



Species Seasonal Development of the *Ulmus* L. Genus in the Right-Bank Forest-Steppe of Ukraine and Features of Shoot Growth During the Vegetation Period



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ARTICLE INFO

Keywords:

Phenological observations
Temperature changes
Dynamics

ABSTRACT

This study examined the features of the phenological phases in four *Ulmus* L. genus species by conducting phenological observations at the educational and production department of the Uman National University Bilohrudivskiy Forest, from 2022 to 2024, using accepted methods. The timing of the seasonal development phases in the *Ulmus* genus species corresponds with the phenological seasons, determined by natural and climatic parameters. A single-peaked curve with a peak from the first decade of May to the second decade of July characterizes indicators of shoot growth dynamics. Shoots of *Ulmus* L. grew to 77–83% of their total length by the end of July during the growing season before adding another 17–21% in August, indicating that, despite temperature variations, the studied species fully adapts to the research region conditions.

TANULMÁNY INFÓ

Kulcsszavak:

Fenológiai megfigyelések
Hőmérséklet-változások
Dinamika

KIVONAT

Az *Ulmus* L. faj szezonális fejlődése, nemzetség fejlődésének alakulása a jobb parti erdőssztyeppéken Ukrajnában, és a hajtásnövekedés jellemzői a vegetációs időszakban. Az erdősztyepében és a kertészetben széles körben használt négy *Ulmus* L. nemzetségfaj fenológiai fázisainak jellemzőit vizsgálták. A fenológiai megfigyeléseket 2022-2024 folyamán az Umani Nemzeti Kertészeti Egyetem Bilohrudivskij erdőben található oktatási és termelési részlegén végezték az általánosan elfogadott módszerek szerint, és megállapították, hogy az *Ulmus* nemzetség fajaiban a szezonális fejlődési fázisok időzítése megfelel a fenológiai évszakoknak, amelyeket a természeti és éghajlati paraméterek alapján határoznak meg. A hajtásnövekedés dinamikájának mutatóit egycsúcsú görbe jellemzi, amelynek csúcspontja a május első dekádjától július második dekádjáig tartó időszakban van, amikor a legintenzívebb növekedésük következik be. Július végén az *Ulmus* hajtáshossza eléri a vegetációs időszak alatti teljes hosszának 77-83%-át. Ez azt jelenti, hogy a vizsgált fajok a hőmérséklet-ingadozások ellenére teljes mértékben alkalmazkodtak a kutatási régió körülményeihez, és aktívan be lehet őket vezetni a kultúrába. Augusztusban a hajtások 17-21%-kal nőnek.

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1 INTRODUCTION

Research on plant growth and development patterns, coupled with the analysis of accumulated information during cultivation, is vital, both scientifically and practically. Plant seasonal development is particularly significant, especially in the context of the phylogeny process, as an adaptation to specific seasonal changes in climatic conditions (Batsaikhan et al., 2020). Lifecycle rhythms of a single species in different plantings and areas depend on botanical, geographical, phytocoenological, and environmental conditions (Antnova et al., 2019). The species phenorhythm of the genus occurs in such a way that the maximum development of plants occurs during a favorable period of the vegetation season. Endogenous and exogenous factors, including genetic characteristics and environmental conditions of the cultivation area, influence phenological development (Gordo–Sanz, 2010).

The dynamics of growth processes in woody plants change rapidly during seasonal changes (Solla et al., 2005; Uchendu et al., 2013; Välimäki et al., 2021). Consequently, their phenological development is defined as seasonal. Seasonal phenomena and their calendar dates of occurrence, which are inconstant, characterize each territory (Antonova et al., 2019, 2020, 2021).

A certain dependence between climatic factors (particularly changes in air temperature) and the annual plant development cycles has been revealed in recent decades. Scientists have noted several indicators whose seasonal development was sensitive to climate change (Chen, 1995; Menzel – Fabian, 1999). In addition, it was noted that the climate region has an impact on the timing of certain phenological phases (Schwartz, 1996). For example, Chen and Xu (2012) found that there is a greater phase dependence on temperature in milder areas than in harsher climates.

Similar studies of the seasonal development dynamics of certain plants in Europe and North America in temperate and Mediterranean climates have shown close to timely and successful development of all phases in plants without much delay (Bradley et al., 1999;; Menzel and Fabian, 1999; Beaubien and Freeland, 2000; Defila and Clot, 2001; Zhao and Schwartz, 2003; Gordo and Sanz, 2009; Myking and Skrøppa, 2007; Cruz et al., 2021). Such studies have not been conducted in the conditions of the Right-Bank Forest-Steppe of Ukraine.

The phenological phases of woody plants are indicators of climatic conditions. Observing them allows us to track tree responses to warming or precipitation changes and how species adapt to such conditions. Shifts in phenophases indicate climate change, which may help predict how global warming affects the growing season durations and ecosystem resources. *Ulmus* phenological growth patterns aid in the preparation of regional seasonal calendars for forestry. Such calendars are also used in the organization of environmental protection measures and pest and disease control of *Ulmus* species.

2 MATERIALS AND METHODS

Phenological observations of vegetative organ development of the *Ulmus* genus species (*U. laevis*, *U. glabra*, *U. pumila*, and *U. minor*) were conducted on the territory of the educational and production department of the Uman National University of Horticulture, Bilohrudivskyyi Forest, during 2022–2024 (*Figure 1*). Uniform temperature conditions characterize the entire territory of Ukraine. Therefore, we assume that the obtained results will be similar in all regions of the country.



Figure 1. Map of Ukraine with the location of the research sites marked

All plants used for phenological observations grow in similar environmental conditions. The weather station is two to three kilometers from the research site.

We selected trees aged 20–30 years for our research. The height of the trees ranged from 10 to 15 m, and the trunk diameter ranged from 12 to 24 cm. The crown diameter ranged from 4 to 9 m.

Phenological observations of the generative and vegetative organs formation were conducted in 2022–2024 according to the method of Kalinichenko (2000) and Santini et al. (2004).

We conducted the research during the growing season and inspected the plots every two to four days for this purpose. Records were collected of the dates of the certain phenophase of each species under study. We selected ten trees of each species of the same age and size. The shoots from these trees were selected randomly from the middle of the crown.

Shoot growth characteristics during the growing season were found according to the Molchanov and Smirnov method (1967). Data was collected from the bud attachment point to the shoot of the previous year. Shoot lengths were measured with a metal ruler three days after the onset of the linear shoot growth phase. Data from the unfolded leaf attachment from the previous year's shoot was collected. The total number of shoots in each model group was 20 pcs. Daily gains were calculated after shoots stopped growing. Daily gains were defined as the difference in length between the next and the earlier values of each measurement period, divided by the number of days of this period. Measurements were performed following three days of intense growth and during the five days of decline afterwards. We recorded the average daily air temperature throughout this time. According to the study results, schedules of shoot growth during the vegetative season and of growth dynamics were drawn. The schedules recorded the dependence of shoot growth intensity on air temperature.

Observations followed model trees of different ages that had reached reproductive capacity. Phenological observations were conducted during the period of physiological activity. Observations were completed only once or twice a week in the summer when development is inhibited.

Based on the research results, we constructed graphs depicting shoot growth during the vegetation period. We established the growth dynamics and shoot growth intensity dependency on air temperature. Examining shoot growth duration and shoot growth dynamics

is vital to determining the winter hardiness of plants because shoots that finish growing early tend to be winter resistant, but slower-growing shoots can also achieve such resistance.

Statistical processing of the research results was performed with Excel. We calculated the Spearman rank correlation using Spearman's correlation coefficient, a nonparametric method that estimates the strength and direction of a monotonic (increasing or decreasing) relationship between two variables. Unlike Pearson's coefficient, Spearman's does not require normal data distribution. The calculation is based on the ranks of values in each variable, rather than on the numerical values themselves. We calculated Kendall's tau with the R program.

A temperate continental climate with warm and soft winters characterizes the research region. According to the Uman meteorological station, the average long-term air temperature is +7.2°C, with the coldest month (January) being minus 5.8°C and the hottest month (July) being 19.7°C. The average absolute minimum air temperature is -21°C. Extreme frosts are rare. The average daily temperature steadily exceeds +5°C in the first decade of April and +10°C in the third. The period with an average daily temperature above +10°C continues for 160–165 days. The duration of sunshine per year is 840 hours and 460–520 hours during the vegetation period. The average sum of daily temperatures above 0°C is 3155°C, +5°C - 3040°C, and +10°C - 2710°C. The weather is warm initially in the summer before turning hot in July and August.

The beginning of spring (steady transition of the average daily air temperature through 0°C) starts on March 15–20 (Table 1). However, late and early springs do occur.

Table 1. Average monthly temperature (°C) for 2022–2024 (according to the Uman weather station)

Year	Month												Year's average
	1	2	3	4	5	6	7	8	9	10	11	12	
2022	-4.7	0.5	4.5	9.6	17.0	23.4	20.0	20.7	15.6	10.0	5.5	2.2	10.4
2023	0.4	2.2	6.3	9.2	12.5	20.9	21.6	21.2	17.8	12.7	3.7	0.0	10.7
2024	-2.3	-3.8	2.0	7.4	14.0	19.8	23.2	20.3	13.0	7.2	4.7	1.3	8.9
Mean	-2.5	-0.4	4.3	8.7	14.5	21.3	21.6	20.7	15.4	9.9	4.6	1.2	9.9
Long-term mean	-5.7	-4.2	0.4	8.5	14.6	17.6	19.0	18.2	13.6	7.6	2.1	-2.4	7.4

Table 1 shows that the research years are characterized by slightly higher temperature values for individual months compared to the average long-term data. Frequent dry periods with air temperatures above 35 °C in the shade mark the spring and summer period. The annual mean air temperature over the years of investigation was +9.9 °C with a maximum of +29.9 °C (August 15, 2023).

3 RESULTS

The vegetation of the studied species begins when the maximum average monthly temperature reaches +17°C or above, the average daily temperature is in the range of +4.2 to 6.6°C, and the minimum is -2.0°C to 5.2°C.

The earliest bud swelling began in *U. laevis* in the third decade of March/first decade of April (March 23–April 4) and continued for 10–14 days. This phase started 4–6 days later in *U. glabra* (March 27–April 4) and continued for 10–12 days. The bud swelling phase was

simultaneously observed in the latest of the *Ulmus* species in our research, *U. pumila* and *U. minor* (March 29–April 4) and lasted 11–18 days (Table 2).

Table 2. The dates of shoot and leaf development in species of the genus *Ulmus* in Uman, 2022–2024

Species	year	Vegetative organs development date								
		Buds and shoots				Leaves				
		bud swelling	bud opening	start of shoots linear growth	end of shoot linear growth	leaf emergence starts	complete leaf emergence	leaf discoloration	falling leaves	leaf fall end
<i>U. pumila</i>	2022	12.04	24.04	03.05	26.08	28.04	01.08	02.10	16.10	19.10
	2023	15.04	23.04	01.05	01.09	26.04	09.08	36.09	13.10	16.10
	2024	30.03	20.04	29.04	23.08	26.04	03.08	28.10	01.11	14.11
<i>U. glabra</i>	2022	31.03	18.04	26.04	23.08	25.04	30.07	25.09	05.10	12.10
	2023	07.04	21.04	30.04	30.08	01.05	05.08	18.10	22.10	30.10
	2024	27.03	15.04	24.04	25.08	22.04	28.08	18.10	23.10	30.10
<i>U. laevis</i>	2022	03.04	12.04	21.04	21.08	23.04	30.07	28.09	02.10	11.10
	2023	10.04	19.04	28.04	27.08	23.04	03.08	12.10	20.10	29.10
	2024	23.03	11.04	20.04	17.08	19.04	28.07	15.10	26.10	02.11
<i>U. minor</i>	2022	08.04	21.04	01.05	25.08	25.04	27.07	03.10	17.10	19.10
	2023	13.04	23.04	04.05	03.09	29.04	03.08	17.10	28.10	13.11
	2024	29.03	17.04	25.04	20.08	21.04	25.07	26.10	28.10	05.11

Budding began in the second to third decade of April during the research years on species and forms of the genus *Ulmus*. The earliest budding was seen in *U. laevis* (April 11–April 19), which lasted 7–9 days. The latest among the studied species was in *U. pumila* (April 20–April 24) and *U. minor* (April 17–April 24).

The linear shoot growth started the earliest in *U. laevis* (20.04–28.04) and *U. glabra* (March 24–April 30). The phase of linear growth occurs 4–9 days later in *U. pumila* and 6–10 days in *U. minor* than in *U. laevis*. Shoot growth completion was noted when the last leaves were finished expanding.

The change in leaf color was most clearly seen in *U. laevis* (September 28–October 23). Under favorable conditions, the color change occurred in the third decade of September and the second decade of October in other *Ulmus* species. The consistently warm autumn of 2023 delayed the discoloration and leaf fall phase, which occurred 15–20 days later than in 2021 and 2022. The life processes in plants are inhibited after leaf fall, and they enter a dormant state.

Research on seasonal shoot growth of species and forms of the genus *Ulmus* indicates that the conditions of the Right-Bank Forest-Steppe of Ukraine induce a growth period of 86 to 127 days. Growth process lengths depend on the biological characteristics of the species.

The linear growth of shoots in all representatives of the genus *Ulmus* began at the same time, at the beginning of the third decade of April.

During all the research years, the shoot growth of *U. laevis* was observed from the transition of the budding phase at the end of the second and beginning of the third decade of April on average (Figure 2).

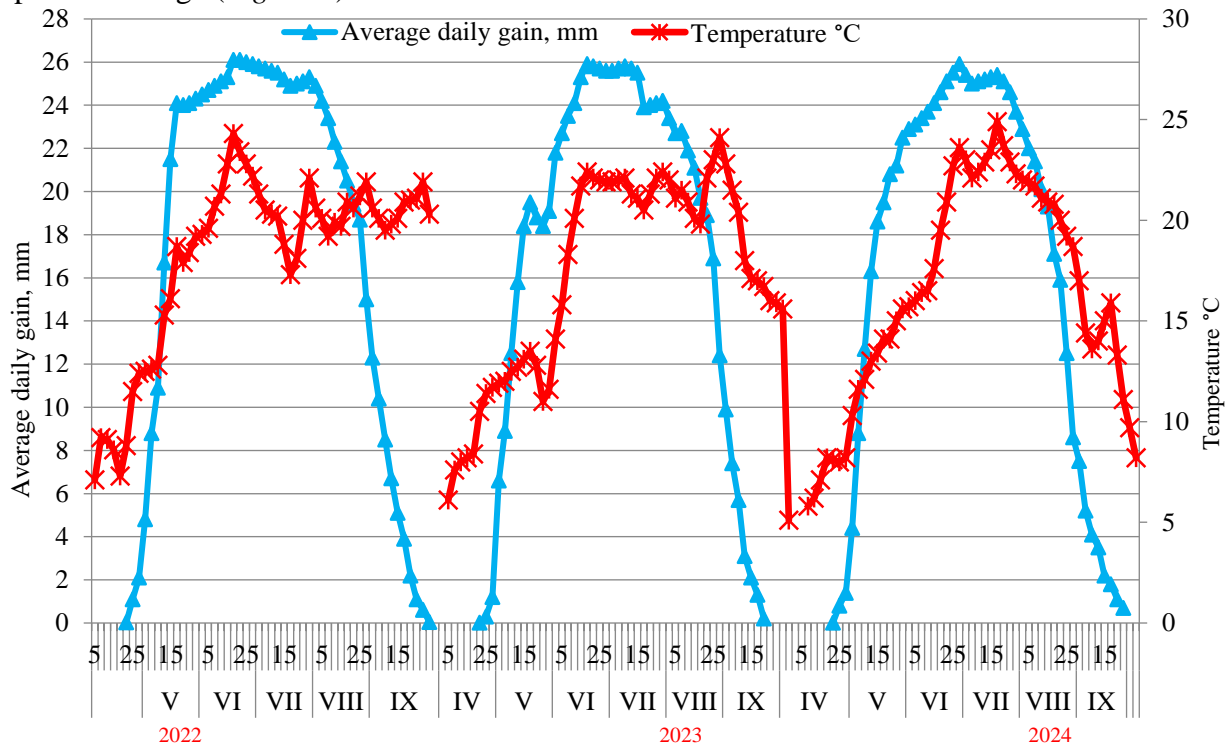


Figure 2. Seasonal growth dynamics of *U. laevis* during 2022–2024

The budding phase transition occurred when the average daily temperature exceeded $+11.5^{\circ}\text{C}$ in 2022 and 2023. Shoot growth was observable at temperatures above $+8^{\circ}\text{C}$ during the slightly colder spring of 2024. Furthermore, daily shoot growth intensified as the temperature increased. The culmination of the species shoot growth for all years varied by dates but occurred in mid-June and was 25.9–26.1 mm per day. For example, there was a rapid increase in temperature to $+23$ – 24°C in the second decade of June 2022, which caused an average daily growth of 26 mm per day. Then, the growth intensity gradually decreased as the temperature dropped. July 2024 recorded a significant increase in temperatures above $+24^{\circ}\text{C}$, which was higher than in June.

According to the research, *U. glabra* begins vegetation at the same time as *U. laevis* on a 3-year average and is dependent on air temperature to some degree (Figure 3).

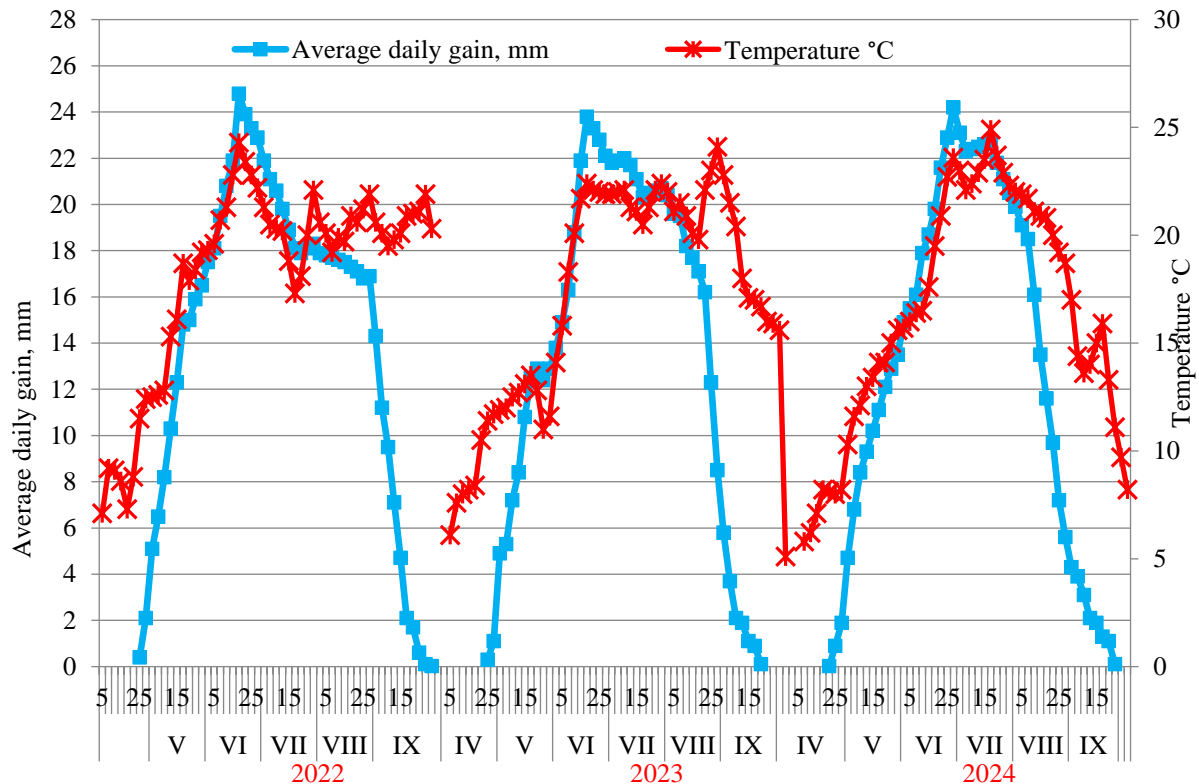


Figure 3. Seasonal growth dynamics of *U. glabra* in 2022–2024

Compared to the species above, *U. glabra* has slightly lower average daily growth value and intensity values. However, it has a rather clear dependence on temperature variations at the beginning of shoot growth and before culmination, so the maximum growth value matches the maximum temperatures of this period. The growth value for *U. glabra* is 23.1–24.2 mm per day, except for 2024 when the highest air temperature for the season was recorded in the second or third decade of August, and growth intensity had already begun to decline. However, there was a slight jump in growth. For this reason, the correlation coefficient here was 0.79, the highest for all years. There were frequent, rapid increases and decreases in temperature by several degrees starting in the third decade of August 2022; however, this had no significant impact on shoot growth during the growing season. The correlation coefficient, which in this case was 0.73, confirmed this. As for 2023, the highest temperature for the season (+24.1°C) was observed at the end of the third decade of August, when the shoots were nearly grown and preparing for dormancy. Therefore, it did not affect growth.

U. pumila starts vegetation 4–6 days later than the previously-mentioned species and has a lower shoot growth rate (Figure 4).

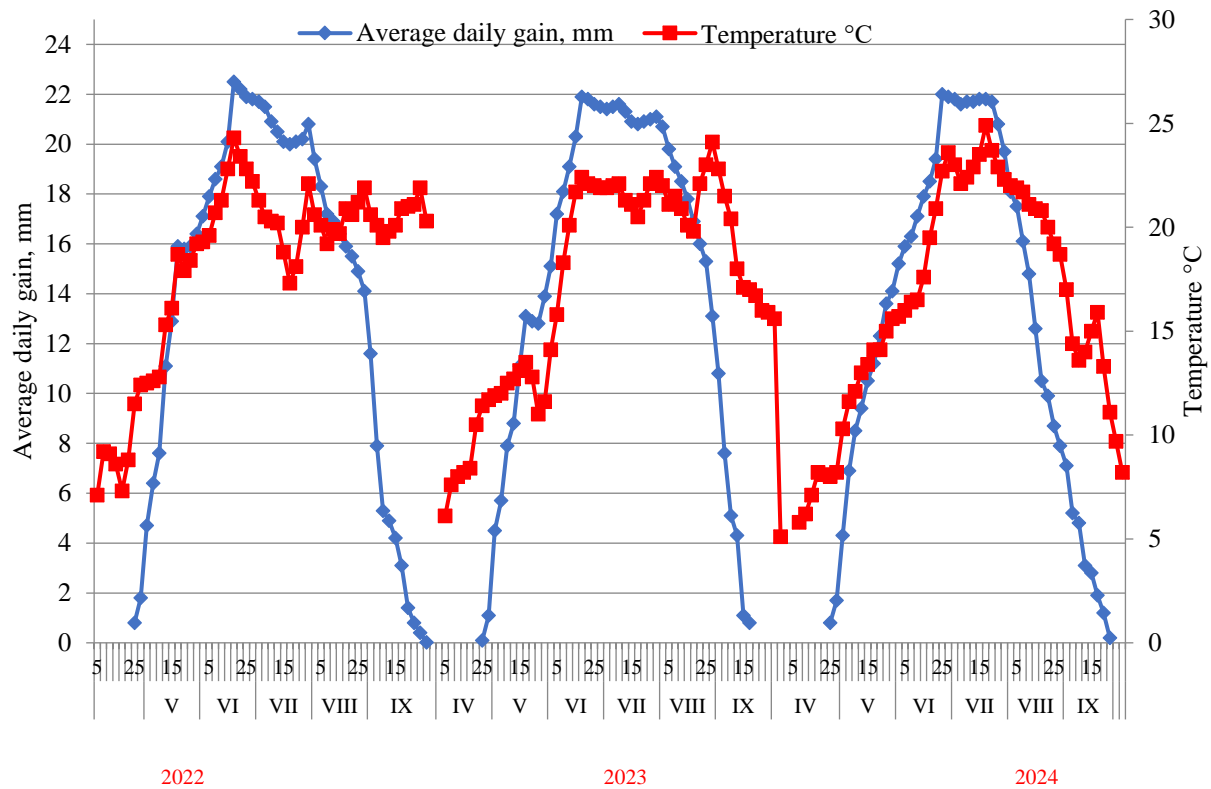


Figure 4. Dynamics of seasonal growth of *U. pumila* during 2022–2024

U. glabra had a shoot growth length of 24.2 mm at the culmination. For *U. laevis*, this figure was 26.1 mm, while for *U. pumila* it was 22.2 mm.

Thus, *U. pumila* showed a greater dependence of growth intensity on temperature changes. The graphs clearly show that after the shoot growth culminated in June, a second wave of growth was seen when the temperature increased in a specific period. In 2022, this was observed in the second decade of July, when a rapid rise in temperature above 21°C caused a short-term jump in growth to 21 mm per day. In 2023, from the first decade of June to mid-July, the air temperature was the same (except for the last days of the first decade of July). This contributed to the fact that the shoot growth curve was also stable during this period. However, the elevated temperatures of September did not affect growth. In 2024, the highest temperature was recorded in the third decade of June (+23.6°C) and in the second decade of July (+24.9°C). In both cases, there was a jump in growth intensity, up to 21.9 mm and 21.8 mm, respectively.

U. minor shoots start growing slightly later than *U. pumila* shoots. In general, these two species begin growing simultaneously with a difference of several days (Figure 5).

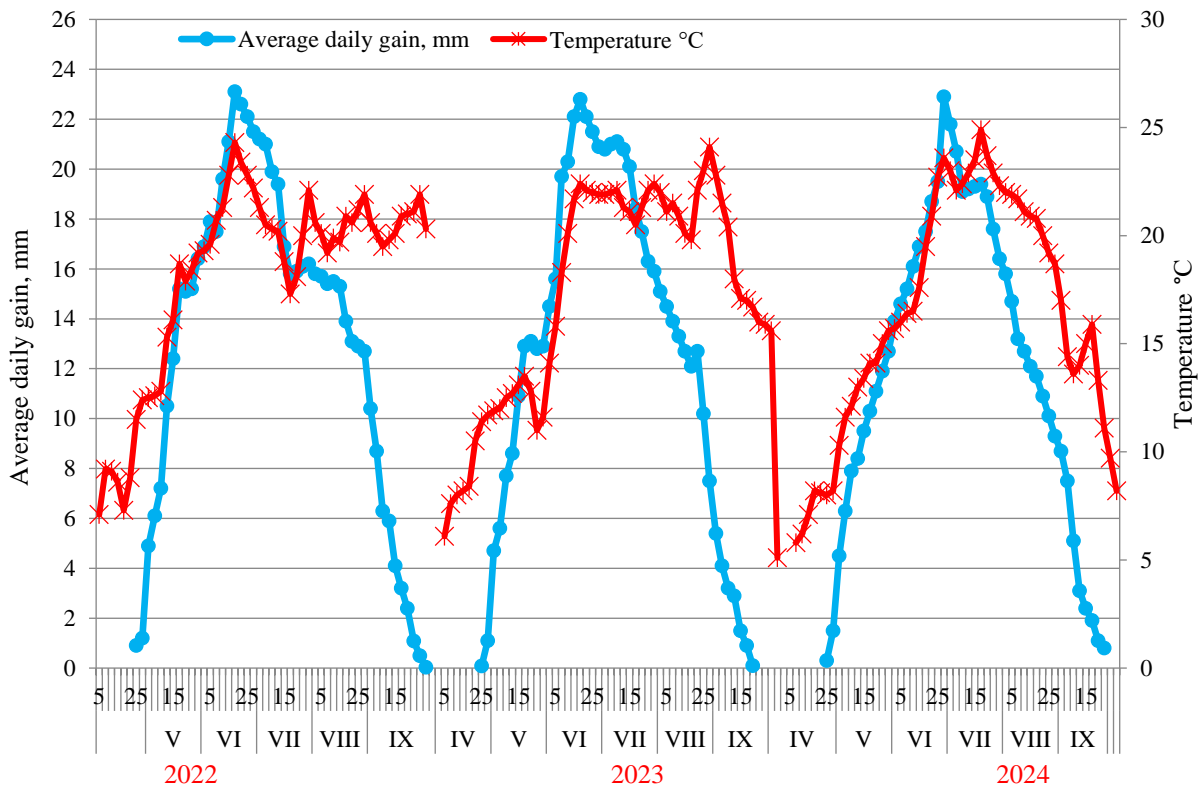


Figure 5. Seasonal growth dynamics of *U. minor* in 2022–2024

U. minor shoots showed a weak reaction to temperature changes at the beginning of their growth. Their average daily growth ranged between 4 and 7 mm and began to increase more intensively at a temperature of +13–15°C. Shoot growth was uniformly steady despite some temperature changes. A rapid increase in the average daily growth and the subsequent culmination of the temperature occurred in the first and second decades of June and matched the maximum air temperature during this period. At that time, the growth rate of this species was 22.5 mm per day. After that, growth intensity declined with different dynamics over the years. For example, starting in the second decade of June 2022, the temperature dropped by several degrees, and the drop in growth was quite clearly accompanied by the same dynamics. From the second decade of August, temperature changes of 1–2°C began to occur; however, growth intensity was steadily declining. The temperature in the second to third decade of June 2023 did not show such rapid changes, and we can see a smooth increase in growth. This contrasts with 2024, where the increase in air temperature after the culmination had almost no effect on shoot growth.

During the statistical processing of the data, we determined the coefficient of determination, which measures the dependence of dependent variables (different species growth) on the variation of independent variables (temperature) (Table 3).

The statistical data reveal a moderate positive relationship: as the temperature rises, the tendency for shoot growth increases. The probability of such a relationship occurring by chance is extremely low, indicating that the result is statistically significant. The data presented denotes a stable monotonic relationship between temperature and growth. The strength of the correlation increases slightly from 2022 to 2024 for all species, showing a strengthening of the linear dependence. Kendall's τ coefficient has marginally lower values but confirms a stable rank (monotonic) dependence.

Table 3. General statistical analysis of the dependence of shoot growth on temperature during the growing season, 2022-2024.

Year	Species	Statistical analyses			
		Kendall's τ	p-value (τ)	Spearman's ρ	p-value (ρ)
2022	<i>U. pumila</i>	0.437	<0.001	0.557	<0.001
	<i>U. glabra</i>	0.483	<0.001	0.611	<0.001
	<i>U. laevis</i>	0.415	<0.001	0.543	<0.001
	<i>U. minor</i>	0.447	<0.001	0.567	<0.001
2023	<i>U. pumila</i>	0.426	<0.001	0.548	<0.001
	<i>U. glabra</i>	0.472	<0.001	0.609	<0.001
	<i>U. laevis</i>	0.421	<0.001	0.556	<0.001
	<i>U. minor</i>	0.458	<0.001	0.571	<0.001
2024	<i>U. pumila</i>	0.468	<0.001	0.648	<0.001
	<i>U. glabra</i>	0.501	<0.001	0.701	<0.001
	<i>U. laevis</i>	0.436	<0.001	0.589	<0.001
	<i>U. minor</i>	0.474	<0.001	0.617	<0.001

If we characterize the dependencies of shoot growth for each species separately, we can see that *Ulmus pumila* is characterized by a stable, moderately strong positive correlation in all the study years. However, in 2024, the correlation significantly increased (especially $r = 0.883$), showing a strong linear dependence of shoot growth on temperature. The same applies to *Ulmus glabra*.

Unlike the species described above, *Ulmus laevis* had a moderate dependence in 2022–2023, which intensified in 2024 ($r = 0.827$). In contrast, *Ulmus minor* had a consistently strong positive correlation throughout all years.

4. DISCUSSION

The timing of the onset of the seasonal development phases in *Ulmus* species corresponds to the phenological seasons, which are distinguished on the basis of natural and climatic parameters (Puzrina – Yavny, 2020). Seasonal rhythms comparison of the *Ulmus* species development showed that they are not significantly different. In general, the onset of phenological phases in the studied species was parallel. The research results on phenological rhythms of development in *Ulmus* species in another region of Ukraine nearly coincide with ours (Stupak, 2024). The shoot growth phase is particularly significant. After all, how long shoots grow depends on the lignification level and, thus, on frost resistance and winter hardiness.

The unexplained variance was the influence of other climatic factors. However, a significant percentage remained for other influencing factors, which is a reason to consider such influences in further research. Weather conditions have a notable impact on the onset of phenological phases. Earlier studies on the dependence of budding and the sum of some temperatures have been conducted (Cannell – Smith, 1983; Murray et al., 1989; Hunter – Lechowicz, 1992; Välimäki et al., 2022).

Some research suggests that temperatures of the previous growth season cause changes in the onset of phenological phases (Chmielewski – Rötzer, 2001; Menzel, 2003; Gordo – Sanz, 2010) and applies to both the early spring and late autumn vegetation (Menzel, 2003; Matsumoto et al., 2003; Gordo – Sanz, 2010). However, other factors such as daylight

hours, precipitation, humidity, and even wind strength are thought to influence the end of the growing season in autumn (Chen – Xu, 2012; Hwa et al., 2021). In addition, plants must undergo a dormant state; otherwise, they will not start growing even under favorable temperature conditions (Wareing, 1956; Nitsch, 1957; Vegis, 1964; Välimäki et al., 2022).

The favorable weather conditions in 2022 induced the onset of phenological phases 3–9 days earlier than in 2023 and 2024. Indicators of seasonal dynamics reflect the adaptive features of the studied species to the growing conditions.

The onset of the phenological phases varies significantly by year. For example, the beginning of leaf budding to complete swelling takes 9 to 18 days. Significant temperature changes help explain this trend, under which shoot development accelerated and slowed down. The growth rate of annual vegetative shoots varied over the entire period. The most significant growth in the species studied occurred up to the second decade of July. After that, the growth processes slowed down significantly. The annual shoot growth indicators are related to the sample ages on which the measurements were made. This parameter is 6.5–7 higher in three-year-old plants than it is in 70-year-old plants. Twelve-year-old plants displayed parameters that were 4.5–5 times higher than in 70-year-old plants.

The difference in shoot growth intensity in adult and young plants is explained by the fact that young seedlings use nutrients only for shoot growth and development, while older ones form generative organs. Early termination of shoot growth in adult plants contributes to better wood maturation and, compared to young individuals, to better adaptation to autumn and winter temperature drops. The largest increase over the research years was seen from the third decade of April to the second decade of July. Thus, *Ulmus* shoots reached 77–83% of their total growth during the growing season by the end of July. *Ulmus* species have only one main growth wave, after the culmination of which the growth rate decreases significantly, despite temperature changes. Starting from the second decade of August, growth begins to decline intensively. At this time, the shoots grew by 17% and 21%. In September, shoot growth decreased to 3% of the total growth during the growing season. In the second decade of September, an increase in temperature above +15°C did not affect growth intensity, because the shoots were already preparing for wintering.

The maximum shoot growth intensity in adults of the studied species and forms of the genus *Ulmus* was recorded in the first half of the growing season. In our opinion, such dynamics of annual vegetative shoots growth and their duration explain the high winter resistance of *Ulmus* species because an early completion of growth processes (early budding, more complete lignification of annual shoots, and wood ripening) causes the appropriate time for the decline of growth processes at the cellular level. This characteristic of growth processes contributed to the timely shoot lignification of *Ulmus* species and forms.

5 CONCLUSIONS

The vegetation of the researched species begins in the third decade of April. The earliest bud swelling began in *U. laevis* in the third decade of March/first decade of April (March 23–April 10) and continued for 10–14 days. This phase started 4–6 days later in *U. glabra* (March 27–April 7) and was 10–12 days. In the *Ulmus* species that proved to be the latest, the bud swelling phase occurred simultaneously in *U. pumila* and *U. minor* (March 29–April 4) and continued for 11–18 days. The duration of a particular phenological phase in elms is closely related to weather conditions. Calculating the determination coefficients showed that temperature and other climatic factors influence plant growth and development. Indicators of shoot growth dynamics are characterized by a single-peaked curve with a peak in the period from the first decade of May to the second decade of July, when the most intensive growth

occurs. *Ulmus* shoot lengths reach 77–83% of their total length during the growing season at the end of July. The shoots grow by 17%–21% in August, indicating that the studied species are fully adapted to the conditions of the research region and can be actively introduced into culture despite temperature variations.

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