Assessment of the ecological and biological features of the development of shrub introduced species in the conditions of the Central Black Earth Region

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Abstract. In the course of research, the authors analyzed the results of the introduction of shrub plants of different taxonomic groups in the conditions of the Central Black Earth Region. Most of the representatives of the collections under consideration (a collection of deciduous shrubs, a collection of ornamental shrubs, a collection of coniferous shrubs) showed significant adaptive capabilities in the conditions of the region under consideration. Recommendations on the possibility of using introduced shrubs in green urban construction are given, and species and forms that are not suitable for this purpose are identified. The authors have developed a methodology for assessing the results of introduction tests of shrub plants using the example of the Central Black Earth Region, which can be used in other regions of the Russian Federation and countries of the world to conduct similar tests. This technique is quite simple, but it allows you to create a complete picture of the adaptive capabilities of introduced species, since is based on basic indicators of plant vitality (drought resistance, winter hardiness, average annual growth, observation of flowering and seed production).

1. Introduction

Our planet is entering an era of global warming. Russian and world scientists have proved this by many studies [1]. The number of dangerous hydrometeorological phenomena increases from year to year. There is reliable evidence for this [2, 3]. Moreover, these phenomena can be of a very different nature - droughts, an increase in the average annual temperature, which leads to an increasing number of forest fires, ice rains, etc. This list can be continued for a long time. It has been reliably established that the rise in temperature over the twentieth century was at least 1 °C, and this increase continues, gaining momentum [4].

Such climatic changes cannot but affect the vital functions and processes of all living organisms on the planet and, of course, plants. Fluctuations in the amount of precipitation, an increase in the average annual temperature affect the ecological and biological features of plant ontogenesis [5, 6]. In this regard, southern species of trees and shrubs are gradually moving to more northern habitats. At the same time, local (flora) species begin to move northward the same [7]. Such displacement can occur up to a certain limit. It will be limited by temperature minimums and maximums, the amount of precipitation, the availability of available mineral nutrients in soils for such plant species.

This movement of plants to other climatic zones by man has been going on for many thousands of years and can occur deliberately and accidentally [8]. The result of the scientific introduction of
species, their cultivation in botanical gardens and the study of the features of ontogeny is their use in green economy in accordance with their phenological characteristics and economic characteristics.

Plant introduction has a long history. Nowadays, in most cases, this process is meaningful in order to use the useful properties of introduced species in a variety of industries. According to researchers in China, more than 50% of alien plants were introduced on purpose [9]. Active processes of introduction, primarily of ornamental plants, are observed in the Mediterranean region [10], Micronesia [11], Europe [12] and other regions of our planet. Introduction processes are actively manifested in the Asian part of Russia, especially in tree species [13].

The classical methods for assessing the success of the introduction of a plant species are to determine its winter hardiness, drought tolerance and seed-bearing ability. In our work, we were the first to use the study of the chemical and physicochemical properties of soil as one of the factors influencing the success of the introduction. The inclusion of the study of the properties of soils on which the introduced species grow is a necessary condition for the reliability of the assessment of the success of the introduction [14].

The purpose of the study is to study the ecological and biological characteristics of shrub introduced species during cultivation for the possibility of their use in economic activities in the territory of the Central Black Earth Region, as well as to develop a methodology for assessing the success of the introduction of shrub plants.

2. Materials and method

Botanical gardens play an important role in biodiversity conservation. On their territory, not only plants of natural flora grow, but also introduced plants brought from various botanical-geographical regions and provinces [15, 16]. The Botanical Garden named after Professor Boris Mikhailovich Kozo-Polyansky was the first botanical garden created in the territory of the Central Black Earth Region in 1937.

Several collections of shrub introduced species were created on the territory of the Botanical Garden of the Voronezh State University named after Professor B.M. Kozo-Polyansky (Russian Federation, Voronezh region, Voronezh) in 2010. Most of the forms and species of these shrubs were tested for the first time.

The first collection included deciduous shrubs brought from the National Botanical Garden. N.N. Grishko (Ukraine, Kiev): Euonymus sachalinensis (F. Schmidt) Maxim., Menispermum canadense L., Euonymus fortunei (Turcz.) Hand.-Mazz., Mespilus germanica L., Actinidia arguta Planch., Myricaria alopecuroides Schrenk., Lonicera periclymenum L. The age of the plants ranged from 1 to 2 years, flowering and seed production were not observed.

The ornamental forms of shrub introductions served as the basis for the formation of the second collection, which is the most numerous in terms of species composition. The material was brought from the Forest-Steppe Experimental Breeding Station (Russian Federation, Lipetsk region). The age of the plants ranged from 1 to 2 years, flowering and seed production were not observed. Collection composition: Cornus alba “Argenteo-marginata”, Lonicera tatarica “Marit”, Dasiphora mandshurica “Alba”, Berberis thunbergii “Atropurpurea”, Spiraea japonica “Atrosanguinea”, Spiraea japonica “Alpina”, Spiraea bumalda “Goldflamme”, Spiraea bumalda “Anthony Waterer”, Spiraea bumalda “Goldmound”, Spiraea bumalda “Crispa”, Spiraea x bumalda “Shirobana”, Spiraea bumalda “Darts Red”, Berberis ottawensis “Superba”, Actinidia colomicta “Clara Teetkin”, Lonicera x brownii “Fuchsioides”, Deutzia scabra “Plena”, Weigela hybrida “Bristol Ruby”, Weigela florida “Alexandra”, Physocarpus opulifolia “Diablo”.

Coniferous shrubs formed the third collection (Forest-steppe experimental selection station): Juniperus scopulorum “Skyrocket”, Juniperus smedia “Mint Julep”, Juniperus scopulorum “Moonglow”, Abies balsamea “Nana”, Juniperus sabina “Tamariscifolia”, Thuja occidentalis “Globosa Nana”. The plants were 3-4 years old.

Latin names of plants are given in accordance with the international classification.
Many possible approaches exist for the way collections are formed in botanical gardens. In our opinion, the geographical method is the most optimal, because plants are planted in group collections in accordance with the place of origin of plant material.

The stability of shrub introduced species was assessed according to the following ecological and biological indicators: 1) study of the chemical and physicochemical properties of the soil; 2) assessment of drought resistance; 3) assessment of winter hardiness; 4) average annual growth; 5) the presence of flowering and seed production; 6) assessment of the possibility of further cultivation for reproduction and use in landscaping in the territory of the Central Black Earth Region.

Soil samples were taken from a collection of deciduous shrubs, a collection of ornamental shrubs, a collection of coniferous shrubs, an area with flora vegetation and a test section to study the chemical and physicochemical properties of the soil.

Each soil sample consisted of pits at different depths: 0-20 cm and 20-40 cm. Then the samples were carefully packed, signed and sent to the laboratory. For each of the samples, the following studies were carried out: determination of gross humus by the method of I V Tyurin as modified by V N Simakov, determination of nitrogen of easily hydrolysable compounds in alkaline extract by the Kornfield method, determination of readily soluble phosphates by the Chirikov method, determination of exchangeable potassium by the Chirikov method with flame photometric end.

The assessment of drought resistance and winter hardiness was carried out according to the scale of introduction resistance, which is based on long-term observations of Soviet and Russian introductors. Taking it as a basis, the authors used a revised methodology, according to which drought resistance, like winter hardiness, was determined every year with the assignment of a point score. The final indicators of these values were determined by summing ten-year indicators (2010-2020) and determining the average value. This average value was the final one for assessing the drought resistance and winter hardiness of a particular species, form.

Drought tolerance assessment scale: 5 points - plant habit is common, turgor of leaves and stems is observed; 4 - the turgor of the aboveground part of the plant is somewhat reduced, it is restored in the evening, after the decrease in daytime temperatures; 3 - yellowing of leaves is observed, leaves and stems are sluggish, turgor is low; 2 - almost complete drying of the surface part of the plant occurs, but with a decrease in temperature or an abundant supply of moisture, it is restored; 1 - the plant dies.

Winter hardiness scale: 5 points - the plant is not damaged after the cold period; 4 points - freezing of annual shoots occurs, in coniferous shrubs during the cold period the number of new shoots formation decreases; 3 points - there is a strong freezing of perennial shoots, coniferous plants are freezing perennial shoots, new shoots are not formed; 2 points - the aboveground part of the plant freezes over, in conifers more than 60% of perennial shoots are damaged; 1 point - the plant dies.

In most cases, the introduction is considered successful when the plant begins to bear fruit and thus bloom. For the entire study period, 0.5 points were assigned to a species if the plant bloomed but did not bear fruit, 1 point if the plant was fruitful and produced seeds, 0 points if the plant did not bloom. The mean and error of the mean were calculated over a ten-year period. The values of this indicator, close to unity, testified to the success of the cultivation of this introduced species.

After studying all the signs, the data obtained were summarized in a general table and a conclusion was made about the possibility of cultivating this introduced species on the territory of the Central Black Earth Region. It should be noted that in the case of ornamental forms, seed production indicates a successful introduction, but the seed material cannot be used for reproduction in accordance with the laws of Gregory Mendel.

The results were statistically processed using the Stadia software package.

3. Results and discussion

During the research, it was found that the soil on which the collections are located belongs to leached chernozem. The chemical and physicochemical properties of the studied soil samples are shown in table 1.
In general, it can be said that the soils on which the collections grow have favorable chemical and physicochemical properties, despite the rather low humus content and low supply of easily hydrolyzable nitrogen, readily soluble phosphorus and exchangeable potassium. The soil under the collection of deciduous shrubs is the most abundant in these essential elements.

### Table 1. Chemical and physicochemical properties of leached black earth.

| Collection from which samples were taken | Sampling depth, cm | Humus content, % | Saturation with bases, % | pH$_{H_2O}$ | $N_{alkaline}$, mg/100 g soil | $P_2O_5$, mg/100 g soil | $K_2O$, mg/100 g soil | pH$_{KCl}$ |
|----------------------------------------|-------------------|-----------------|-------------------------|-------------|-----------------------------|------------------------|------------------------|----------|
| Deciduous shrubs 0-20                  | 5.59              | 90.31           | 6.00                    | 4.64        | 4.88                        | 8.74                   | 5.9        |
|                                        | 20-40             | 4.66            | 90.65                   | 6.14        | 6.38                        | 4.25                   | 8.39                   | 5.6        |
| Ornamental shrubs 0-20                 | 4.24              | 91.88           | 5.81                    | 5.80        | 2.25                        | 7.43                   | 5.5        |
|                                        | 20-40             | 3.94            | 92.81                   | 6.07        | 5.04                        | 2.19                   | 7.05                   | 5.7        |
| Coniferous shrubs 0-20                 | 4.69              | 92.32           | 6.31                    | 2.90        | 3.13                        | 7.95                   | 5.3        |
|                                        | 20-40             | 4.48            | 93.36                   | 6.22        | 3.48                        | 2.13                   | 7.35                   | 5.3        |
| Fallow 0-20                            | 5.79              | 93.74           | 6.34                    | 3.48        | 3.50                        | 8.16                   | 5.5        |
|                                        | 20-40             | 5.06            | 93.73                   | 6.01        | 3.35                        | 2.38                   | 8.03                   | 5.4        |
| Test section 0-20                      | 5.87              | 92.23           | 5.93                    | 3.48        | 2.50                        | 8.76                   | 5.2        |
|                                        | 20-40             | 5.53            | 100                     | 6.05        | 6.38                        | 2.50                   | 8.29                   | 5.3        |

Note: author's own calculations.

The results of studies of ecological and biological indicators of the studied shrub introduced species are presented in table 2. The study of the ecological and biological characteristics of introduced plants has a number of its own characteristics. The results of observations on winter hardiness and drought resistance of species are taken for at least a five-year period, in our case this period was 10 years. The time of active growth of the shrub and the achievement of maximum height depends on the species. In this regard, the table provides information on the average growth in the period of active growth until the moment the maximum height is reached. According to our proposed methodology, seed production is estimated at 1 point, and flowering at 0.5 points.

In species growing in the collection of deciduous shrubs, drought resistance ranged from 4 to 5 points, i.e. in accordance with this indicator, all species can be recommended for cultivation in the Central Black Earth Region. The minimum winter hardiness was noted in Actinidia arguta. In this species, in cold winters, the entire ground part can freeze up, so it requires shelter. In addition, Actinidia arguta did not bloom or bear fruit during the entire research period, although both female and male specimens were presented in the collection. Of the 6 species included in the collection (Euonymus fortune, Mespilus germanica), only 2 species exhibited flowering. The collected seeds did not show germination throughout the entire observation period. In general, the species of this collection can be widely used in green building, with the exception of Actinidia arguta, which will not be able to adapt to difficult urban environmental conditions.

The forms belonging to the collection of ornamental shrubs show good adaptability. All species have a drought resistance of 5 points. The winter hardness of the species in this collection reaches maximum values in most species. The minimum scores were noted in Lonicera x brownii "Fuchsioides", Weigela hybrida "Bristol Ruby", Weigela florida "Alexandra" (3-4 points) and Actinidia colomista "Clara Tsetkin" (2-3 points). Flowering and seed production are noted for most forms. As in the collection of deciduous shrubs, flowering was not detected in the representative of the genus Actinidia.

The main indicators for assessing the introduction success in coniferous shrubs are the indicators of drought resistance and winter hardiness. This is due to the fact that the growth rate of conifers is much lower, and seed reproduction is a very long process, which, moreover, cannot be used for species forms.
### Table 2. Ecological and biological indicators of shrub introduced species.

| Shrub type or shape                  | Drought tolerance | Winter hardness | Average annual growth, cm± error of mean | Flowering and seeds | Cultivation possibility |
|-------------------------------------|-------------------|-----------------|------------------------------------------|---------------------|-------------------------|
| **Deciduous shrub collection**      |                   |                 |                                          |                     |                         |
| *Euonymus sachalinensis* (F. Schmidt) Maxim. | 4                 | 5               | 10.8±2.5 0.75±0.11                         | +                   |                         |
| *Menispermum canadense* L.          | 5                 | 3               | 15.6±1.8 0.81±0.01                         | +                   |                         |
| *Euonymus fortunei* (Turcz.) Hand.-Mazz. | 5                 | 5               | 5.4±1.2 0.54±0.05                          | +                   |                         |
| *Mespilus germanica* L.             | 4                 | 4               | 7.8±3.5 0.56±0.1                           | +                   |                         |
| *Actinidia arguta* Planch.          | 4                 | 2-3             | 21.5±3.8 0                               | 0                   | ±                       |
| *Myricaria alopecuroides* Schrenk.  | 5                 | 4               | 15.1±2.4 0.84±0.18                        | +                   |                         |
| *Lonicera periclymenum* L.          | 5                 | 4               | 15.7±2.8 0.76±0.2                         | +                   |                         |
| **Collection of decorative forms of deciduous shrubs** |                   |                 |                                          |                     |                         |
| *Cornus alba* “Argenteo-marginata” | 5                 | 5               | 13.5±0.5 0.45±0.01                         | +                   |                         |
| *Lonicera tatarica* “Marit”         | 5                 | 4-5             | 9.8±0.04 0.55±0.03                        | +                   |                         |
| *Dasiphora mandshurica* “Alba”      | 5                 | 5               | 5.8±0.25 0.87±0.1                         | +                   |                         |
| *Berberis thunbergii* “Atropurpurea” | 5              | 5               | 9.8±0.1 0.88±0.02                         | +                   |                         |
| *Spiraea japonica* “Atrosanguinea”  | 5                 | 5               | 5.4±0.1 0.95±0.11                         | +                   |                         |
| *Spiraea japonica* “Alpina”         | 5                 | 5               | 3.4±0.011 0.59±0.19                       | +                   |                         |
| *Spiraea bumalda* “Goldflamme”      | 5                 | 5               | 5.7±0.05 0.84±0.11                        | +                   |                         |
| *Spiraea bumalda* “Anthony Waterer” | 5                 | 5               | 6.4±0.14 0.93±0.2                         | +                   |                         |
| *Spiraea bumalda* “Goldmound”       | 5                 | 5               | 6.5±0.04 0.93±0.03                        | +                   |                         |
| *Spiraea bumalda* “Crispa”          | 5                 | 5               | 3.4±0.11 0.65±0.12                        | +                   |                         |
| *Spiraea x bumalda* “Shirohana”     | 5                 | 5               | 4.75±0.03 0.94±0.1                        | +                   |                         |
| *Spiraea x bumalda* “Darts Red”     | 5                 | 5               | 3.95±0.25 0.89±0.12                       | +                   |                         |
| *Berberis ottawensis* “Superba”     | 5                 | 5               | 11.2±0.3 0.91±0.01                        | +                   |                         |
| *Actinidia kolomikta* “Clara Tcekin” | 5             | 2-3             | 16.8±0.5 0                                | 0                   | ±                       |
| *Lonicera x brownii* “Fuchsioides”  | 5                 | 3-4             | 25.8±0.5 0.67±0.1                         | +                   |                         |
| *Deutzia scabra* “Plena”            | 5                 | 5               | 7.1±0.15 0.59±0.21                        | +                   |                         |
| *Weigela hybrida* “Bristol Ruby”     | 5                 | 3-4             | 4.4±0.1 0.64±0.11                         | ±                   |                         |
| *Weigela florida* “Alexandra”       | 5                 | 3-4             | 4.7±0.12 0.68±0.13                        | ±                   |                         |
| *Physocarpus opulifolia* “Diablo”    | 5                 | 5               | 15.9±0.5 0.79±0.01                        | +                   |                         |
| **Coniferous shrubs collection**    |                   |                 |                                          |                     |                         |
| *Juniperus scopulorum* “Skyrocket”  | 5                 | 4-5             | 16.1±0.3 0                                | 0                   | +                       |
| *Juniperus scopulorum* “Mint Julep” | 5                 | 5               | 5.4±3 0                                  | 0                   | +                       |
| *Juniperus scopulorum* “Moonglow”    | 5                 | 5               | 11.8±0.12 0                              | 0                   | +                       |
| *Abies balsamea* “Nana”             | 4                 | 5               | 4.8±0.1 0.5±0.01                         | +                   |                         |
| *Juniperus sabina* “Tamariscifolia”  | 5                 | 5               | 7.7±0.25 0.65±0.15                       | +                   |                         |
| *Thuja occidentalis* “Globosa Nana” | 5                 | 5               | 3.4±0.03 0.84±0.24                       | +                   |                         |

Note: author's own calculations.

### 4. Conclusion

In the course of research, the authors analyzed the results of the introduction of shrub plants of different taxonomic groups in the conditions of the Central Black Earth Region. Most representatives of all three considered collections (a collection of deciduous shrubs, a collection of ornamental shrubs, a collection of coniferous shrubs) showed significant adaptive capabilities in the conditions of the
region under consideration. Recommendations are given on the possibility of using introduced shrubs in economic activities, species and forms unsuitable for this purpose are revealed. The results of the research carried out make it possible to expand the list of introduced plant species in the Central Black Earth Region under the conditions of climatic changes.

The authors have developed a methodology for assessing the results of introduction tests of shrub plants using the example of the Central Black Earth Region, which can be used in other regions of the Russian Federation and countries of the world to conduct similar tests. This technique is quite simple, but it allows you to create a complete picture of the adaptive capabilities of introduced species, since is based on basic indicators of plant vitality (drought resistance, winter hardiness, average annual growth, observation of flowering and seed production).

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