, flowering and fruiting, development of beautiful and constantly flowering compositions of plants during greening and phytomeliorative works. Many botanical scientists relate winter-resistance, drought-resistance, morphological characteristics of aboveground organs, qualitative and quantitative indicators of the generative sphere with the phenological characteristics of introducers [3-10]. They admit that one of the main criteria for the introduction value of taxa is the degree of their seasonal development dynamics compliance with the meteorological conditions of the cultivation region in comparison with the places of natural growth.

Conduct of phenological observations is a very complex research process due to the coverage of a large number of taxa, variety of concepts and terms used (object of observation, seasonal phenomenon, phenodate, phenophase, interphase period, phenointerval, indicator phenomenon, etc.) and implementation of a number of work stages: visual observation, fixation of phenophases (up to the 26th), filling in of summary tables, development of phenospectra, analysis of the collected materials due to the meteorological conditions of the research year, etc.

Statistical processing of phenological observation materials is of particular difficulty, since all seasonal phenomena have to be converted to an ordinal day of some year, starting from January 1 (or March 1), and return to the date format after calculation of the mathematical characteristics. A similar problem arises when correlation and regression analysis is performed concerning the onset of phenophases and meteorological factors.

Within the practice of introduction studies, in order to reduce labor intensity, there is a long-time need to translate phyto-phenological studies into electronic programming languages, which contain dozens of special commands and functions to work with dates and allow not only to create full-fledged databases but also to compile various graphical and textual reports, carry out statistical processing of research material and export it to various file formats, as well as to exchange the phenological information online. Therefore, starting from 2018, Mangyshlak Experimental Botanical Garden (MEBG) as the part of the grant project

Revised Manuscript Received on April 12, 2019.

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"The development of scientific, methodological and computer-informational bases to conduct phenological observations in the botanical gardens of Kazakhstan for forecasting perspectives of plant introduction, maintaining and using their biodiversity efficiently" (during 2018–2020), the work is underway to compile a multifunctional phenological computer program, called *Feno-S*, which would be compatible with modern operating systems, graphic and text editors and also contain the necessary Web-based applications.

II. MATERIALS AND STUDY METHODS.

The objects of the phenological observations were species, varieties and forms of plants from the MEBG collection with 1,270 taxa from 250 genera and 88 families [11].

The studies of seasonal developmental rhythms were based on the main generally accepted concepts and terms used in phenology [6-8, 12-16]:

- object of observation – a specific type, form or variety of plants that undergoes cyclical morphological and physiological changes in a certain geographic point of growth during a year;
- seasonal phenomenon – state of the object at the date of observation;
- phenological date - the main element of phenological study information concerning the plant kingdom of the nature, which is a fixed day of a seasonal phenomenon occurrence;
- phenological phase – a certain stage or period of a plant development, which, in contrast to the seasonal phenomenon, is characterized by 2-3 dates of existence beginning, culmination and ending;
- Interphase period – time (in days) between the individual phases of the observed object development;
- phenological interval – an interval (in days) between the dates of occurrence of any two seasonal phenomena, regardless of whether they belong to the same or different observation objects;
- phenological indicator – a seasonal phenomenon that performs the signal and the predictive functions of probabilistic period for other phenodate occurrence.

In the botanical centers of Kazakhstan, the “Methodology of Phenological Observations in the Botanical Gardens of the USSR” [17] was adopted as the main one, which was included into the collection “The methods of introduction research in Kazakhstan” in 1987 [18] and assumes fixation of seasonal development separately for three morphologically-systematic groups of plants: herbaceous, deciduous and coniferous woody plants. According to this system of observations, the phenological formula reflecting the state of a plant was recorded into the journal at least twice a week for at least 5 years for each vegetative and generative organ of an introduced species during the growing season. Moreover, all phenophases were observed, which are observed at the given moment of time, and their quantitative parameters were noted simultaneously using the numbers in front of the phenophase designations: I - in the case if less than 50% of organs entered the phenophase and 2 – for more than 50.

For research via the "Method of phenological observations ..." [17-18], we chose at least five model specimens of each species or intraspecific rank. The study of plants of different ages and origins was carried out separately to reflect intraspecific phenological heterogeneity.

The compilation of algorithms for mathematical processing of the research material was based on the methods by G.F. Lakin [19,20] and B.A. Dospekhov [21,26]. 4 programming languages were used to develop the computer program: Microsoft Visual FoxPro 9 SP2, Visual Basic For Applications 7.0, HTML 4.0 and JavaScript API 2.1.

During development of the database (DB) structure, it was planned to save phenological materials in two formats: actual dates of ten characters (for example, 08/17/2018) and numeric ones as a number of calendar days before the phenophase from the starting point – January 1 of each year – (234). This greatly simplified the procedure of the research material statistical processing. The correlation coefficients were calculated both between the dates of phenophase occurrence for the same plant during different years of observation, and with the main meteorological factors of introduction point.

Taxonomic and registration information about the plant was initially entered into the phenological database, indicating Latin, Russian, Kazakh names, location in the garden, registration numbers, donor organization, type of original reproductive material, etc. In order to simplify the input of taxonomic units, the computer program used the childbirth lists by R.K. Brummitt [22,25]. The systematics is based on the phylogenetic system by A.L. Tahtajyan [23,24,26].

III. RESEARCH RESULTS AND THEIR DISCUSSION.

Two basic principles were strictly observed during the development of the computer program *Feno-S*: 1) Phenological database should be closely related with the collection one via identification indicators, and 2) The information processing on seasonal development should be carried out separately for three groups of plants in all algorithms of the program modules (deciduous and coniferous woody, grassy species) due to the difference in their morphological and ecological-biological properties. In order to solve the tasks of accounting, registration and mathematical processing of the phenodata, 11 items are included into the main menu of the program: “File”, “Edit”, “Input”, “Search”, “View”, “List”, “Phenology", "Assortment", "Databases", "Service", and "Help" (Fig. 1).

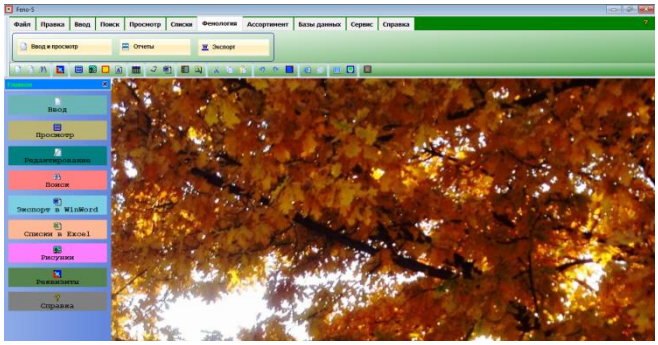

Figure1 – Main window of «Feno-S» program

The “File” main menu item includes a standard set of sub-items: “Open ...”, “My Computer”, “Print”, “Filer”, “File Search”, “Server”, “Internet”, “Mail” and “Exit”, and is designed to create new and work with existing files, print information, send it to the server and by e-mail, as well as to exit from the Program.

The “Edit” item is required to edit the active text fields of the input and view information forms, as well as for search and replacement of words and phrases, adjustment of their fonts, letter colors and backgrounds.

From the “Enter” item, one starts the forms for new database filling and editing of input information. It includes three subparagraphs - “All Information”, “Organization Details” and “Editing”.

"Search" allows you to search for plants in the database within the following options: by identification number; by the Latin name, Russian name, national name of a taxon, by family and name, and by any word or a word fragment from the names. Almost all of the above methods are combined in the "Advanced Search".

“View” is used to work with already entered information for a plant with the possibility of its printing and export to external editors and programs in various formats - doc, docx, rtf, txt, pdf, xml, etc.

Using the “Lists” item, one can generate a variety of reports on plants by taxonomic, morphological and other characteristics.

Actually, four commands - “Input and View”, “Search”, “Export” and “Lists” of the “Phenology” item in the Main Menu (MM) – enable full-fledged work with the information on seasonal rhythms of plant growth as the main task of *Feno-S* program (fig. 1-2).

The “Assortment” main menu item includes three subitems “By features”, “By value” and “By systematics” and is necessary for data output from the database on predetermined conditions. The MM item "Databases" is designed to execute the following commands: "Copy", "Restore", "Export", "Import", "Reindex", "Index Repair" and "Information about database". The “Service” contains additional features of the *Feno-S* program for its design and general setting, viewing graphic materials in a separate form, and work with the interactive maps on the Internet. "Help" is included in the MM for the purpose of background information obtaining.

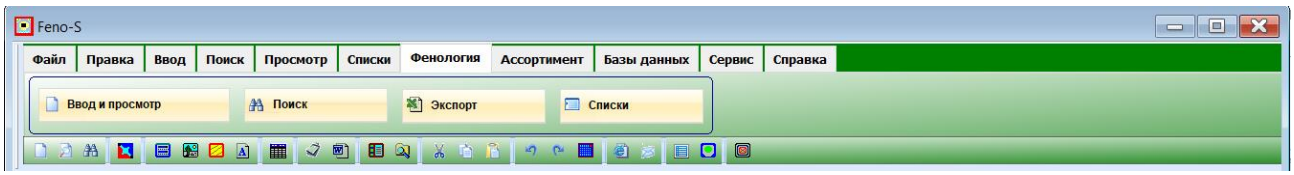

Figure 2 – "Phenology" item of the Main menu of "Feno-S" software

The main form for phenological information entering and viewing is displayed in *Feno-S* simultaneously with the list of Latin and Russian names of collection plants in alphabetical order (Fig. 3). When one chooses any taxon, all information in the form is updated automatically. There is a list of years of the observation period, and control buttons for adding, copying and deleting the current year in the right side of it. There is a set of buttons for moving between years, information export, editing and saving changes to the database at the bottom of the form. All pheno-information, both input and calculation, is divided into 8 groups (pages): “Deciduous”, “Coniferous”, “Herbal”, “Statistics”, “Correlation”, “Meteorological data”, “Advanced” and “Charts”. The first three pages present the opportunity to enter and edit the values of phenodates for each morphologically-systematic group of plants.

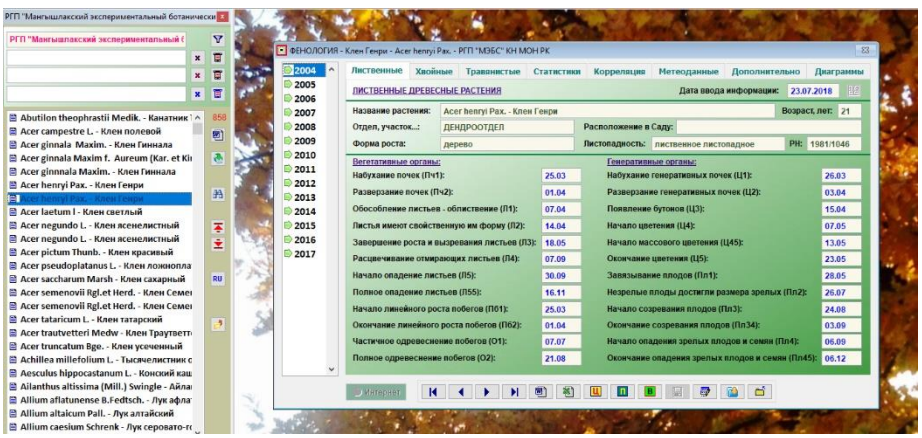

Figure 3 - View of phenological information input, viewing and processing form ("Deciduous" page) with the list of plant titles

The algorithms introduced into the electronic shell on the fourth page (Fig. 4) allow calculating the duration of phenophases (lining, flowering, growth and lignification of shoots, ripening and subsidence of fruits, etc.), as well as the basic statistics for the chosen phenological phase.

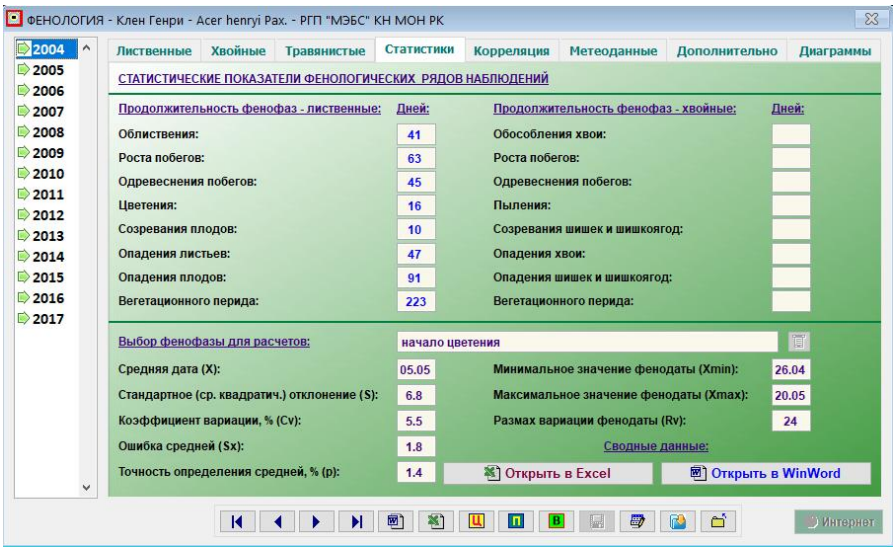

Figure 4 - «Statistics» page

The data on multiple statistical calculations can be obtained by clicking the corresponding buttons on the bottom button menu. In this case, the table containing the following indicators will be formed in Microsoft Excel or Word (table 1): number of observations (N, years); average date in numeric (X, days) and time formats (X, date); standard deviation (S); variation coefficient (Cv); mean error (Sx); accuracy of mean determination (p,%), the minimum (Xmin) and the maximum (Xmax) date of phenophase duration and variation rank (Rv, days).

Table 1 - The statistics of the onset and duration of phenophases for maple Henry (Acer henryi Pax.) during the observation period of 2004-2017.

Phenophase, period	N, years	X, days	X, date	S	Cv	Sx	p, %	Xmin	Xmax	Rv, days
Phenological phases										
Vegetative organs										
PCh1 - bud swelling	14	95	05.04	8,7	9,2	2,3	2,4	26.03	28.04	33
PCh2 - bud opening	14	98	08.04	6,2	6,3	1,6	1,6	02.04	25.04	23
L1 - isolation of leaves (foliage development)	14	103	13.04	6,3	6,2	1,7	1,7	06.04	01.05	25
L2 - leaves have their own form	14	108	18.04	6,2	5,8	1,7	1,6	10.04	04.05	24
L3 - the completion of growth and the maturation of leaves	14	138	18.05	5,3	3,8	1,4	1,0	12.05	01.06	20
L4 - the decolouration of dying leaves	14	246	03.09	7,8	3,2	2,1	0,9	23.08	12.09	20
L5 - the beginning of leaf fall	14	270	27.09	5,5	2,0	1,5	0,6	20.09	13.10	23
L55 – the end of leaf fall	14	315	11.11	8,8	2,8	2,3	0,7	25.10	19.11	25
PB1 - the beginning of the linear growth of shoots	14	109	19.04	7,3	6,7	1,9	1,7	11.04	08.05	27
PB2 - the end of the linear growth of shoots	14	176	25.06	13,9	7,9	3,7	2,1	12.06	29.07	47
O1 - partial lignification of shoots	14	198	17.07	14,9	7,5	4,0	2,0	07.07	21.08	45

Phenophase, period	N, years	X, days	X, date	S	Cv	Sx	p, %	Xmin	Xmax	Rv, days
O2 - full lignification of shoots	14	241	29.08	10,4	4,3	2,8	1,2	21.08	22.09	32
Generative bodies										
C1 - the swelling of generative buds	14	95	05.04	6,3	6,7	1,7	1,8	28.03	21.04	24
C2 - the opening of generative buds	14	101	11.04	6,4	6,4	1,7	1,7	05.04	28.04	23
C3 - budding	14	110	20.04	6,8	6,3	1,8	1,6	16.04	14.05	28
C4 - the beginning of flowering	14	123	03.05	5,3	4,3	1,4	1,1	26.04	11.05	15
C45 - mass flowering	14	129	09.05	7,2	5,6	1,9	1,5	28.04	23.05	25
C5 - the end of flowering	14	140	20.05	4,8	3,4	1,3	0,9	09.05	27.05	18
PL1 - fruit set	14	143	23.05	4,7	3,3	1,3	0,9	16.05	01.06	16
PL2 - immature fruits reached the size of mature ones	14	207	26.07	2,1	1,0	0,6	0,3	22.07	30.07	8
PL3 - the beginning of fruit ripening	14	238	26.08	1,8	0,8	0,5	0,2	24.08	30.08	6
PL34 - the end of fruit ripening	14	250	07.09	4,6	1,8	1,2	0,5	02.09	16.09	14
P4 - the beginning of ripe fruit and seed falling	14	254	11.09	5,1	2,0	1,4	0,6	04.09	21.09	17
PL45 - the end of ripe fruit and seed falling	14	335	01.12	9,1	2,7	2,4	0,7	14.11	13.12	29
The duration of:										
- leaf development	14		35,5	3,0	8,5	0,8	2,3	31	41	10
- flowering	14		17,4	2,8	16,0	0,7	4,0	11	22	11
- shoot growth	14		66,2	8,0	12,1	2,1	3,2	55	82	27
- lignification of shoots	14		42,6	5,0	11,7	1,3	3,1	32	50	18
- leaf fall	14		44,9	7,3	16,2	1,9	4,2	30	53	23
- fruit ripening	14		12,1	4,2	34,9	1,1	9,1	4	21	17
- fruit fall	14		81,5	12,4	15,2	3,3	4,0	61	96	35
- growing season	14		212,3	12,8	6,0	3,4	1,6	189	227	38

The “Correlation” page (Fig. 5) is intended to establish the connection closeness between various phenophases and meteorological factors. Here one can set 5 variants of correlation calculations: 1) the chosen phenodate with the rest during the observation period; 2) between all phenodates (correlation matrix); 3) between the years of the observation period for all phenodates; 4) all phenodates with meteorological factors (correlation matrix) and 5) the duration of phenophases with meteorological factors.

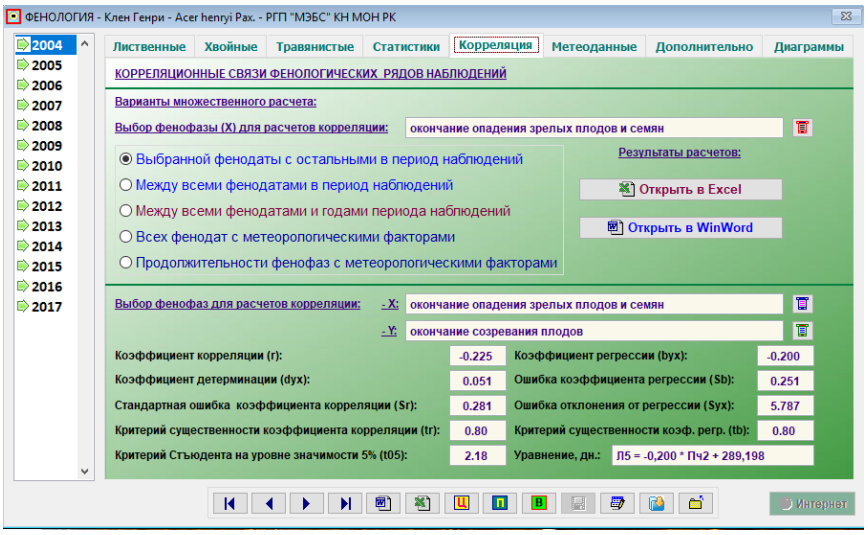

Figure 5 - «Correlation» page

Published By:
Blue Eyes Intelligence Engineering
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The computer program performs all the necessary calculations and can simultaneously send a tabular report to Microsoft Excel or Word with the following parameters (Table 2) automatically: correlation (R) and determination (Dyx) coefficient; correlation coefficient error (Sr); criterion of correlation coefficient significance (Tr); regression coefficient (Byx); errors of regression coefficient (Sb) and deviations from regression (Syx); criteria of regression coefficient significance (Tb) and Student coefficient at 5% significance level (T05). Besides, in the case of using the option "Selected phenodate with the rest", along with the correlation analysis, *Feno-S* derives the regression equation between the phenodates, which can be used in the future to forecast their occurrence.

The tables formed as the result of export can be fully used after minor editing for composing scientific articles and reports.

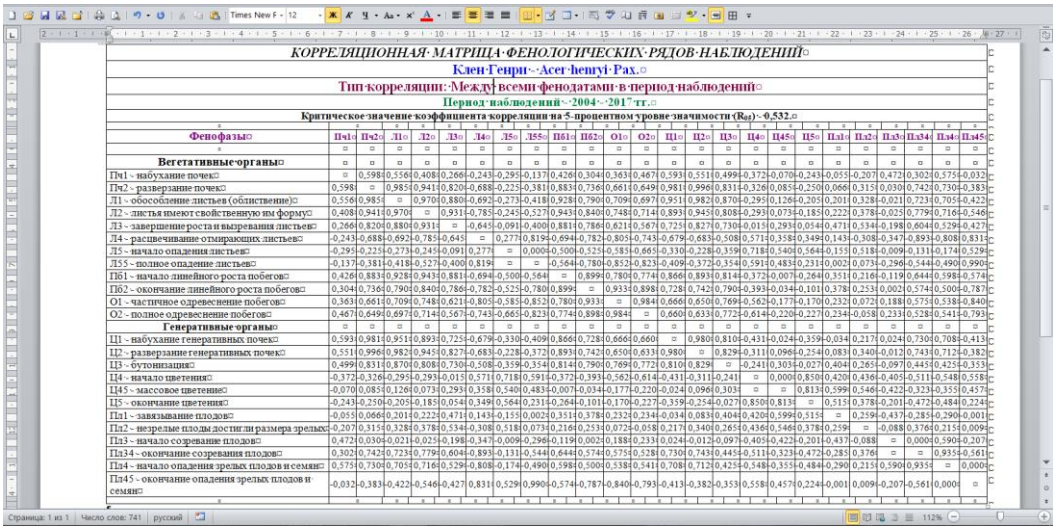
As we can see from Table 2, even with the example of one type of tree plants (Henry maple - Acer henryi Pax.) and one type of correlation (the selected phenodate with the others), the computer program provides the significant material to the introducer for scientific analysis.

Table 2 - Correlations of the phenophase for bud opening (PC2, X) of Henry maple (Acer henryi Pax.) with the rest of the phenodates during the period of observations - 2004 - 2017. (N - 14 years)

Phenophases - Y	R	D_{yx}	S_r	T_r	B_{yx}	S_b	S_{yx}	T_b	T_{05}	Equation, days
Vegetative organs										
PCh1 - bud swelling	0,598	0,358	0,231	2,59	0,841	0,325	7,5	2,59	2,18	Пч1 = 0,841 * Пч2 + 12,571
L1 - isolation of leaves (foliage development)	0,985	0,969	0,051	19,45	1,008	0,052	1,2	19,45	2,18	Л1 = 1,008 * Пч2 + 3,871
L2 - leaves have their own form	0,941	0,885	0,098	9,63	0,947	0,098	2,3	9,63	2,18	Л2 = 0,947 * Пч2 + 14,725
L3 - the completion of growth and the maturation of leaves	0,820	0,672	0,165	4,96	0,703	0,142	3,3	4,96	2,18	Л3 = 0,703 * Пч2 + 69,128
L4 - the decoloration of dying leaves	-0,688	0,473	0,209	3,28	-0,864	0,263	6,1	3,28	2,18	Л4 = -0,864 * Пч2 + 329,821
L5 - the beginning of leaf fall	-0,225	0,051	0,281	0,80	-0,200	0,251	5,8	0,80	2,18	Л5 = -0,200 * Пч2 + 289,198
L55 – the end of leaf fall	-0,381	0,145	0,267	1,43	-0,542	0,380	8,8	1,43	2,18	Л55 = -0,542 * Пч2 + 367,520
PB1 - the beginning of the linear growth of shoots	0,883	0,779	0,136	6,50	1,040	0,160	3,7	6,50	2,18	Пб1 = 1,040 * Пч2 + 7,356
PB2 - the end of the linear growth of shoots	0,736	0,542	0,195	3,77	1,659	0,440	10,2	3,77	2,18	Пб2 = 1,659 * Пч2 + 13,127
O1 - partial lignification of shoots	0,661	0,437	0,217	3,05	1,594	0,522	12,1	3,05	2,18	О1 = 1,594 * Пч2 + 42,146
O2 - full lignification of shoots	0,649	0,421	0,220	2,95	1,093	0,370	8,5	2,95	2,18	О2 = 1,093 * Пч2 + 133,637
Generative bodies										
C1 - the swelling of generative buds	0,981	0,962	0,056	17,42	1,007	0,058	1,3	17,42	2,18	Ц1 = 1,007 * Пч2 - 4,135
C2 - the opening of generative buds	2	3	4	5	6	7	8	9	10	11
C3 - budding	0,996	0,992	0,025	39,19	1,037	0,026	0,6	39,19	2,18	Ц2 = 1,037 * Пч2 - 1,266
C4 - the beginning of flowering	0,831	0,691	0,160	5,18	0,921	0,178	4,1	5,18	2,18	Ц3 = 0,921 * Пч2 + 19,289
C45 - mass flowering	-0,326	0,106	0,273	1,20	-0,278	0,233	5,4	1,20	2,18	Ц4 = -0,278 * Пч2 + 149,498
C5 - the end of flowering	0,085	0,007	0,288	0,30	0,100	0,335	7,7	0,30	2,18	Ц45 = 0,100 * Пч2 + 118,697
PL1 - fruit set	-0,250	0,063	0,279	0,90	-0,195	0,218	5,0	0,90	2,18	Ц5 = -0,195 * Пч2 + 158,843

Phenophases - Y	R	D_{yx}	S_r	T_r	B_{yx}	S_b	S_{yx}	T_b	T_{05}	Equation, days
PL2 - immature fruits reached the size of mature ones	0,066	0,004	0,288	0,23	0,050	0,219	5,1	0,23	2,18	Пл1 = 0,050 * Пч2 + 137,452
PL3 - the beginning of fruit ripening	0,315	0,099	0,274	1,15	0,108	0,094	2,2	1,15	2,18	Пл2 = 0,108 * Пч2 + 195,775
PL34 - the end of fruit ripening	0,030	0,001	0,289	0,10	0,009	0,086	2,0	0,10	2,18	Пл3 = 0,009 * Пч2 + 236,481
P4 - the beginning of ripe fruit and seed falling	0,742	0,550	0,194	3,83	0,554	0,145	3,3	3,83	2,18	Пл34 = 0,554 * Пч2 + 195,388
PL45 - the end of ripe fruit and seed falling	0,730	0,533	0,197	3,70	0,608	0,164	3,8	3,70	2,18	Пл4 = 0,608 * Пч2 + 194,071
Vegetative organs	-0,383	0,147	0,267	1,44	-0,567	0,394	9,1	1,44	2,18	Пл45 = -0,567 * Пч2 + 390,297

In the case of correlation calculations between all phenodates, the data is exported as a matrix (Fig. 6); and to assess the significance of the coefficients by the relevance of 5%, their critical value (R_{05}) is derived.



КОРРЕЛЯЦИОННАЯ МАТРИЦА ФЕНОЛОГИЧЕСКИХ РЯДОВ НАБЛЮДЕНИЙ

Клен Генри - Acer henryi Pax.

Тип корреляции: Между всеми фенодатами в период наблюдений

Период наблюдений - 2004 - 2017 гг.

Критическое значение коэффициента корреляции на 5-процентном уровне значимости (R_{05}) - 0,532.

Фенофазы	Пч1	Пч2	Л1	Л2	Л3	Л4	Л5	Л55	П61	П62	О1	О2	Ц1	Ц2	Ц3	Ц4	Ц45	Ц5	Пл1	Пл2	Пл3	Пл34	Пл4	Пл45
Вегетативные органы																								
Пч1 - набухание почек	=	0,598	0,556	0,408	0,266	-0,243	-0,295	-0,137	0,426	0,304	0,363	0,467	0,593	0,551	0,499	-0,372	-0,070	0,243	-0,055	-0,207	0,472	0,302	0,575	-0,032
Пч2 - развертание почек	0,598	=	0,985	0,941	0,820	-0,688	-0,225	-0,381	0,883	0,736	0,661	0,649	0,981	0,996	0,831	-0,326	0,085	-0,250	0,066	0,315	0,030	0,742	0,730	-0,383
Л1 - обособление листьев (облиственье)	0,556	0,985	=	0,970	0,880	-0,692	-0,273	-0,418	0,928	0,790	0,709	0,697	0,951	0,982	0,870	-0,295	0,126	-0,205	0,201	0,328	-0,021	0,723	0,705	-0,422
Л2 - листья имеют свойственную им форму	0,408	0,941	0,970	=	0,931	-0,785	-0,245	-0,527	0,943	0,840	0,748	0,714	0,893	0,945	0,808	-0,293	0,073	-0,185	0,222	0,378	-0,025	0,779	0,716	-0,546
Л3 - завершение роста и вызревания листьев	0,266	0,820	0,880	0,931	=	-0,645	-0,091	-0,400	0,881	0,786	0,621	0,567	0,725	0,827	0,730	-0,015	0,293	0,054	0,471	0,534	-0,198	0,604	0,529	-0,427
Л4 - расцвечивание отмирающих листьев	-0,243	-0,688	-0,692	-0,785	-0,645	=	0,277	0,819	-0,694	-0,782	-0,805	-0,743	-0,679	-0,683	-0,508	0,571	0,358	0,349	-0,143	-0,308	-0,347	-0,893	-0,808	0,831
Л5 - начало опадения листьев	-0,295	-0,225	-0,273	-0,245	-0,091	0,277	=	0,000	-0,500	-0,525	-0,585	-0,665	-0,330	-0,228	-0,359	0,718	0,540	0,564	-0,155	0,518	-0,009	-0,131	-0,174	0,529
Л55 - полное опадение листьев	-0,137	-0,381	-0,418	-0,527	-0,400	0,819	=	=	-0,564	-0,780	-0,852	-0,823	-0,409	-0,372	-0,354	0,591	0,483	0,231	-0,002	0,073	-0,296	-0,544	-0,490	0,990
П61 - начало линейного роста побегов	0,426	0,883	0,928	0,943	0,881	-0,694	-0,500	-0,564	=	0,899	0,780	0,774	0,866	0,893	0,814	-0,372	-0,007	0,264	0,351	0,216	-0,119	0,644	0,598	-0,574
П62 - окончание линейного роста побегов	0,304	0,736	0,790	0,840	0,786	-0,782	-0,525	-0,780	0,899	=	0,933	0,898	0,728	0,742	0,790	-0,393	-0,034	0,101	0,378	0,253	0,002	0,574	0,500	-0,787
О1 - частичное одревеснение побегов	0,363	0,661	0,709	0,748	0,621	-0,805	-0,585	-0,852	0,780	0,933	=	0,984	0,666	0,650	0,769	-0,562	-0,177	0,170	0,232	0,072	0,188	0,575	0,538	-0,840
О2 - полное одревеснение побегов	0,467	0,649	0,697	0,714	0,567	-0,743	-0,665	-0,823	0,774	0,898	0,984	=	0,660	0,633	0,722	-0,614	-0,220	0,227	0,234	-0,058	0,233	0,528	0,541	-0,793
Генеративные органы																								
Ц1 - набухание генеративных почек	0,593	0,981	0,951	0,893	0,725	-0,679	-0,330	-0,409	0,866	0,728	0,666	0,660	=	0,980	0,810	-0,431	-0,024	0,359	-0,034	0,217	0,024	0,730	0,708	-0,413
Ц2 - развертание генеративных почек	0,551	0,996	0,982	0,945	0,827	-0,683	-0,228	-0,372	0,893	0,742	0,650	0,633	0,980	=	0,829	-0,311	0,096	-0,254	0,083	0,340	-0,012	0,743	0,712	-0,382
Ц3 - бутонизация	0,499	0,831	0,870	0,808	0,730	-0,508	-0,359	-0,354	0,814	0,790	0,769	0,772	0,810	0,829	=	-0,241	0,303	-0,027	0,404	0,265	-0,097	0,445	0,425	-0,353
Ц4 - начало цветения	-0,372	-0,326	-0,295	-0,293	-0,015	0,571	0,718	0,591	-0,372	-0,393	-0,562	-0,614	-0,431	-0,311	-0,241	=	0,000	0,850	0,420	0,436	-0,405	-0,511	-0,548	0,558
Ц45 - массовое цветение	-0,070	0,085	0,126	0,073	0,293	0,358	0,540	0,483	-0,007	-0,034	-0,177	-0,220	-0,024	0,096	0,303	=	=	0,813	0,599	0,546	-0,422	-0,323	-0,355	0,457
Ц5 - окончание цветения	-0,243	-0,250	-0,205	-0,185	0,054	0,349	0,564	0,231	-0,264	-0,101	-0,170	-0,227	-0,359	-0,254	-0,027	0,850	0,813	=	0,515	0,378	-0,201	-0,472	-0,484	0,224
Пл1 - завязывание плодов	-0,055	0,066	0,201	0,222	0,471	0,143	-0,155	0,002	0,351	0,378	0,232	0,234	-0,034	0,083	0,404	0,420	0,599	0,515	=	0,259	-0,437	0,285	0,290	-0,001
Пл2 - незрелые плоды достигли размера зрелых	-0,207	0,315	0,328	0,378	0,534	-0,308	0,518	0,073	0,216	0,253	0,072	0,058	0,217	0,340	0,265	0,436	0,546	0,378	0,259	=	-0,088	0,376	0,215	0,009
Пл3 - начало созревания плодов	0,472	0,030	0,021	0,025	0,198	0,347	0,009	0,296	0,119	0,002	0,188	0,233	0,024	0,012	0,097	0,405	0,422	0,201	0,437	0,088	=	0,000	0,590	0,207
Пл34 - окончание созревания плодов	0,302	0,742	0,723	0,779	0,604	0,893	0,131	0,544	0,644	0,574	0,575	0,528	0,750	0,743	0,445	0,511	0,323	0,472	0,285	0,376	=	=	0,935	0,561
Пл4 - начало опадения зрелых плодов и семян	0,575	0,730	0,705	0,716	0,529	0,808	0,174	0,490	0,598	0,500	0,538	0,541	0,708	0,712	0,425	0,548	0,355	0,484	0,290	0,215	0,590	0,935	=	0,000
Пл45 - окончание опадения зрелых плодов и семян	-0,032	-0,383	-0,422	-0,546	-0,427	0,831	0,529	0,990	-0,574	-0,787	-0,840	-0,793	-0,413	-0,382	-0,353	0,558	0,457	0,224	-0,001	0,009	-0,207	-0,561	0,000	=

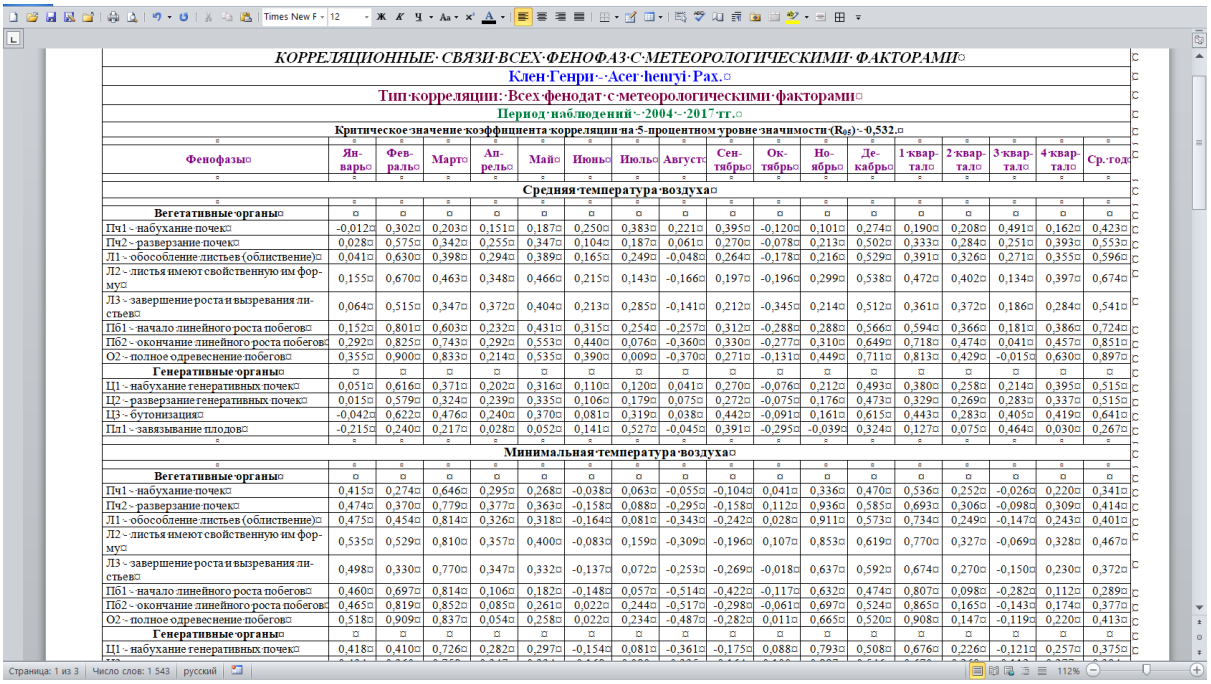
Figure 6 – A type of a report in Microsoft Word on correlations between all Henry maple phenodates during observation period of 2004-2017 (N - 14 years)

During the calculation of phenodate correlation with meteorological factors, the program gives a tabular report in a seasonal aspect on the correlations with all 85 meteorological factors, grouping them in rows by average, minimum and maximum values of air temperature, relative humidity and precipitation volume. The fragment of the report in Microsoft Word on the correlation of phenophase occurrence dates with the average and minimum air temperatures is shown on Figure 7.

The group of signs “Meteorological data” of the input and view form serves to enter the values of temperature, air humidity, the amount of precipitation, etc.

The "Advanced" page contains the fields of plant introduction value indicators, notes, names of the user organization and performers. Perspective points are required to establish the correlations with the phenological values of introducers.

The last page of the form (Fig. 8) provides automatic development of Gantt charts and histograms for the duration of 8 phenophases with simultaneous graphical representation in a special container.



КОРРЕЛЯЦИОННЫЕ СВЯЗИ ВСЕХ ФЕНОФАЗ С МЕТЕОРОЛОГИЧЕСКИМИ ФАКТОРАМИ

Клен Генри - Acer henryi Pax.

Тип корреляции: Всех фенодат с метеорологическими факторами

Период наблюдений - 2004 - 2017 гг.

Критическое значение коэффициента корреляции на 5-процентном уровне значимости (R_{05}) - 0,532.

Фенофазы	Январь	Февраль	Март	Апрель	Май	Июнь	Июль	Август	Сентябрь	Октябрь	Ноябрь	Декабрь	1 квартал	2 квартал	3 квартал	4 квартал	Ср. год
Средняя температура воздуха																	
Вегетативные органы																	
Пч1 - набухание почек	-0,012	0,302	0,203	0,151	0,187	0,250	0,383	0,221	0,395	-0,120	0,101	0,274	0,190	0,208	0,491	0,162	0,423
Пч2 - развертание почек	0,028	0,575	0,342	0,255	0,347	0,104	0,187	0,061	0,270	-0,078	0,213	0,502	0,333	0,284	0,251	0,393	0,553
Л1 - обособление листьев (облиственье)	0,041	0,630	0,398	0,294	0,389	0,165	0,249	-0,048	0,264	-0,178	0,216	0,529	0,391	0,326	0,271	0,355	0,596
Л2 - листья имеют свойственную им форму	0,155	0,670	0,463	0,348	0,466	0,215	0,143	-0,166	0,197	-0,196	0,299	0,538	0,472	0,402	0,134	0,397	0,674
Л3 - завершение роста и вызревания листьев	0,064	0,515	0,347	0,372	0,404	0,213	0,285	-0,141	0,212	-0,345	0,214	0,512	0,361	0,372	0,186	0,284	0,541
Пб1 - начало линейного роста побегов	0,152	0,801	0,603	0,232	0,431	0,315	0,254	-0,257	0,312	-0,288	0,288	0,566	0,594	0,366	0,181	0,386	0,724
Пб2 - окончание линейного роста побегов	0,292	0,825	0,743	0,292	0,553	0,440	0,076	-0,360	0,330	-0,277	0,310	0,649	0,718	0,474	0,041	0,457	0,851
О2 - полное одревеснение побегов	0,355	0,900	0,833	0,214	0,535	0,390	0,009	-0,370	0,271	-0,131	0,449	0,711	0,813	0,429	-0,015	0,630	0,897
Генеративные органы																	
Ц1 - набухание генеративных почек	0,051	0,616	0,371	0,202	0,316	0,110	0,120	0,041	0,270	-0,076	0,212	0,493	0,380	0,258	0,214	0,395	0,515
Ц2 - развертание генеративных почек	0,015	0,579	0,324	0,239	0,335	0,106	0,179	0,075	0,272	-0,075	0,176	0,473	0,329	0,269	0,283	0,337	0,515
Ц3 - бутонизация	-0,042	0,622	0,476	0,240	0,370	0,081	0,319	0,038	0,442	-0,091	0,161	0,615	0,443	0,283	0,405	0,419	0,641
Пл1 - завязывание плодов	-0,215	0,240	0,217	0,028	0,052	0,141	0,527	-0,045	0,391	-0,295	-0,039	0,324	0,127	0,075	0,464	0,030	0,267
Минимальная температура воздуха																	
Вегетативные органы																	
Пч1 - набухание почек	0,415	0,274	0,646	0,295	0,268	-0,038	0,063	-0,055	-0,104	0,041	0,336	0,470	0,536	0,252	-0,026	0,220	0,341
Пч2 - развертание почек	0,474	0,370	0,779	0,377	0,363	-0,158	0,088	-0,295	-0,158	0,112	0,936	0,585	0,693	0,306	-0,098	0,309	0,414
Л1 - обособление листьев (облиственье)	0,475	0,454	0,814	0,326	0,318	-0,164	0,081	-0,343	-0,242	0,028	0,911	0,573	0,734	0,249	-0,147	0,243	0,401
Л2 - листья имеют свойственную им форму	0,535	0,529	0,810	0,357	0,400	-0,083	0,159	-0,309	-0,196	0,107	0,853	0,619	0,770	0,327	-0,069	0,328	0,467
Л3 - завершение роста и вызревания листьев	0,498	0,330	0,770	0,347	0,332	-0,137	0,072	-0,253	-0,269	-0,018	0,637	0,592	0,674	0,270	-0,150	0,230	0,372
Пб1 - начало линейного роста побегов	0,460	0,697	0,814	0,106	0,182	-0,148	0,057	-0,514	-0,422	-0,117	0,632	0,474	0,807	0,098	-0,282	0,112	0,289
Пб2 - окончание линейного роста побегов	0,465	0,819	0,852	0,085	0,261	0,022	0,244	-0,517	-0,298	-0,061	0,697	0,524	0,865	0,165	-0,143	0,174	0,377
О2 - полное одревеснение побегов	0,518	0,909	0,837	0,054	0,258	0,022	0,234	-0,487	-0,282	0,011	0,665	0,520	0,908	0,147	-0,119	0,220	0,413
Генеративные органы																	
Ц1 - набухание генеративных почек	0,418	0,410	0,726	0,282	0,297	-0,154	0,081	-0,361	-0,175	0,088	0,793	0,508	0,676	0,226	-0,121	0,257	0,375

Figure 7 - A fragment of a report in Microsoft Word on the correlation between phenodates and meteorological factors for Henry Maple during observation period of 2004-2017 (N - 14 years)

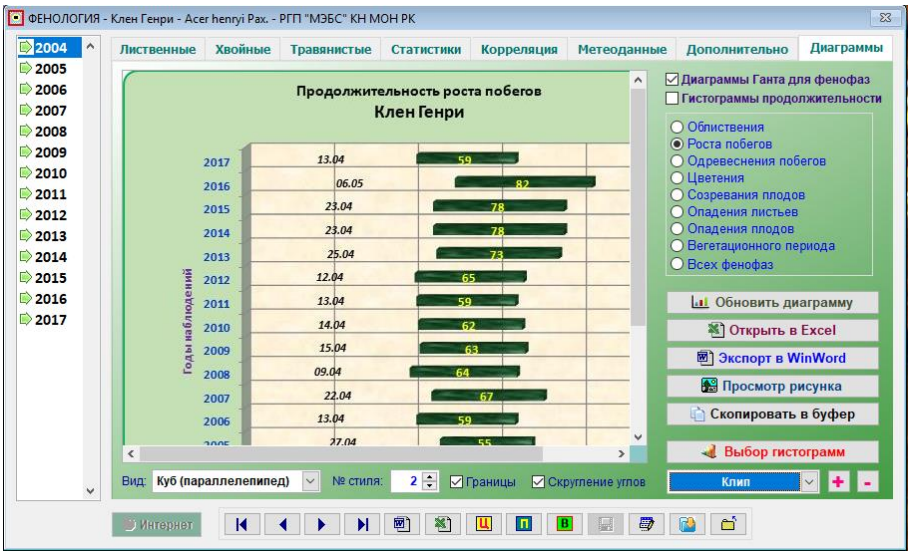
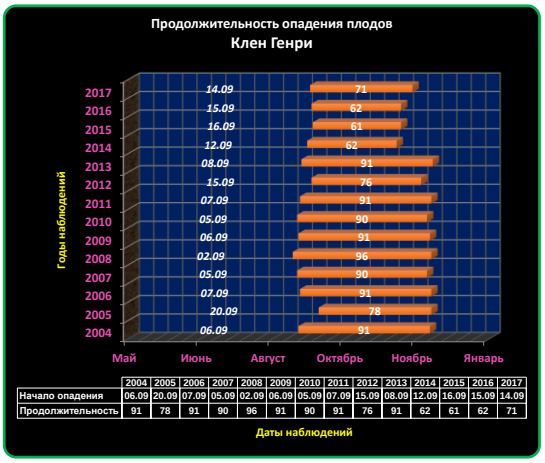


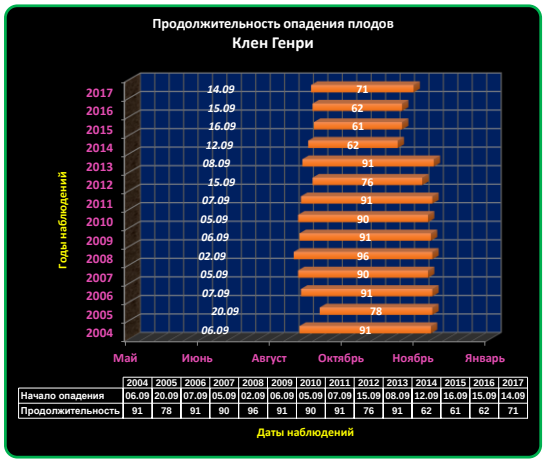
Figure 8 - «Diagrams» page

The "Diagrams" page also provides the ability to copy the graphical reports to the Windows clipboard, to view them in an external editor and to download them into Microsoft Excel and Word.

Depending on taxon belonging to coniferous, deciduous or herbaceous plant groups, the program can generate up to 17-19 graphic reports on the duration of seasonal development rhythms: foliage, shoot growth and lignification, flowering, leaf fall, ripening and the fall of fruits, vegetation period, and all phenophases (Fig. 9A-9B, 10A-10B).

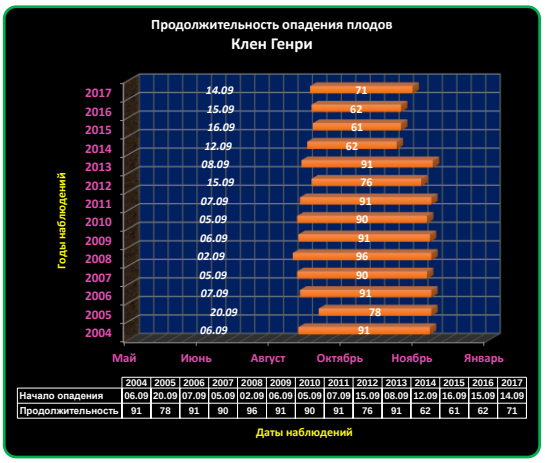


А –Fruit fall

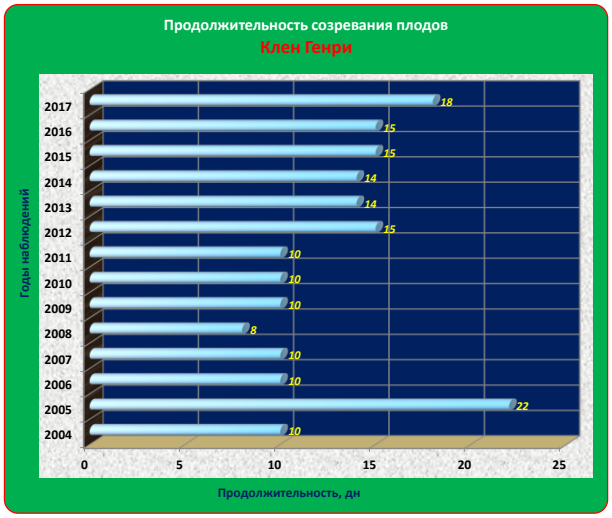


Б – Vegetation period

Figure 9 - Examples of Gantt chart development for the duration of phenophases Acer henryi Pax. - Maple Henry



А – Leaf development



Б – Fruit ripening

Figure 10 - Examples of histogram development for the duration of Acer henryi Pax. - Maple Henry phenophases

Here, using the “Histogram Selection” button, one can launch a special "FoxCharts" graph development object, which allows customizing the style, shape type, color and fonts of the graphical reports on phenology without exiting the program, as well as saving them in various file formats including web-oriented ones - “.html” (Fig. 11).

Simultaneously with the compilation of the program algorithm, the work was carried out to collect, systematize and prepare for entering into Microsoft Excel spreadsheets of the multiyear material phenological studies accumulated over the past 19 years (1999-2017) for 710 species, varieties and forms of botanical garden collection plants from 58 families and 131 genera. The majority of the processed information on phenology relates to foreign-leafy plants (dendrology department) - 417 items (58.7%), including 398 species, 1 type, 12 forms and 6 hybrids. Quite a lot of phenodata are systematized and prepared for the rosary (100 species and varieties, 14.1%) and the department of fruit plants (83 species and varieties, 11.7%). Aceraceae Juss (17 taxa), Berberidaceae Juss. (28), Caprifoliaceae Juss. (52), Fabaceae Lindl. (42), Oleaceae Hoffm. (39), Ranunculaceae Juss. (19), Rosaceae Juss. (326) and Vitaceae Juss. (28) dominate significantly among the families of those prepared for entering into Excel.

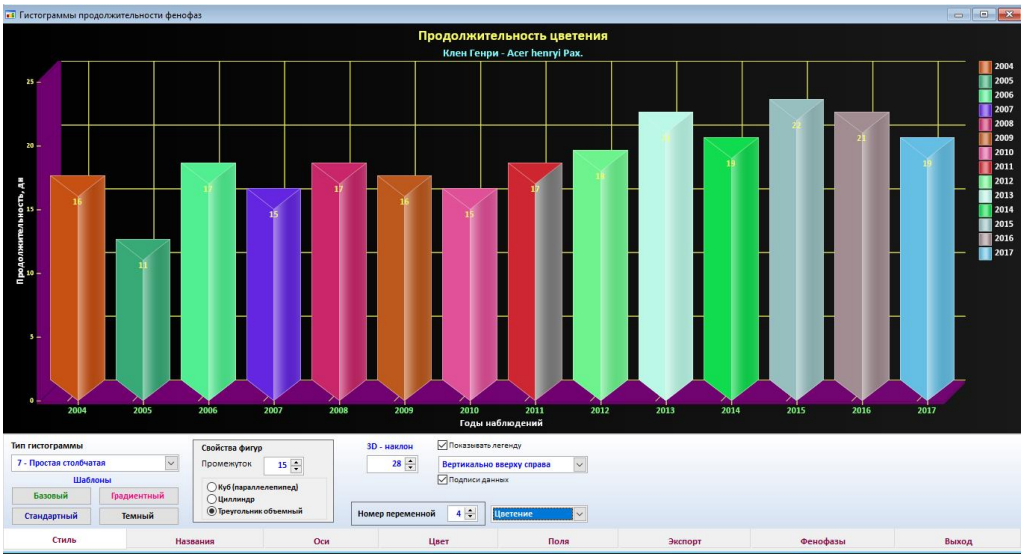


Figure 11 - A form with "FoxCharts" object to work with Histograms

The composition of the phenological database was developed using the special SQL commands of Microsoft Visual FoxPro 9 SP2 programming language and was combined with the simultaneous import of the data entered into Excel spreadsheets according to seasonal rhythms of introducer development. The initial algorithm envisages sampling of the required taxonomic and registration fields from the collection database, then the intermediate cursor is merged with the entered data table from Excel, and at the last stages, the phenophase duration is added in a command way and the validation of their input is done. Thus, 130 information fields of character, numeric, logical and temporary types were created with a total length of 2290 characters, including 6 - identification, 12 - registration, 8 - taxonomic, 33 - statistical and 60 - phenological ones in the structure of phenology. 11 fields are intended to characterize the introduction value of plants on the regional integrated scale. The storage of phenological information for 26 vegetative and generative phenophases is provided for deciduous woody plants, 21 - for gymnosperm woody, and 12 - for herbaceous. The accepted field names correspond to their abbreviated names by phenophases and the method of observation (for example, the beginning of flowering - “C4”).

At this time, the phenological database contains the information for 865 taxons, 533 of which contain the materials on phenology for the period from 1 to 17 years, including 267 representatives of the dendrology department, 21 - of gymnosperm plant department, 10 - local flora, 83 - fruit growing, 100 - rosary, 31 - the sites of climbing plants and 21 - flowering plants. They represent 5 systematic divisions, 8 classes, 11 subclasses, 24 superorders, 49 orders, 8 suborders, 52 families and 108 genera.

The overwhelming number of taxa falls in the database on species (374 - 70.2%) and cultivars (138 - 25.9%). Among the other intraspecific taxonomic ranks, 1 sub-species, 11 forms and 9 hybrids are found.

The most widely represented species in the phenological DB are the species of the families of Aceraceae Juss. (11 taxa), Berberidaceae Juss. 27), Caprifoliaceae Juss. (32), Fabaceae Lindl. (15), Oleaceae Hoffm. (10) Rosaceae Juss. (290) and Vitaceae Juss. (24). The most numerous genera by composition are Acer L. (11), Amygdalus L. (7), Armeniaca Mill. (18), Berberis L. (27), Cotoneaster Medik. (39), Crataegus L. (30), Juniperus L. (8), Lonicera L. (19), Malus Mill. (38), Py-rus L. (12), Rosa L. (111) and Vitis L. (18).

To carry out the correlation calculations, the meteorological database for the current year has been created as well. The structure of this database consists of 103 information fields, of which 85 are for meteorological factor storage, one for the year of observation and 17 – for registration and geographical indicators of the user organization and introduction area. The database provides the variables for the minimum, maximum and average values of air temperature, its relative humidity and precipitation amount, both by months and quarters, and by the year of meteorological observations on average. Nowadays, weather conditions have been collected and introduced for Aktau for 17-year seasonal rhythm study of plant development in the MEBG.

This year, it is planned to compile software modules for *Feno-S* to identify plant perspective phenotypes, construct phenospectrum and classify introducers according to phenotypes, compile reports with multiple mathematical processing for large taxonomic units, etc.

IV. SUMMARY.

Further maturation and introduction of the phenological computer program into the practice of botanical research will significantly simplify creation of information databases and mathematical processing of materials on the seasonal rhythm of plant development, will allow prompt search for taxons, and reduce costs for selection of the most decorative and biologically sustainable range of introductions differentiated by the types of greenery.

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