PAPER • OPEN ACCESS

A comprehensive assessment of the sustainability of nuts of the genus Juglans on adaptive features in the Voronezh region

View the article online for updates and enhancements.

A comprehensive assessment of the sustainability of nuts of the genus Juglans on adaptive features in the Voronezh region

V Slavskiy[1], A Vodolazhskiy[1], S Biganova[2]

[1]Faculty of Forestry, *Voronezh State University of Forestry and Technologies named after G F Morozov*, 8 Timiryazeva Street, Voronezh 394087, Russian Federation
[2]Faculty of Ecological, *Maikop State Technological University*, 191 Pervomaiskaya Street, Maikop 385000, Republic of Adygea, Russian Federation

[1]E-mail: slavskiyva@yandex.ru

Abstract. Taking into account the high value of nuts of the genus Juglans, the increase in their production should go not only through the selection and breeding of the best varieties and forms, but also by shifting the existing border of cultivation to the north, into "new" regions, where nut-bearing crops are not yet widespread. For full adaptation, all components of plant resistance should be at a high level. In this regard, the main purpose of the work is to study and analyze the adaptive features of plants. Were studied local forms of the walnut, nut the manchurian, nut the black, nut the gray and nut the heartshaped. In determining the resistance of plants according on the main adaptive attributes, generally accepted methods based on artificial modeling of unfavorable conditions were used. An integrated approach to the determination of the stability of forms and species of nuts is proposed, which consists of an integrated assessment of the main components of plants, which has an advantage over the conventional field method of evaluation, since a reliable determination of stability in the field requires a long observation (sometimes several years). On the basis of indicators of comprehensive of the sustainability, a scale for the optimal use of forms and species of nuts of the genus Juglans in the Voronezh region was compiled.

1. Introduction

Nuts of the genus Juglans are unique plants. By the combination of useful properties, acad. F.L. Shchepotyev [1] called them ones of the most valuable plants on the planet. This is confirmed by the constant increase in the areas occupied by nuts in all countries of the world [2, 3]. The main goal is to identify and select winter-hardy and fruitful types and forms of nuts, capable of growing and fruitier to the north of the borders of the natural range.

It is important to note that in recent years there has been a significant increase in the average annual air temperature in the region under investigation [4]. Changes in climate parameters are characterized by a significant increase in temperature (especially cold seasons). The most important result of warming is decrease in the quantities of winters with a minimum soil and air temperature [5].

The introduction of heat-loving rocks into more northern regions is fraught with a number of difficulties, the overcoming of which is possible only with a competent approach to introductions. The productivity of plants is affected by the ability to withstand winter temperature depressions and other adverse weather events – resistance to diseases and pests, springs freezing, the heat and drought conditions. Adaptation of plants is made up of a complex of factors that act not only in winter, but also throughout the vegetative period. For successful growth and stable fruiting, all major adaptive

attributes should be at a high level [6]. In this regard, the study and analysis of adaptive attributes the plants is the important issue.

2. Material and methods

Objects of research were garden, park and shelterbelts, plantations, landscape groups and separately standing trees of local forms of the walnuts (*J. regia L.*), nut the manchurian (*J. manchurica Max.*), nut the black (*J. nigra L.*), nut the gray (*J. cinerea L.*) and nut the heartshaped (*J. cordiformis Max.*), growing in 12 districts of the Voronezh Region.

In the determination of frost resistance and frost sustainability of plants, laboratory methods of accelerated evaluation were used, based on artificial freezing [7, 8]. Experiments on artificial freezing were carried out in the climatic camera "Feitron-2101" [9, 10]. The repeatability of the tests executed twice. Annual shoots were cut from the peripheral parts of the crown of trees that have reached the age of fruiting at an altitude of about 1.5 meters. Cuttings had a length of 25-40 cm and were harvested at the end of the autumn period before the onset of severe frost.

Frost sustainability was determined from the degree of damage to the wood on long oblique cuts in the middle of the branches [7]:

    0 – there is no color change, the tissue is light green;
    1 – light yellowing of the tissue;
    2 – the wood is light brown, there are separate dead areas (from 20 to 40%);
    3 – light brown wood, at least half of the tissue (from 40 to 60%) died;
    4 – the wood is all brown;
    5 – the wood is dead.

Frost resistance and resistance to sharp changes in winter temperatures were determined on the basis of the following experiment options:

    – maximum frost resistance – hardening at –5 °C, freezing at -40 °C;
    – resistance to sharp changes in temperature – thaw + 3 °C for 5 days, freezing at –30 °C. Exposure in all cases was 18 h, the rate of temperature decrease 5 °C per hour [7-11].

When establishing the ability of plants to withstand early autumn and late spring frosts, 50 peduncles were cut, placed in a vessel with a capacity of 150-200 ml, half filling with water, and delivered to the laboratory for freezing. To avoid sudden changes in temperature, the peduncles along with the vessels were placed in an icebox with a temperature of 1-3 °C one hour prior to freezing. The freezing was carried out at a temperature of –4 °C for 2 h, after which the peduncles were transferred to an illuminated room at a temperature of 18-25 °C. The next day, counted the number of damaged flowers and buds. The percentage of damaged flowers was calculated and the average sustainability to spring frosts was calculated, according to the scale:

    1 – no damage to flowers and buds;
    2 – damage to 10% of the flowers and absence of damaged buds;
    3 – 11-30% of the flowers had damage and no damage in the buds;
    4 – damaged 31-50% of flowers and up to 10% of buds;
    5 – all flowers and more than 10% buds were damaged.

In connection with the complex effect of drought (dehydration and overheating), it is necessary to diagnose plants it is simultaneously for resistance to heat and drought [12, 13]. It should be borne in mind that indirect methods of determining drought resistance, based on correlation links, do not give a true characteristic of the drought resistance of the introduced culture [14]. The existing methodology was slightly modernized, buts taken into account the recommendations given by leading specialists in recent years [15-17].

When simulating the conditions of drought, the leaves of the investigated plants are lowered consecutively for 30 min in water at temperature of 40, 45, 50 ... to 80 °C, and then into cold water for 10 minutes at temperature of 5-10 °C, after of this is transferred in 0.2 N. HCl [11, 18]. Dead (damaged) parts of the leaves have a brown color. According to the degree of leaf tissue change in color, the sustainability of the studied species was assessed according to scale (point) [12, 18]:

1 – very weak – up to 10% of the sheet area is damage ding;
2 – weak – the damage dings from 11 to 30%;
3 – medium – the damage dings from 31 to 50%;
4 – strong – the damage ding from 51 to 80%;
5 – very strong – 81 to 100% of the area of area the leaf is damaged.

The degree of damage to diseases during the vegetative period was determined in natural conditions without introduction off artificial infection. Accounting of damage was determined separately for each part of the plants (for flowers, leaves, shoots and fetuses) according to the recommendations of Yu I Sukhorukikh and others [19]. The sensitivity of flowers was determined in may; leaves, shoots and fetuses – in august, when the diseases reach maximum development. The intensity of the lesion was determined separately for each indicator:

0 – there is no defeat;
1 – single spots, amaze to 5% of surface of the plant;
2 – amazed 6 to 10% of the plant surface is affected;
3 – amazed from 11 to 25% of the surface of the plant is affected;
4 – amazed from 26 to 50% of the plant surface is affected;
5 – amazed from 50 to 75% of the surface of the plant is affected;
6 – more than 75% of the surface of the plant is affected, the leaves are the fall off.

Proposed estimated scale was slightly amended, to bring it into a comparative form.
1 – highly resistant plants (0-1.0 points);
2 – resistant plants (1.1-2 points);
3 – medium resistant plants (2.1-3 points);
4 – affected plants (3.1-4 points);
5 –strongly affected plants (4.1-5 points).

Experimental samples were taken from trees, age not less than 20 years. In the program STATISTICA-6.0 [20], calculations of statistical characteristics were performed and the experimental data were aligned by using regression analysis [21].

3. Results and discussion

Insufficient winter hardiness is the main limiting factor in the introduction. Winter hardiness is determined during the vegetation period and includes not only resistance to low temperatures, but also to early autumn and late spring frosts, sharp temperature drops after thaws and solar heating, sleet, winter desiccation, i.e. is a complex property [11, 22, 23]. In order for plants to be reliably resistant to various damaging factors, all adaptive components must have a high level. The resistance of plants to low temperatures can be divided into cold resistance, frost resistance and frost sustainability. Cold resistance refers to the ability of plants to tolerate positive temperatures slightly above 0 °C. Frost resistance is the ability of plants to withstand severe frosts (primarily, over –35 °C). By frost sustainability is understood the ability of the plant for a long period without damage to withstand negative temperatures (Table 1).

From the data given in Table 1 it follows that local forms of nuts vary greatly in both of the traits studied. The average to frost sustainability and frost resistance of *J. regia* in the Voronezh region is not high (2.12 and 1.90 points, respectively). Consequently, the *J. regia* is not a very winter hardy woody species. However, are selected the most winter hardiness plants, which annually bear fruit and can bear low winter temperatures almost painlessly [22, 24]. They should form the basis of the seed fund in the cultivation of the *J. regia*.

J. manchurica can be attributed to the number of tree species having a very high frost sustainability and especially frost resistance – the average score for resistance to low temperatures is 1.6 and 1.5 points, respectively. Long-term temperature drops of -20 °C do not do any harm to adult plants. The frost sustainability of the *J. manchurica* is comparable to that of the maple aquifolium and the ash-tree common, which are one of the mains forest-forming species of the region. *J. nigra* is a

frost resistant species – the average score is 1.58. However, a long-term winter decrease in temperature can cause significant damage to plants.

Table 1. Average statistic indicators of frost resistance and frost sustainability of nuts of the genus Juglans in the Voronezh region.

Types of nuts of the genus *Juglans*	Frost sustainability, point				Frost resistance, point			
	M±m	C, %	P	t	M±m	C, %	P	t
J. regia	2.12±0.058	37.22	2.63	37.77	1.90±0.062	45.02	3.30	30.47
J. manchurica	1.56±0.045	41.01	2.88	34.71	1.51±0.044	41.71	2.93	34.31
J. nigra	1.67±0.057	49.69	3.40	29.32	1.58±0.046	43.01	2.90	34.42
J. cinerea	1.58±0.049	40.53	3.11	32.17	1.52±0.043	41.70	2.80	35.31
J. cordiformis	1.83±0.061	45.18	3.03	32.91	1.79±0.060	34.88	3.32	31.09

Where: M – mean value of the feature, m – error of the mean value, C – coefficient of variation, P – possible error in the study, t – reliability of the study.

J. cinerea is a very frost resistant and frost sustainability species, both under natural area condition and in the Voronezh region [1, 22]. Due to the early termination of vegetation and a long period of rest, the *J. cinerea* without visible damage can withstand temperature drops down to -40 ºC, which allows cultivating this species in the Central zone of the European part of Russia. Also, with a certain risk, it can be grown in the southern zone of the taiga and Western Siberia. It should be noted that the frost resistance and frost sustainability of the *J. cordiformis* are not high (1.79-1.83 points), but since winters with extremely low temperatures in the investigated climatic zone are not frequent, this circumstance not to be critical.

In winter, plants are affected by various extreme factors, associated not only with the freezing of various organs and tissues. Large damage is caused by thaws, and excessive moisture of tissues with sudden changes in positive temperatures negative, may lead to the death of not only shoots, but also perennial branches [1, 6, 7]. The reliability of the differences between the average values of the stability of nuts of the genus Juglans to the changes in the temperature regime in the investigated region are given in Table. 2.

Table 2. An assessment of the reliability of the differences between the average values of the stability of nuts of the genus Juglans to sharp temperature changes.

Types of nuts of the genus *Juglans*	Differences between mean values				
	M_1	M_2	M_3	M_4	$t_{0.05}$
J. regia (M_1)	–	–	–	–	1.96
J. manchurica (M_2)	1.07	–	–	–	1.96
J. nigra (M_3)	2.04	1.04	–	–	1.96
J. cinerea (M_4)	0.13	1.15	1.93	–	1.96
J. cordiformis (M_5)	2.00	0.88	0.16	2.07	1.96

From the data in Table 2 it can be seen that the reliability of the differences between the average values of resistance to temperature changes is, in most cases, recognized as random at a probability level of 0.95. There are slight differences between the average values of *J. cinerea* and *J. cordiformis* (2.07), *J. regia* and *J. cordiformis* (2.00) and *J. regia* and *J. nigra* (2.04), which is slightly higher than the standard Student's criterion ($t_{0.05}$) = 1.96.

Consequently, temperature changes and winter desiccation have less effect on the overall winter hardiness of fruit-bearing plants, in comparison with low temperatures, although some harms is nevertheless caused. In the course of the regression analysis, the universal coefficients of resistance to temperature changes (change of negative temperatures by positive ones) are found which are equal to:

- 1.25 – for winter temperature changes within 3-5 days;

- 1.37 – for winter temperature changes within 6-10 days;
- 1.5 – for winter conditions with extreme temperature conditions (more than 10 days).

An important obstacle to the introduction of the *J. regia* is the low resistance to late spring frosts [22, 24]. Frosts damage the tops of young shoots, foliage, male and female flowers, significantly reducing yields. Walnut has a weak sustainability to spring frosts, especially during the flowering period, which is characteristic of it in all places of cultivation [1, 6, 24, 25]. In the climatic conditions of the region under investigation, the early onset of the vegetation of the *J. manchurica* has been noted, as a result of which there is a great danger of freezing of the flower buds, which inevitably leads to a decrease in yield. Nuts *J. nigra* on reaching the fruiting age is most adapted to returns of low spring temperatures and spring frosts does not cause significant damage to the plant. At a young age, plants a *J. cinerea* are often damaged by late spring frosts, but upon entering the fruiting phase, resistance to various unfavorable factors increases dramatically [24]. Nuts *J. cordiformis* the least damage by late spring frosts, which is a positive moment and favorably affects the yield. The average sustainability to spring frosts for the studied species of nuts of the genus Juglans was processed by statistical analysis methods and is given in Table. 3.

Like any other culture, the nut from the first years of life is damaged by diseases and pests. Despite the fact that nuts in general can not be called very sustainable breeds, nevertheless, they are less are subject to damage by disease and pest than most fetusplants. In addition, in the Voronezh region there is a much smaller list of diseases and pests of nuts, in comparison with the natural area. A number of pests and diseases can affect all species of the genus Juglans, but some of them can focus on a particular species. The most common nuts diseases in the investigated region are marsonina, bacteriosis and damage by wood-destroying fungi. Among the pests, the most dangerous are unpaired silkworm, nut moth, warty mite and aphids.

Table 3. The average statistical indicators of the stability of the nuts the genus Juglans to late spring and early autumn frosts, as well as to diseases and pests in the Voronezh region.

Types of nuts of the genus *Juglans*	Sustainability to spring frosts, point				Resistance to diseases and pests, point			
	M±m	C, %	P	t	M±m	C, %	P	t
J. regia	2.68±0.066	33.92	2.50	40.62	1.57±0.045	31.89	2.81	34.91
J. manchurica	2.33±0.061	36.53	2.61	38.24	1.53±0.042	26.53	2.72	36.38
J. nigra	1.72±0.058	47.08	3.30	29.69	1.52±0.046	37.17	3.03	33.02
J. cinerea	2.06±0.063	43.62	3.09	32.75	1.56±0.044	31.77	2.80	35.52
J. cordiformis	1.75±0.055	40.61	3.10	31.82	1.25±0.031	20.21	2.38	40.34

From the data of Table 3 it follows that *J. nigra* (1.72 points) and *J. cordiformis* (1.75 points) are the most adapted to return low temperatures during the growing season. The nuts *J. cinerea* and *J. manchurica* that show very high resistance to winter low temperatures are damaged by spring frosts much more often. All the walnut trees that grow in the Voronezh region suffer to frosts to some extent – low sustainability to spring frosts (average grade 2.68 points) is a real scourge for this breed. It should be noted the low sustainability to spring frosts of the *J. manchurica* (2.33 points). First of all, this is due to the earliest among all the species of nuts investigated, the beginning of vegetation. Nuts *J. manchurica*, *J. cinerea* and especially *J. cordiformis* show high resistance to diseases and pests, the main of which are marsonina and aphids of various species. In the case of weakening of plants due to unfavorable factors, it is possible to watch damages individual trees to several types of diseases and pests.

In the Voronezh region, cases of damage to the nuts of the genus Juglans from drought were rare, mainly in the southern steppe regions. The death of healthy adult plants from lack of moisture was not noted, but a possibly lag in growth and deterioration of fruiting. Long-term temperature rise up to + 32-35 ºC and more can cause yellowing and premature falling off of leaves, and in cases of

temperature increase up to +40 ºC and above, the seedlings can die. In Table 4 shows the results of experimental observations and their subsequent mathematical processing.

Table 4. Average indicators of heat resistance and drought resistance of nuts of the genus Juglans in the Voronezh region.

Types of nuts of the genus *Juglans*	Drought resistance, point				Heat resistance, point			
	M±m	C, %	P	t	M±m	C, %	P	t
J. regia	1.61±0.038	33.51	2.43	42.36	1.97±0.062	44.55	3.13	31.76
J. manchurica	2.35±0.067	40.53	2.92	35.12	2.82±0.079	39.41	2.82	35.71
J. nigra	2.16±0.055	36.50	2.51	39.31	2.33±0.066	40.30	2.81	35.33
J. cinerea	2.30±0.067	39.62	2.82	35.80	2.82±0.081	40.81	2.89	34.80
J. cordiformis	2.28±0.061	37.98	2.70	37.42	2.71±0.074	38.67	2.71	36.62

From the data given in Table 4 it follows that for *J. regia* is inherent is very high drought resistance in the Voronezh region, and damage from high temperatures are so rare that they can be considered an exception. Compared to other species of the genus Juglans, the walnut is the most drought- and heat-resistant (1.61 and 1.97 points). The remaining species of the genus Juglans do not show an increased drought resistance (mean score of 2.16 to 2.35), but since in the Voronezh region, long arid drought periods do not occur annually, high heat and drought are not critical.

In the course of the regression analysis, equations were found for the dependence of complex plant resistance on adaptive features (1-5). The level of accuracy of the received coupling equations was maximized by stepwise multiple regression. The attributes with the least level of significance (F <2.5) were excluded from the analysis, which is especially important when the coefficient of determination (R^2) is less than 0.95 [21]. As a result of the calculations, the follow in equations are formed:

Juglans regia: $y = 5.5 - 0.25\tilde{o}_1 - 0.37\tilde{o}_2 - 0.63\tilde{o}_3 - 0.17\tilde{o}_6 - 0.22\tilde{o}_7$ (1);

where: y – a comprehensive sustainability (point);

x_1 – a frost sustainability (point);

x_2 – a frost resistance (point);

x_3 – a sustainability to spring frosts (point);

x_4 – a drought resistance (point);

x_5 – a heat resistance (point);

x_6 – a resistance to diseases and pests (point);

x_7 – a resistance to sharp temperature changes (point).

Juglans manchurica: $y = 5.1 - 0.28\tilde{o}_2 - 0.71\tilde{o}_3 - 0.18\tilde{o}_4 - 0.12\tilde{o}_7$ (2);

Juglans nigra: $y = 4.8 - 0.37\tilde{o}_2 - 0.25\tilde{o}_3 - 0.19\tilde{o}_4 - 0.26\tilde{o}_6 - 0.10\tilde{o}_7$ (3);

Juglans cinerea: $y = 4.8 - 0.22\tilde{o}_1 - 0.30\tilde{o}_2 - 0.39\tilde{o}_3 - 0.24\tilde{o}_6$ (4);

Juglans cordiformis: $y = 5.1 - 0.28\tilde{o}_1 - 0.41\tilde{o}_2 - 0.52\tilde{o}_3 - 0.09\tilde{o}_4$ (5).

The level of significance (F) for sustainability to spring frosts for most species of nuts had a maximum value (37.5-78.2). Heat resistance does not have a significant effect on the complex resistance of fruit-bearing plants for all types of nuts - the level of significance of (F) was in the range from 0.32 to 0.88, which is a positive moment and allows to exclude this factor from the calculations. The compiled equations of a comprehensive sustainability provide the required accuracy (R^2 varies from 0.955 to 0.971). In addition, the Durbin-Watson (DW) values calculate for each nut species are calculated, which range from 1.51 to 2.06 and fall within the required range (1.5-2.5) [26].

This confirms that the regression models obtained were completely adequate to the experimental data. Based on the calculation of a comprehensive sustainability, an evaluation scale was compiled

(Table 5), which characterizes the optimal (rational) cultivation of forms and species of nuts of the genus Juglans in the Voronezh region.

Table 5. Evaluation scale of nuts of the genus Juglans by groups of useful properties.

Graduations a comprehensive sustainability (score)	Field of application of nut species
Less 1.00	Not suitable for cultivation in the investigated region
1.01-1.50	Suitable for landscaping, use as a forest tree, for breeding along roads and field shelter strips
1.51-2.00	Suitable for planting of greenery, individual trees are suitable for getting fruits in the garden of local residents
2.01-2.50	Can be used as a fruit crop for the creation of plantations (in full accordance with the conditions of growth)
2.51-3.00	Suitable for use as a fruit crop, no restrictions
3.01-3.50	Culture can take a full place in the assortment of species for reforestation and aforestation in the region
More 3.51	Suitable for any purpose, including, for the creation of industrial plantations

4. Summary

An integrated approach to the determination of the stability of forms, varieties and species of nuts of the genus Juglans is proposed. It consists in the integral evaluation of the main components of plants, carried out on the basis of taking into account the effect of adaptive features, the parameters of which are established by laboratory methods. Such a rapid method has the advantage over the conventional field method of assessment, since reliable determination of stability in the field conditions requires a lot of time (sometimes several years). In the course of the regression analysis, equations were found for the dependence of complex plant resistance on adaptive features (coefficient of determination 0.955-0.971). Proceeding from the received calculations and established dependencies, according to the average index of a comprehensive sustainability (score), the species and forms of nuts of the genus Juglans in ascending order can be arranged as follows: *J. regia* – 2.18; *J. manchurica* – 2.37; *J. cinerea* – 2.74; *J. nigra* – 2.91; *J. cordiformis* – 2.92. An evaluation scale is drawn up for optimal cultivation of forms and species of nuts of the genus Juglans in the Voronezh region.

References
[1] Schepot'ev F L, Richter A A, Pavlenko F A, Molotkov P I, Kravchenko V I, Iroshnikov A I 1985 *Walnut forest and horticultural crops* [in Russian] (Moscow: Agropromizdat) p 224
[2] Agricultural Research Service United States Department of Agriculture: (Electronic resource), available at: https://www.ars.usda.gov/
[3] Biganova S G, Sukhorukih Yu I 2017 Peculiarities of using the method of as-sessing the quality of walnut fruit *Woks of the State Nikit. Botan. Gard*. **144** (I) 102
[4] Weather and Climate – The climate of Voronezh 2016 [in Russian] (Electronic resource), available at: *http://www.weather.ru.net/climate/34123*
[5] Assessment report of Roshydromet on climate change and their consequences on the territory of the Russian Federation 2008 (Electronic Materials Russia vol 2) p 291
[6] Slavskiy V A, Chernyshov M P 2018 Comprehensive assessment of walnut winter hardiness in the Voronezh region *Saint-Petersburg State Forest Technical University* [in Russian – *Izvestia Sankt-Peterburgskoj Lesotehniceskoj Akademii*] **224** 37
[7] Rezvyakova S V 2015 *Theoretical and practical bases of increasing the bioresource potential of resistance of garden crops to temperature factors* [in Russian] PhD thesis, Orel, p 385

[8] Tumanov I I 1979 *Physiology of hardening and frost resistance of plants* [in Russian – Fiziologia i morozostoykoct rasteniy] (Moscow: Nauka) p 352

[9] Tyurina M M and Gogoleva G A 1978 *Accelerated evaluation of winter hardiness of fruit and berry plants* Method. recommendations [in Russian] (Moscow: Nauka) p 38

[10] Tyurina M M, Gogoleva GA, Efimova NV, Goloulina LK, Morozova NG, Echedi JJ, Volkov FA, Arsentiev AP and Matyash NA 2002 *Determination of the resistance of fruit and berry crops to stressors of the cold season in field and controlled conditions* [in Russian] (Moscow: Nauka) p 120

[11] Yushkov A N 2017 *Adaptive potential and selection of fruit plants for resistance to abiotic stressors* [in Russian] PhD thesis, Federal Scientific Center named after I.V. Michurina Michurinsk: p 388

[12] Rollins J A, Habte E, Templer S E, Colby T, Schmidt J and Von Korff M 2013 Leaf proteome alterations in the context of physiological and morphological responses to drought and heat stress in barley (Hordeum vulgare L.). *J. Exp. Bot.* **64** 3201

[13] Zhuchenko A A 2000 *Fundamental and applied scientific priorities of adaptive intensification of plant growing in the 21st century* [in Russian] (Saratov: SGAU) p 276

[14] Budagovskiy A V, Dubrovskiy M L, Pimkin M Yu, Budagovskaya O N, Milyaev A I 2011 *New methodical approach to the assessment of the heat resistance of fruit plants* [in Russian] (Bryansk: *Agroecological Aspects of Sustainable Development Agroindustrial complex: Proc. VIII Int. Sci. Conf.*) pp 317-319

[15] Charrier G, Poirier M, Bonhomme M, Lacointe A and Améglio T 2013 Frost acclimation in different organs of walnut trees Juglans regia L.: how to link physiology and modelling *Tree Physiol.* chapter 33 pp 1229-1241

[16] Gusta L V and Wisniewski M 2013 Understanding plant cold hardiness: an opinion *Phycologia* **147** 4

[17] Bressan R, Bohnert H., Zhu J K 2009 Abiotic stress tolerance: from gene discovery in model organisms to crop improvement *Mol. Plant.* **2** (1) 214

[18] Orlova D G 2014 *Features of heat resistance of representatives of the genus Aronia Pers., Chaenomeles Lindl., Sorbus L. at introduction in the conditions of the steppe zone on the example of Orenburg (Electronic Materials vol 1)* available at: https://science-education.ru/en/article/view?id=12161.

[19] Sukhorukikh Yu I, Lugovskoy A P, Biganova S G 2007 *Program and methodology of selection of walnut* [in Russian] (Maykop: Quality) p 58

[20] STATISTICA ver. 6.0 2001 StatSoft [Electronic resource]

[21] Dospekhov B A 2011 *Technique of field experience (with the basics of statistical processing of research results): textbook* [in Russian] (Moscow: Kolos) p 547

[22] Slavskiy V A and Chernyshov M P 2018 Stability of nuts of the genus Juglans to negative winter temperatures in the Voronezh region *Forest Engineering Journal* [in Russian – Lesotekhnichesky Zhurnal] **8** 1(28) 69

[23] Poirier M, Lacointe A, Ameglio T 2010 A semi-physiological model of cold hardening and dehardening in walnut stem. *Tree Physiol.* **12** 1555

[24] Slavskiy VA, Nikolaev EA, Kalaev VN 2013 *Introduction, selection and cultivation of nuts of the genus Juglans in the Central Chernozem Region* [in Russian] (Voronezh: Wind Rose) p 262

[25] Sukhorukikh Yu I and Alentiev P I 1999 *Walnut greek and black in the south of Russia* [in Russian] (Maikop: MGTI) p 210

[26] Anatolyev S. 2003 *Durbin–Watson statistic and random individual effects* (Electronic resource) Econometric Theory (Problems and Solutions), Available at: http://pages.nes.ru/sanatoly/Papers/DW.htm