

Seasonal growth and development of taxa of the genus *Forsythia* Vahl in the conditions of Kyiv

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Abstract

In the Right-Bank Forest-Steppe of Ukraine, 6 species, 2 hybrids, 2 varieties and about 10 cultivars of the genus *Forsythia* Vahl are cultivated. The phenology of the species of the genus is not sufficiently covered in the literature. The available information is mostly about flowering and fruiting periods of individual species, varieties and cultivars at various points of introduction. Due to the lack of information on the rhythms of growth and development of plants of most taxa of the genus *Forsythia* in the Right-Bank Forest-Steppe of Ukraine, there was a need to conduct such studies. The purpose of the work is to recognize the features in seasonal rhythms of growth and development of *Forsythia* taxa in the Right-Bank Forest-Steppe of Ukraine and to study their consistency with the natural and climatic conditions of this region. The studied objects are within the normal limits of 3–4 phoenodata. Only *Forsythia ovata* Nakai, whose phenophases are shorter than normal, does not fit into this range. 20 % of the research objects are within the normal range for all phoenodata, and 93.33 % are within the normal range for 3–4 phoenodata. *F. giraldiana* Lingelsh., *F. ovata* 'Tetragold', *F. suspensa* (Thunb.) Vahl, *F. suspensa* var. *fortunei*, and *F. suspensa* var. *sieboldii*, growing in the city of Kyiv, are within the norm for the dates of onset of all phenophases and have an unused part of the growing season in reserve. In the majority of forsythias (86.67 %), the phenological atypicality indicator is less than 1, which indicates the correspondence of the seasonal rhythms of growth and development of most of the studied forsythias to the climatic conditions of the Right-Bank Forest-Steppe of Ukraine.

Key words: phoenodate, phenological abnormality indicator, phenology, phenophase.

Introduction

In Ukraine, over the years, 6 species, 2 varieties, 2 hybrids and more than 10 cultivars of the genus *Forsythia* Vahl have been introduced (Kokhno and Kurdyuk

1994). Six species, 2 varieties, 2 hybrids and 10 cultivars of the genus *Forsythia* grow in the Right-Bank Forest-Steppe of Ukraine (Andriienko et al. 2007; Honcharenko 2009, 2014).

It is known that fluctuations in the tim-

ing of the onset of any phenophase over the years mainly depend on the meteorological conditions of the year. The difference in the timing of the onset of the same phenophases in different species during the year indicates different rhythms of development that have developed in the process of phylogenesis (Plotnikova 1971).

The phenology of *Forsythia* taxa is not sufficiently covered in the literature. The available information is mostly about the flowering and fruiting periods of individual species, varieties and cultivars at various points of introduction (Visyulina 1957, Misnik 1976, Kokhno et al. 1991). Some information on the peculiarities of the growth and development of forsythia in the conditions of the city of Vinnytsia (Ukraine) are presented in the works of Matusiak and Vargatiuk (2020) and (Matusiak 2020). Information on the phenology of *Forsythia velutina* in Korea is given in the work of Sung et al. (2021). As there is a lack of information on the rhythms of growth and development of most *Forsythia* taxa in Right-Bank Forest-Steppe of Ukraine, we believe it is relevant to study these issues and to generalize them.

The purpose of the work is to recognize the features in the seasonal rhythms of growth and development of *Forsythia* taxa in the Right-Bank Forest-Steppe of Ukraine and to study their consistency with the natural and climatic conditions of this region.

Material and Methods

The research was conducted with the following taxa of the genus *Forsythia*: *F. giraldiana* Lingelsh., *F. × intermedia* Zab., *F. × intermedia* 'Densiflora', *F. × intermedia* 'Golden Ranchen', *F. × intermedia* 'Lynwood', *F. × intermedia* 'Spectabilis', *F.*

ovata Nakai, *F. ovata* 'Tetragold', *F. suspensa* (Thunb.) Vahl, *F. suspensa* var. *fortunei* (Lindl.) Rehd., *F. suspensa* var. *sieboldii* Zab., *F. suspensa* 'Decipiens', *F. suspensa* 'Variegata', *F. viridissima* Lindl., *F. europaea* Deg. et Bald. The research objects grow in open ground in the collection plantations of the M. M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, A.V. Fomin Botanical Garden of Taras Shevchenko National University of Kyiv, National University of Life and Environmental Sciences of Ukraine. The city parks and plantings of Kyiv were also surveyed. Research was conducted in 2010–2015.

Phenological observations were carried out according to the 'Methodology of phenological observations in botanical gardens of the USSR' (Lapin 1975). For the integral evaluation of each studied plant based on the complex of all its phenodata, we applied the phenological atypicality (F) and the phenological abnormality (F_1) indicators according to Zaitsev (1981). The phenological atypicality indicator or the average standard deviation is calculated without taking into account the signs of deviations according to formula (1), and the phenological abnormality indicator is calculated taking into account the signs of deviations according to formula (2).

$$F = \sum |t| \cdot n^{-1}, \quad (1)$$

$$F_1 = \sum t \cdot n^{-1}, \quad (2)$$

where: $t = (x - M) \cdot \sigma^{-1}$ – normalized deviations of features, x – the value of the characteristics of an individual, M – the arithmetic mean of the characteristic, σ – the root mean square deviation of the characteristic; n – the number of features in this complex.

Statistical processing of the data was

carried out according to the method of Zaitsev (1984). Six main indicators were determined: the arithmetic mean, its error, the root mean square deviation, standard deviation, the coefficient of variation and the indicator of accuracy of the experiment.

Phoenospectra were compiled according to the method of Bulygin (1985). Field data expressed as ordinary calendar dates are difficult to process mathematically, so they were converted into a continuous series of numbers in the form of the number of days starting from 1 March according to the method (Zaitsev 1981).

The phoenodates were statistically processed and summarized according to the following phenophases: the beginning of flowering, the end of flowering, the appearance of a green cone of leaves (vegetative bud break), the beginning and end of shoot growth, fruiting and the beginning of abscission. These phoenodata also made it possible to determine the duration of periods of flowering, growth of shoots and vegetation of the studied plants.

In total, 720 phoenodates (15 objects $\times$ 8 phenophases $\times$ 6 years) were statistically processed.

For each phenophase, there is an optimum combination of environmental factors, taking into account the qualitative difference of the phases. The arithmetic mean date of a phenological phase is the typical date of onset of a separate phase, and species with their mean phoenodates the closest to the general mean are in optimal conditions for the realization of the corresponding phenological phase. To assess the compliance of phoenodates with the general norm of one or another phenophase, standard deviations were used.

The phenological atypicality indicator

(F) or the average standard deviation, is calculated without taking into account the signs of deviations and characterizes the degree of compliance of the phenophases of a specific plant of a certain species with the environmental conditions in which it grows. The closer the F value is to 0, the more optimally the phenology of plants of a certain species is following the environmental conditions. At the same time, the plants not only receive everything necessary for their growth and development, but also use the available resources of the environment in most rationally during the growing season (Zaitsev 1981, 1983).

The phenological abnormality indicator (F_1) is calculated taking into account the signs of deviations and characterizes the degree of deviation of the phoenodata of the research object from the norm (its limits from -1 to +1) based on the complex of all phoenodata. This indicator is used to assess the degree of plant phenophase shift of a particular taxon in one direction or another compared to others. The sign of the indicator shows in which direction (late or early onset) the phoenodates of plants of a certain taxon deviate. The negative value of the indicator (F_1) means that the phoenodates of the plants of this taxon come earlier than the average ones, and these plants fit into the vegetation period of the area of their growth and, even, some part of the vegetation period remains unused. A positive value of this indicator demonstrates that plants of a certain taxon are late with their phenology compared to the general average terms, and with a large value of F_1 , it may not even have time to complete the seasonal cycle of its growth and development during the growing season (Zaitsev 1981).

Deviations are within the normal range if its absolute value is less than 1. If the

deviation with the '+' sign is greater than 1, then the corresponding phoenodata is longer than normal; if the deviation with the '-' sign is more than 1, then this phoenodata is shorter than normal in duration.

In accordance with the value of the indicator F_1 , Zaitsev (1981) created scale to assess the mismatch of the phenology of introduced species to the climate of the secondary range.

The characteristic of the climate of Kyiv is presented according to Vyshnevskiy et al. (2023). Observations have shown that average air temperatures in Kyiv are higher than in the suburbs. In clear weather

during the day, air temperature in the central areas of the city is 2.0–3.0 °C higher than in its outskirts. In the evening hours of summer, this difference can reach 6.0–8.0 °C. Data on the average monthly air temperature in the city are shown in Table 1.

Relative air humidity is highest in winter (primarily in December), lowest – in April–August (Table 2).

During 1991–2020, the average annual rainfall in Kyiv was 618 mm. On average, over many years, the most precipitation occurred in summer, the least in January–March (Table 3).

Table 1. Average air temperature in Kyiv by month during 1991–2020, °C.

Monts												Annual average
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
3.2	2.3	2.5	10.0	15.8	19.5	21.3	20.4	14.9	8.6	2.6	1.8	9.0

Table 2. Average relative air humidity in Kyiv for 1991–2020, %.

Monts												Annual average
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
84	80	72	61	62	64	66	64	71	77	85	86	73

Table 3. Typical rainfall in Kyiv by month for the period 1991–2020, mm.

Indicator	Monts												Sum
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Average	37	39	40	42	65	74	68	56	58	46	46	47	618
Min	9	12	7	2	25	7	6	3	5	0	5	11	450
Max	59	79	113	123	172	190	153	132	211	110	98	133	805

Among the other factors influencing the climate of the city is its terrain, including significant differences in elevation between its left-bank and right-bank parts. The left-bank area has a typical height of 100–110 m above sea level, while the right-bank area ranges from 140 to 160 m. The highest points reach elevations of 195–197 m, whereas the lowest points correspond to the level of the Dnipro River, approximately 91.5 m.

Results and Discussion

After calculating the standard deviations from the arithmetic mean for specific phenophases in the array of species, we determined the species whose individual phenophases occur at optimal times (Table 4). The phase of 'flowering bud break' takes place at the optimal time in *Forsythia × intermedia* 'Lynwood', *F. ovata* 'Tetragold', *F. suspensa* 'Decipiens', *F. sus-*

Table 4. Average annual phenodates of species, varieties, hybrids and cultivars of the genus *Forsythia* in Kyiv, 2010–2015.

Species, hybrids, varieties, cultivars	Flowering			Duration of shoot growth, days	Fruiting	Beginning of abscission	Vegetation duration, days	Phenological	
	Flowering bud break	Beginning	End					atypicality indicator F_1	Phenological abnormality indicator F_2
<i>Forsythia europaea</i>	29.40	45.20	65.20	20.00	117.00	244.6	215.20	0.75	0.75
	-1.853	-0.606	0.053	1.041	-0.801	-0.503	0.656	-0.73	-0.73
<i>F. giraldiana</i>	38.6	46.40	62.4	16.00	122.40	236.20	197.60	0.81	0.81
	0.538	-0.216	-0.681	-0.974	-0.439	-1.814	-2.303	-0.54	-0.54
<i>F. x intermedia</i>	42.40	49.20	68.40	19.20	129.20	254.20	211.80	1.03	1.03
	1.525	0.694	0.892	0.638	0.017	0.994	0.085	1.03	1.03
<i>F. x intermedia</i>	40.20	50.00	66.40	16.40	123.20	255.20	215.00	0.86	0.86
'Densiflora'	0.954	0.954	0.368	-0.772	-0.385	1.150	0.623	0.86	0.86
<i>F. x intermedia</i>	38.80	49.00	63.20	14.20	143.00	259.20	220.40	0.87	0.87
'Golden Ranchen'	0.590	0.629	-0.471	-1.881	0.944	1.774	1.530	0.63	0.63
<i>F. x intermedia</i>	35.8	43.60	62.60	19.00	104.60	250.80	215.00	0.60	0.60
'Lynwood'	-0.190	-1.126	-0.628	0.537	-1.634	0.464	0.623	-0.37	-0.37
<i>F. x intermedia</i>	39.80	50.20	70.00	19.80	115.6	250.00	210.2	0.88	0.88
'Spectabilis'	0.850	1.019	1.311	0.940	-0.895	0.339	-0.184	0.88	0.88
<i>Forsythia ovata</i>	29.00	38.00	54.20	16.20	134.60	240.8	211.8	2.21	2.21
	-1.957	-2.946	-2.830	-0.873	0.380	-1.096	0.085	-2.21	-2.21
<i>F. ovata</i> 'Tetragold'	37.40	46.60	64.80	18.20	122.4	254.80	217.40	0.38	0.38
	0.226	-0.151	-0.052	0.134	-0.439	1.088	1.026	0.28	0.28
<i>F. suspensa</i>	38.75	47.75	63.75	16.00	124.5	242.00	203.25	0.51	0.51
	0.577	0.223	-0.327	-0.974	-0.298	-0.909	-1.353	-0.11	-0.11
<i>F. suspensa</i>	38.40	48.00	69.00	21.00	161.4	249.00	210.60	0.51	0.51
'Decipiens'	0.486	0.304	1.049	1.545	2.179	0.183	-0.117	0.51	0.51

<i>F. suspensa</i> 'Variegata'	<u>35.20</u> -0.345	<u>47.00</u> -0.021	<u>67.20</u> 0.577	<u>20.20</u> 1.142	<u>126.60</u> -0.157	—	<u>244.20</u> -0.566	<u>209.00</u> -0.386	<u>0.38</u> -0.09
<i>F. suspensa</i> var. <i>fortunei</i>	<u>34.80</u> -0.449	<u>47.60</u> 0.174	<u>64.60</u> -0.104	<u>17.00</u> -0.470	<u>125.4</u> -0.238	<u>220.60</u> 0.71	<u>243.80</u> -0.628	<u>209.00</u> -0.386	<u>0.41</u> 0.06
<i>F. suspensa</i> var. <i>sieboldii</i>	<u>37.00</u> 0.122	<u>48.20</u> 0.369	<u>65.00</u> 0.001	<u>19.00</u> -0.571	<u>127.80</u> -0.076	<u>217.40</u> -0.71	<u>242.80</u> -0.784	<u>205.80</u> -0.924	<u>0.40</u> -0.2
<i>F. viridissima</i>	<u>32.40</u> -1.073	<u>49.20</u> 0.694	<u>68.20</u> 0.839	<u>19.00</u> 0.537	<u>156.40</u> 1.843	—	<u>249.80</u> 0.308	<u>217.40</u> 1.026	<u>0.73</u> 0.19
<i>M</i>	36.53	47.06	65.00	17.93	128.94	219	247.83	211.30	
σ	3.848	3.077	3.815	1.985	14.900	2.263	6.411	5.948	
$\pm m$	0.993	0.794	0.985	0.513	3.847	1.600	1.655	1.536	
<i>V</i> , %	10.535	6.538	5.870	11.070	11.555	1.033	2.587	2.815	
<i>P</i> , %	0.027	1.69	1.516	2.858	2.980	0.731	0.668	0.727	

Note: in the numerator are the average phoenodata, in the denominator are the standard deviations; the data in columns 2–4 and 7–8 are the number of days after March 1 until the corresponding phenological manifestation; *M* is the arithmetic mean, σ is the root mean square deviation, $\pm m$ is an error of the arithmetic mean, *V* is coefficient of variation, *P* is the indicator of the accuracy of the experiment.

pensa 'Variegata', *F. suspensa* var. *sieboldii*. The 'beginning of flowering' phase occurs at the optimum time in *F. giraldiana*, *F. ovata* 'Tetragold', *F. suspensa*, *F. suspensa* 'Variegata', *F. suspensa* var. *fortunei*. The 'end of flowering' phase takes place at the optimal time in *F. europaea*, *F. ovata* 'Tetragold', *F. suspensa*, *F. suspensa* var. *fortunei*, *F. suspensa* var. *sieboldii*. The 'beginning of abscission' phase occurs at the optimum time in *F. europaea*, *F. × intermedia* 'Lynwood', *F. × intermedia* 'Spectabilis', *F. suspensa* 'Decipiens' and in *F. viridissima* (Table 4). These forsythias have minimum standard deviations according to these phoenodata. The objects studied by us are within the normal limits of 3–4 phoenodata. Only *F. ovata*, whose phenophases are shorter than normal, does not fit into this range. Within the normal range for all phoenodata lies 20 % of the research objects. Within the normal range for 3–4 phoenodata lies 93.33 % of them.

The minimum phenological atypicality indicators are observed in *F. ovata* 'Tetragold' (0.38), *F. suspensa* (0.51), *F. suspensa* 'Decipiens' (0.51), *F. suspensa* 'Variegata' (0.38), *F. suspensa* var. *fortunei* (0.41), *F. suspensa* var. *sieboldii* (0.40). It should be noted that in most of the forsythia (86.67 %), the phenological atypicality indicator is less than 1, which shows that the seasonal rhythms of growth and development of most of the studied forsythia correspond to the climatic conditions of Kyiv.

According to the value of the phenological abnormality indicator (F_1), all studied forsythia are with-

in the normal range, except for *Forsythia ovata* ($F_1 = -2.35$) and *F. × intermedia* ($F_1 = 1.03$). Of this series, only *F. viridissima* does not match the forsythia range obtained using the indicator F . The phenophases of *Forsythia ovata* take place earlier compared to the corresponding phenophases of plants of other taxa of this genus, and the phenophases of *F. × intermedia* take place later (the phenological phase of 'flowering bud break'). *F. ovata* fits with excess into the growing season. In *F. × intermedia*, the 'flowering bud break' phase is observed somewhat later compared to plants of other forsythia taxa. In general, of the 15 studied taxa of forsythia plants, only *F. × intermedia* and

F. ovata are not within the normal range according to indicators F and F_1 .

Based on the sign of the indicator F_1 , it can be concluded that *F. giraldiana*, *F. ovata* 'Tetragold', *F. suspensa*, *F. suspensa* var. *fortunei* and *F. suspensa* var. *sieboldii*, growing in the city of Kyiv, are within the norm for the dates of onset of all phenophases and have an unused part of the growing season in reserve.

According to the scale of assessments of the discrepancy of the phenology of the climate introducers of the secondary range following the value of the indicator (F_1) according to Zaitsev (Zaitsev 1981), we divided the research objects into four groups (Table 5).

Table 5. Groups of representatives of the genus *Forsythia* depending on the indicator of phenological abnormality (F_1) and their assessment in points.

Group	Phenological abnormality indicator F_1	Point	Species, hybrids, varieties, cultivars
I	from -2 to -3	2	<i>F. ovata</i>
II	from 0 to -1	4	<i>F. europaea</i> , <i>F. giraldiana</i> , <i>F. × intermedia</i> 'Lynwood', <i>F. suspensa</i> , <i>F. suspensa</i> 'Variegata', <i>F. suspensa</i> var. <i>sieboldii</i>
III	from +1 to 0	5	<i>F. × intermedia</i> 'Densiflora', <i>F. × intermedia</i> 'Gold Ranchen', <i>F. × intermedia</i> 'Spectabilis', <i>F. ovata</i> 'Tetragold', <i>F. suspensa</i> 'Decipiens', <i>F. suspensa</i> var. <i>fortunei</i> , <i>F. viridissima</i>
IV	from +2 to +1	6	<i>F. × intermedia</i>

Forsythia ovata plants fit with excess into the growing season. Plants of species, varieties and cultivars from the second group are in the upper half of the normal (supernormal) region or optimum for the realization of their phenophases, their development cycle meets the requirements of the growing season of the place of introduction. Plants of the species, varieties and cultivars from the third group are in the lower half of the normal range (subnormal).

Species with 4–5 points can grow successfully in the appropriate introduction

area. These are all studied plants, except of *F. × intermedia* plants (6 points), the phenological rhythm of which does not completely fit into the growing season. Due to this, in the conditions of the research region, *F. × intermedia* plants can freeze in severe winters. However, the value of the indicator F_1 of *F. × intermedia* plants is close to 1.

For plants with 2–5 points, the ratio between their needs to satisfactorily overcome the seasonal processes of growth and development and the possibilities of the growing season is optimal. Their de-

velopment cycle corresponds to the growing season of the place of introduction, so they can be successfully cultivated in the research region. Our research findings align with those of the study on the seasonal rhythms of the development of forsythia in the conditions of Vinnytsia according to Matusiak (2020).

According to the results of phenological observations in 2010–2015, phenospectra of the seasonal development of introducers of the genus *Forsythia* in the conditions of Kyiv were compiled (figs 1 and 2).

Vegetation of forsythia in Kyiv begins at the end of March with the phase of 'flowering bud break'. *F. ovata* (28.03), *F. europaea* (29.03) are the first to start vegetation, after 3–6 days, this phase starts in *F. viridissima* (2.04), *F. suspensa* var. *fortunei* (4.04), *F. suspensa* 'Variegata' (5.04), *F. × intermedia* 'Lynwood' (5.04). The rest

of the forsythia plants start growing from 6 April (*F. suspensa* var. *sieboldii*) to 12 April (*F. × intermedia*). The beginning of flowering of representatives of the genus *Forsythia* was noted from 28.03. (the earliest date of the beginning of flowering in *F. ovata*) to 28.04. (the latest date of the beginning of flowering in *F. viridissima*).

Conclusion

Based on the analysis of the results of the studies, taxa of the genus *Forsythia* were identified, some of the phenological phases of which occur in optimal time frames.

Forsythia giraldiana, *F. ovata* 'Tetragold', *F. suspensa*, *F. suspensa* var. *fortunei* and *F. suspensa* var. *sieboldii*, growing in the city of Kyiv, are within the norm for the dates of onset of all phenophases

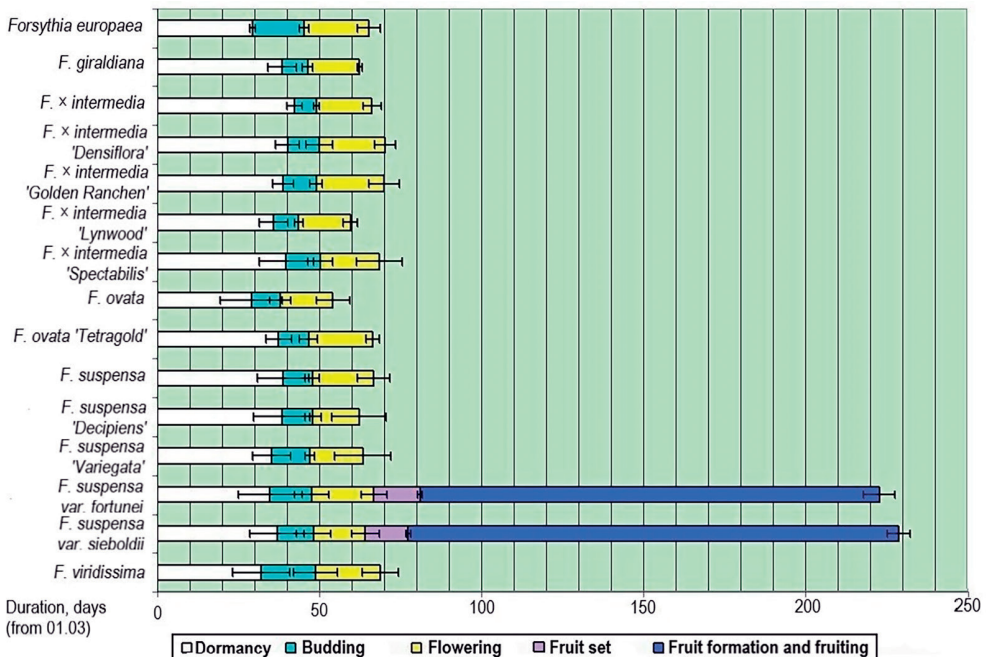


Fig. 1. Phenospectrum of seasonal generative development of introducers of the genus *Forsythia* in the conditions of Kyiv.

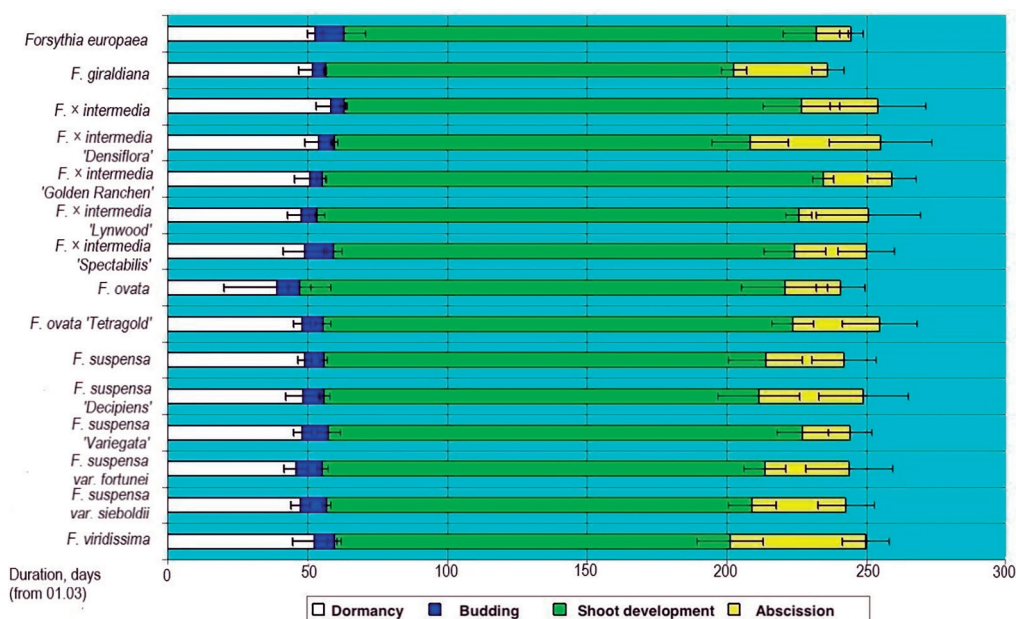


Fig. 2. Phenospectrum of seasonal vegetative development of introducers of the genus *Forsythia* in the conditions of Kyiv.

and have an unused part of the growing season in reserve.

Of the plants of 15 studied forsythia taxa, only two (*F. × intermedia* and *F. ovata*) are not within the normal range according to indicators of phenological atypicality and phenological abnormality.

F. ovata fits with excess into the growing season. Plants of species, varieties and cultivars from the second group are in the upper half of the normal (supernormal) region or optimum for the realization of their phenophases, their development cycle meets the requirements of the growing season of the place of introduction. Plants of the species, varieties and cultivars from the third group are in the lower half of the normal range (subnormal).

The plants with 4–5 points usually grow successfully in the relevant introduction area. In our case, these are all the studied plants, with the exception of *F. ×*

intermedia, whose phenological rhythm does not completely fit into the growing season. Due to this, in the conditions of the research region, *F. × intermedia* can freeze in severe winters.

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