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Peculiarities of seasonal development and influence of ecological factors on the growth of thuja giant (*Thuja Plicata* Donn Ex D. Don) in the conditions of introduction in the right-bank forest-steppe of Ukraine

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Abstract: Generalization and analysis of experimental data concerning peculiarities of passing and duration of various phenological phases of *Th. plicata*, their consistency with the sums of effective temperatures is provided in the article. Conducted researches based on observations and mathematical processing allowed to reveal the regularity of passing of all vegetative and generative phases in the area of introduction and to reveal the dependence of these processes on ecological factors. It was found that the vegetation period of this species is 151 ± 3 days. Influence of nature and degree of temperature, air humidity and rainfall on the growth of shoots were also determined. It turned out that air temperature has the greatest influence on the growth peculiarities of one-year shoots. Growth of shoots begins after changing of the average daily temperature above +9°C. Culmination of increments is observed in May, when the temperature is 13–18°C. Then, increments are fading with the increase in temperature and decrease in humidity and the second wave of growth occurs in August. Shoots completely finish their growth in September. Precipitation and humidity do not have a significant effect on the growth of shoots.

Keywords: phenological observations; plants adaptation; temperature; humidity; precipitation; shoots

Rhythms of seasonal development reflect the interaction of plant genotype with the surrounding environment. Successfulness of plants adaptation to certain natural-and-climatic conditions is determined, evaluation of ecological features of species under research is given, recommendations for their reproduction and growth are developed according to the results of phenological observations. Peculiarities of seasonal development are determined in particular by the following indicators of ecological stability of plants as their winter resistance and drought tolerance, and these features, as is known, determine the ability of the species to survive and reproduce in certain conditions of growth (Adamenko at al. 2018). Changing of ecological conditions affects the duration of certain phenological phases, as well as external features of the plants. Constant observation of the phenology of introduced species, their growth and development and resistance to various natural-and-climatic factors makes it possible to determine the level of their adaptation to new conditions (Medvediev 2013).

https://doi.org/10.17221/52/2019-JFS

Table 1. Average monthly air temperature (C) in Uman city during 2015–2017 research years (according to the data of Uman Meteorological Station)

Years	Months												For the year
	1	2	3	4	5	6	7	8	9	10	11	12	
2015	–8.0	–5.9	0.5	12.1	18.3	21.3	23.4	20.8	16.4	9.3	3.6	2.1	8.2
2016	2.0	–2.9	5.5	10.9	18.4	20.5	20.0	23.0	12.2	9.1	0.6	–1.0	10.1
2017	–3.1	0.4	4.6	17.5	19.6	21.6	26.1	26.6	15.4	9.9	3.8	–0.4	9.5
Average for 3 years	–3.1	–2.8	3.4	13.5	18.7	21.1	23.1	23.4	14.6	9.4	2.6	0.7	9.1
Average multiannual	–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

MATERIAL AND METHODS

The object of the research was *Th. plicata* introduced type, which plantations are located on the territory of the National Dendrology Park "Sofiivka" of the National Academy of Sciences of Ukraine, Uman. Phenological observations of generative and vegetative organs formation was carried out during 2015–2017 under "Methodology of phenological observations in botanical gardens of the USSR" (1975) and according to the methodology of O.A. Kalinichenko (2000).

The climate of the studied region is moderately continental with relatively warm and mild winter (Table 1).

Spring-summer period was characterized by long dry periods with air temperatures above 35°C in the shade. Characteristic feature of the winter season was the presence of frequent thaws, when the air temperature rose to + 9–10° C, and so the snow cover was unstable. Often there were fogs and glazed frost. Freezing of soil began in the first decade of December.

The data in Table 2 indicate that the weather conditions during the research years were not very favorable in the humidification regime for plant growth.

Thus, in 2016, humidity content (415 mm) was 118 mm lower than average multiannual (633 mm). In summer, there were dry periods, due to the long absence or inconsiderable amount of precipitation under steady increase in air temperature which led to the loss of productive humidity reserves in the plants.

Average annual air humidity during the period of our research was 76% (Table 3).

In 2016, humidity content was lower in comparison with average multiannual. There were dry periods in summer because of the long absence or slight amount of precipitation under stable rise of air temperature led to the loss of productive humidity reserves in the plants.

Growth peculiarities of shoots of *Th. plicata* during the vegetative period in plants of different ages was determined by the method of Smirnov and Molchanov (1967). Records were done from the place of opening bud attachment to the shoot of a last year. Shoots were taken from the middle part of the crown. The total number of shoots in each model group was 20 pcs. After shoots growth stopping, the daily gain was calculated, which was defined as the difference of length between the next and the previous values of each measurement period, divided by the number of days in that period.

Measurements were done in three days during the period of intense growth, and in five days in periods of its decline. Simultaneously, average

Table 2. Average monthly rainfall (in mm) in Uman city during 2015–2017 research years (according to the data of Uman Meteorological Station)

Years	Months												For the year
	1	2	3	4	5	6	7	8	9	10	11	12	
2015	20.2	38.6	84.6	38.0	48.6	24.5	69.8	28.7	63.0	44.8	23.2	10.7	495.7
2016	36.8	36.1	12.8	26.0	80.5	135.3	153.3	55.4	17.1	13.2	64.6	29.8	415.9
2017	17.9	8.5	49.6	34.5	53.7	30.2	65.7	34.3	70.8	17.5	33.0	51.4	516.1
Average for 3 years	30.4	37.9	45.8	41.2	36.6	49.9	42.5	30.4	52.1	29.8	40.2	41.2	510.1
Average multiannual	47	44	39	48	55	87	87	59	43	33	43	48	633

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Table 3. Average monthly air humidity (%) during 2015–2017 research years (according to the data of Uman Meteorological Station)

Years	Months												For the year
	1	2	3	4	5	6	7	8	9	10	11	12	
2015	81	85	82	71	63	61	64	66	72	84	90	89	77
2016	80	85	71	57	57	63	58	71	75	79	86	93	73
2017	85	80	77	68	64	66	67	69	73	84	85	91	77
Average for 3 years	83	84	76	67	65	70	64	68	74	81	87	90	76
Average multiannual	86	85	82	68	64	66	67	68	73	80	87	88	76

daily air temperature and humidity were recorded. Based on the results of the research, diagrams of shoots growth during a vegetative season and growth dynamics were constructed and the dependence of shoots growth intensity on the temperature of air, humidity and precipitation was established.

The following main phases in the seasonal rhythm of plant development were distinguished during phenological observations: rest period, beginning of generative buds enlargement, pollen of male strobiles, flowering of female strobiles, beginning of vegetative buds enlargement, breaking of vegetative buds, beginning of shoots growth, finishing of shoots growth, forming of seeds, ripen of cones, sowing of seeds. Observation was carried out over modeling 20 year old trees that reached reproductive capacity. Phenological observations were done during the period of physiological activity on a daily basis. In summer, observations were conducted 1–2 times a week when the development was slowed down.

RESULTS AND DISCUSSION

It was found that the formation of generative organs began in the III decade of March – I decade of April according to the analysis of the results of phenological observations over *Th. plicata*. Plants actively entered the phase of pollen and pollination immediately after enlarging of generative buds. This period was in the I–II decade of April.

Beginning of enlarging of *Th. plicata* vegetative buds in different years was noticed since the III decade of March to the III decade of April. Growth of shoots began in April and ended in September. Formation of generative buds (ears) started after finishing of shoots growth during September. Ears were located on the tops of the side shoots in the leaves axils. In 2012, there was a massive needle fall on *Th. plicata* trees, which lasted until 14th August.

Rest period is an obligatory phase for passing of cells renewal processes and restoration of growth processes in spring. It was 214 ± 4 days during the studied years in the conditions of the Right-Bank Forest-Steppe of Ukraine for *Th. plicata* plants. Period of vegetation was 151 ± 3 days, respectively.

Based on conducted researches, it was planned to develop scientific approaches and to propose real ways to increase phytomelioration efficiency of woodlands using *Th. plicata*, to generalize knowledge about this species and to give an assessment of its introduction and possibilities of use in green construction of the Right-Bank Forest-Steppe of Ukraine.

Connection between the phases of development and temperature can be noticed comparing the results of phenological observations with the corresponding meteorological data. It was found that plant growth began in spring when the thermal energy reached the necessary level for this plant. Such temperature level for the beginning of *Th. plicata* development was average daily temperature of about 6°C.

Period of cones ripen and sowing of seeds was greatly dependent on the climatic conditions. Ripen of *Th. plicata* cones in the studied region lasted throughout September. Sowing of seeds was observed since the II decade of September to the II decade of October. Rapid fall of seeds from cones occurred only in dry warm weather, in other cases the seeds can be stored in cones and gradually fall during winter.

Cycle of *Th. plicata* development from flowering to seeds ripen occured within one year (Fig. 1).

Air temperature has direct influence on the mechanisms regulating growth processes in plants. The indicator of heat amount required for plants vegetation is the sum of effective tem-

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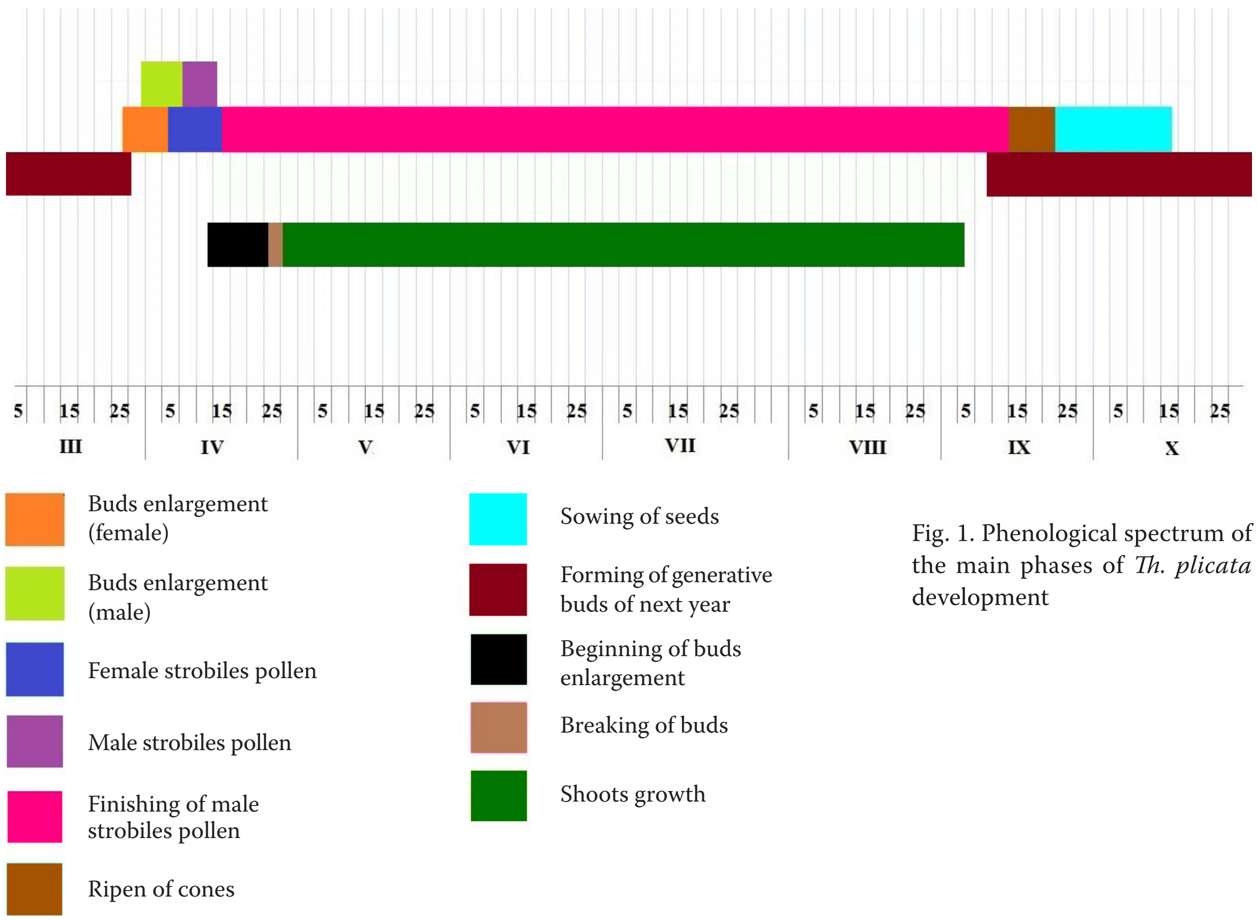

Fig. 1. Phenological spectrum of the main phases of *Th. plicata* development

peratures ($\Sigma_{ef.}$ °C) (Termena 1984). Using this, it is possible to accurately reflect the microclimatic features of plants growth of this or that region, and it allows plan correctly the appropriate agrotechnical methods during their growing. In different climatic zones, one can predict the growth rates of this or that tree species according to the data of temperature sums during the period preceding the flowering phase (Fuertes-Rodríguez at al.). Dissimilar number of days is needed to accumulate the sum of effective temperatures to the corresponding calendar period in different years. This fact causes terms variability of the beginning of the corresponding phases of plants development. The sum of active temperatures of above +10° C was determined in the process of the researches when the main phases of *Th. plicata* development occurred (Table 4).

Consequently, it was found in the result of observations that the vegetation period of *Th. plicata* was 151 ± 3 days. This cycle of development coincided with the duration of the vegetative period in the area under research. During this time, *Th. plicata* managed to prepare for passing to the rest state in full. Generative development of *Th. plicata* passed all phases in the conditions of the research, resulting in similar seeds formation. This characterized the degree of success of introduced species adaptation.

One of the indicators of successful plants introduction was the determination of climatic conditions peculiarities that affected the seasonal dynamics of plants development. They were the indicators of air temperature, humidity and precipitation. Existing dependence between these indicators and vegetation period in plants was established. Although each species had its own certain differences, in general, this dependence was noticed very clearly (Harrington 2016).

It is worth noting that average annual shoots growth of *Th. plicata* fluctuated every year depending on meteorological conditions. The graphic data shown in Fig. 2 indicates about the dependence between temperature fluctuations and shoots growth. It was found that shoots began to grow in the first-second decade of April after the changing of av-

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Table 4. Sum of active temperatures at the beginning of the main phenological phases of *Th. plicata* development (during 2015–2017)

Phase of development	Term	Σ_t (°C)
Phase of generative organs development		
Beginning of buds enlargement (female)	26.03 ± 3	21
Beginning of buds enlargement (male)	29.03 ± 3	22
Beginning of female strobiles pollen	04.04 ± 4	26
Beginning of male strobiles pollen	06.04 ± 4	34
Finishing of male strobiles pollen	13.04 ± 3	53
Finishing of female strobiles pollen	15.04 ± 3	64
Forming of generative buds of next year	08.09 ± 7	1,857
Ripen of cones	13.09 ± 8	2,180
Sowing of seeds	20.09 ± 14	2,269
Phase of vegetative organs development		
Beginning of buds enlargement	13.04 ± 11	55
Breaking of buds	21.04 ± 11	82
Beginning of shoots growth	25.04 ± 11	115
Finishing of shoots growth	07.09 ± 12	2,123

erage daily temperature to +9°C and higher while studying the seasonal shoots growth.

It was known that apical and lateral buds on one shoot grew almost simultaneously (Parker at al. 1987). Culmination of the first wave of growth was observed in May, when the average daily temperature was + 13–18°C. Amount of growth gradually decreased starting since the first decade of June and the shoots completely finished their growth by the end of the second decade of September. Correlation coefficient ranged from 0.71–0.79. This means that there was a correlative connection between the beginning of growth and increasing of average daily air temperature to +9°C. In the future, the intensity of shoots growth was also connected with air temperature. Particularly noticeable dependence of the amount of growth on air temperature was noticed after its increasing to +20°C, when the intensity of shoots growth slowed down sharply. Then, there was the second wave of shoots growth starting since the second decade of August when the temperature got lower. According to the graph, growth stopping also had close connection with further changes in air temperature.

Annual amount of growth of *Th. plicata* trees was 32.1–36.1 cm throughout the vegetative period. 76% of annual growth was formed during the period of intense shoots growth and the beginning of the culmination of the firth growth wave. Therefore, the greatest effect of forest management measures aimed at increasing the productivity of the forest stand can be achieved by conducting them prior to the slowing down of growth processes.

The process of photosynthesis in plants occurred most productively at a relative air humidity of 60–70%. (Kishchenko 2011). The study of the connection between humidity and shoots growth showed that average daily air humidity ranged within 56–78% at the beginning of shoots growth period over the years of research. Sufficiently large variation in the figure of this factor indicated about absence of its effect on the terms of the beginning of the meristemic tissues activity. This phenomenon can be explained by the fact that growth processes in the beginning period were due to the reserve food material. In the future, the role of assimilants of the current year begins to increase and the change in air humidity can already be reflected in the intensity of growth processes (Kischenko & Vantenkova 2011).

Results of the statistical analysis (Fig. 3) showed that this dependence had a determination coefficient within the range of 0.53–0.57, which indicated about a weaker dependence than with temperature. Analyzing the data, we could see the cases of lowering or rising the growth of vegetative organs with a corresponding increase or decrease in air humidity. For example, in 2015, the maximum daily amount of growth was observed since mid-May to mid-June, when air humidity fluctuated within 64–68%. At this time, the amount of growth was 3.6–3.8 cm per day. At the same time, the daily intensity of shoots growth slightly increased under air humidity raising. Stopping of the first wave of growth observed in the third decade of June – the first decade of July occurred under air humidity of 60–65%. That is, it can be assumed that decrease in humidity below 60% affected the intensity decrease for growth. That was because the beginning of the second wave of growth and its culmination, happening in the second decade of August, occurred

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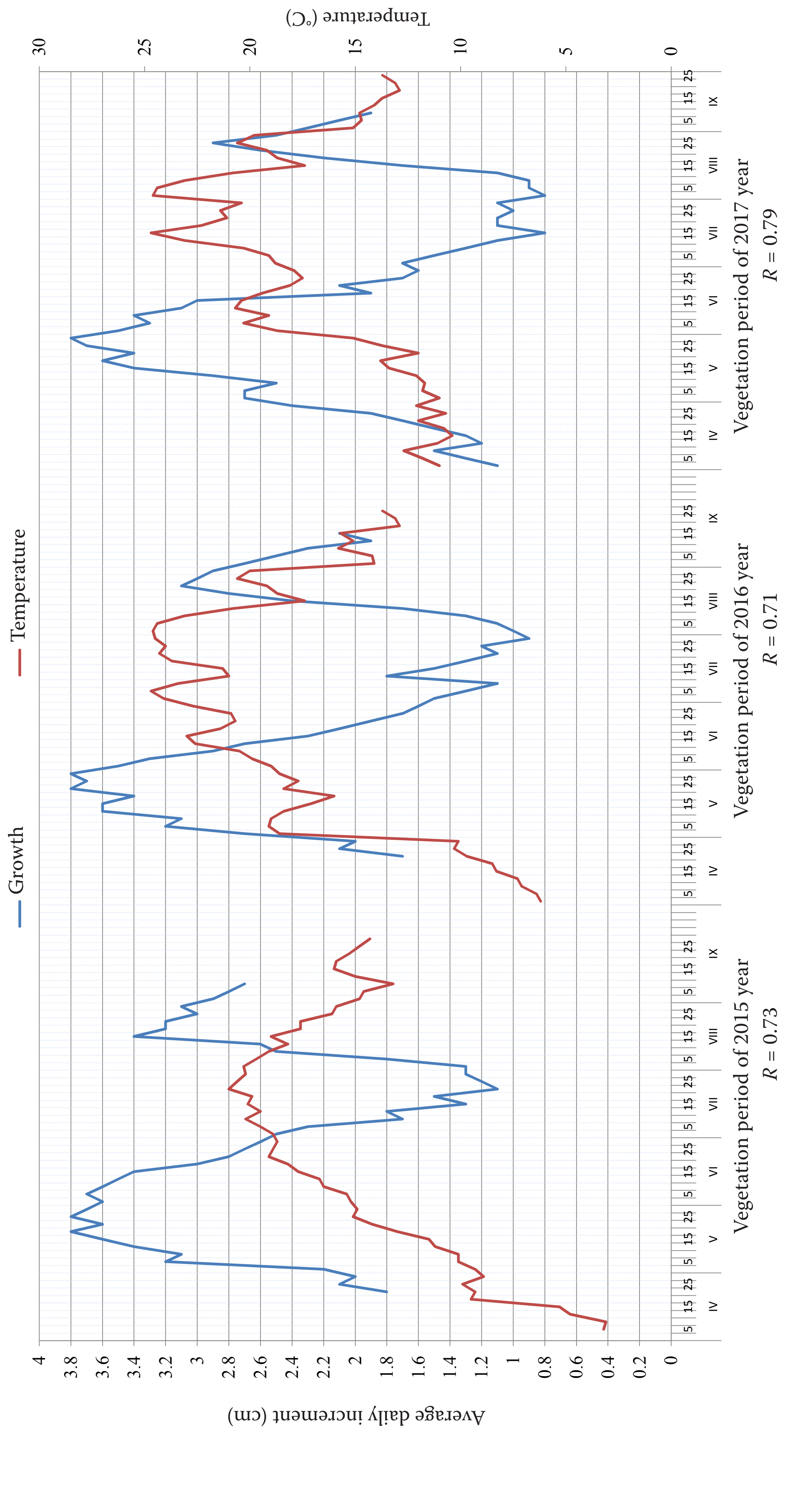

Fig. 2. Average annual shoots growth of *Th. plicata* fluctuated every year depending on meteorological conditions – temperature

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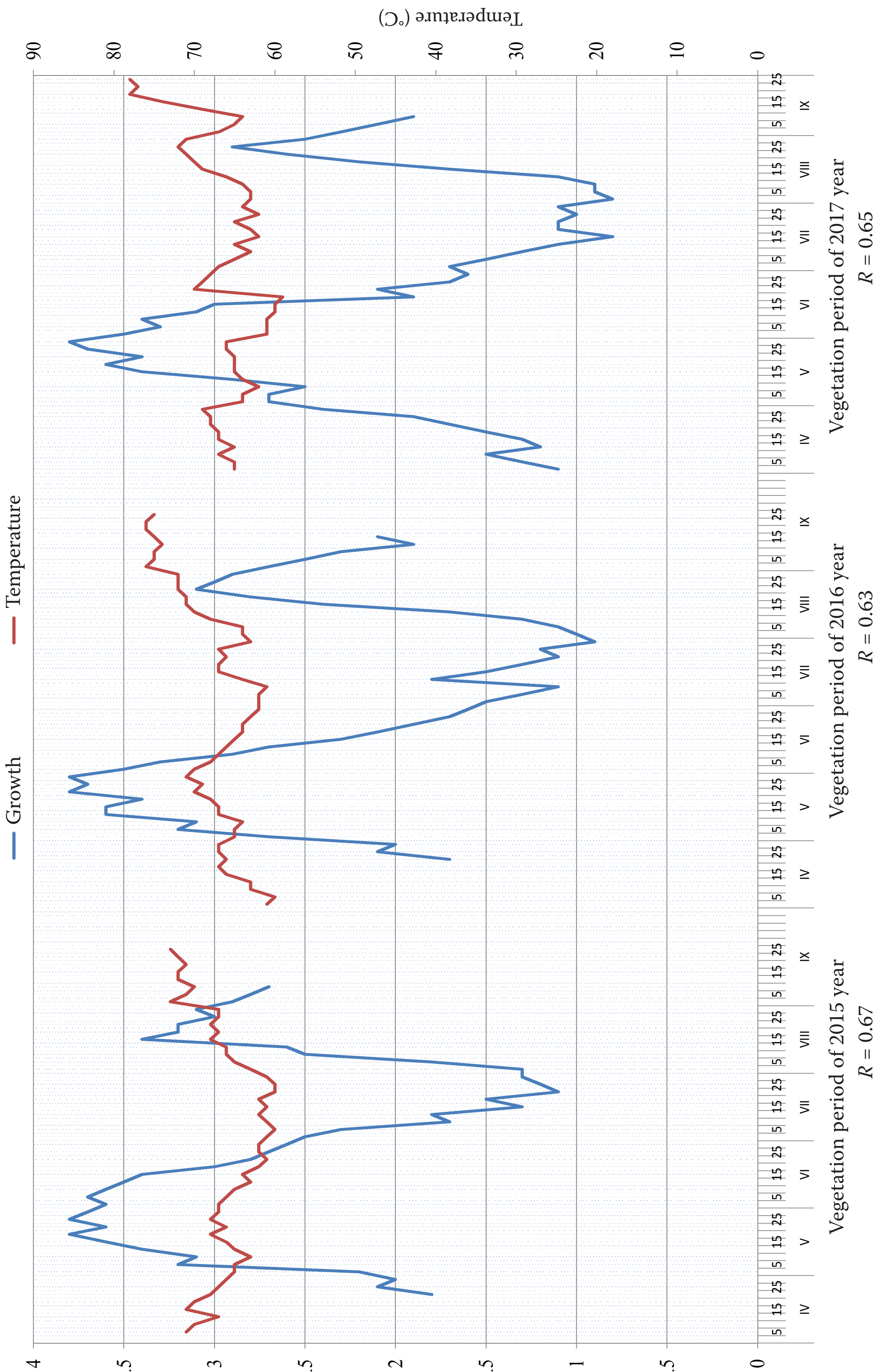

Fig. 3. Average annual shoots growth of *Th. plicata* fluctuated every year depending on meteorological conditions – humidity

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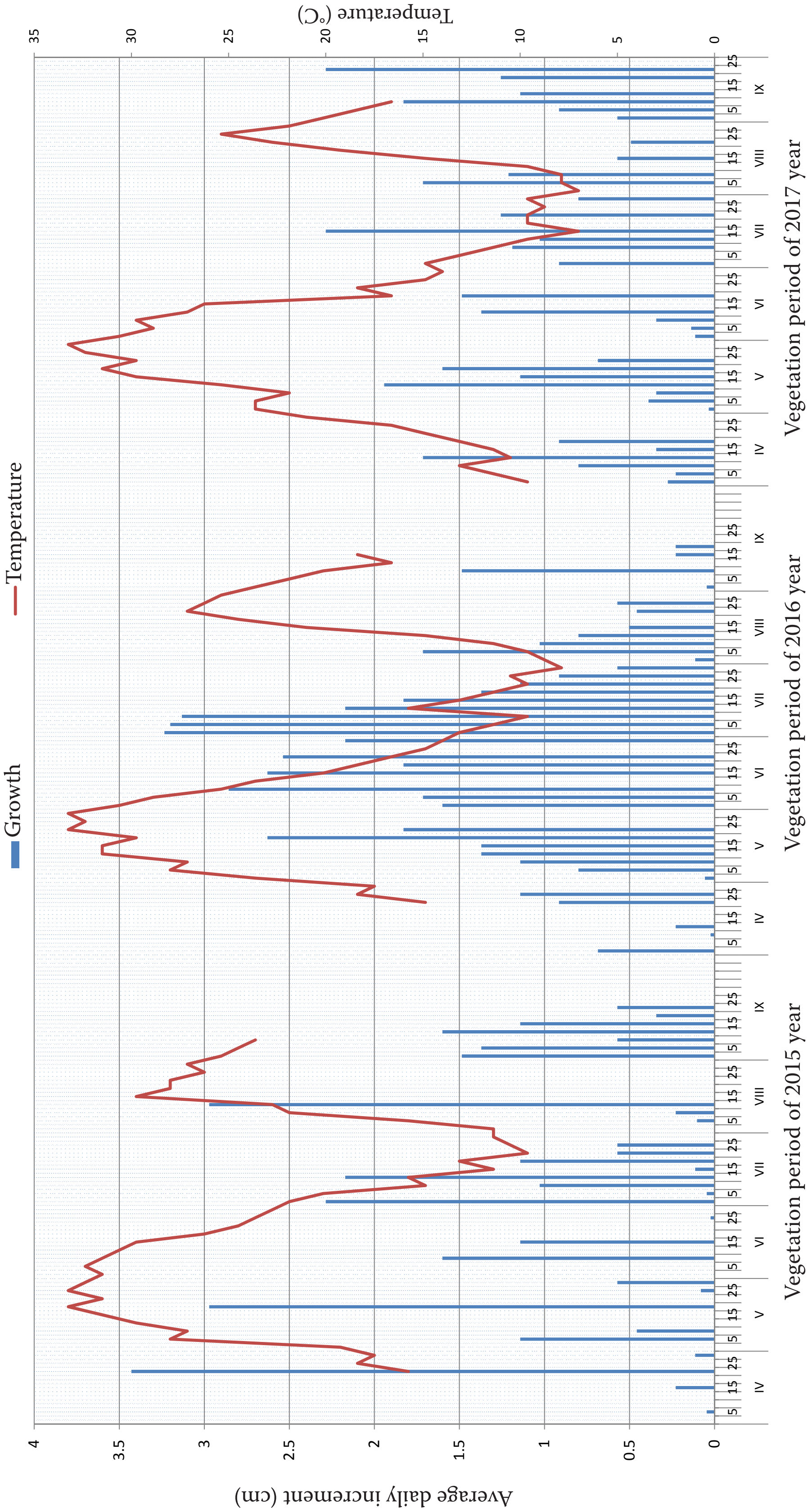

Fig. 4. Average annual shoots growth of *Th. plicata* fluctuated every year depending on meteorological conditions – precipitation

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under the increase in air humidity of 66–68%. However, in 2016, culmination of the first wave was in May with humidity of 71%, while decline in the first wave of growth occurred at 62–67%. The second wave of growth, that year, began under humidity of 71–76%. In 2017, culmination of the first wave passed since mid-May to mid-June at humidity of 61–66%, and slowing down – at 62–65%. The second wave was observed under humidity of 67–71%. Consequently, regardless of the humidity indicators, varied by years, a partial pattern of fluctuations in amount of growth and humidity over a period of one year could be noticed.

Finishing of shoots growth was observed at values of air humidity of 70–73%. Most likely, the terms of finishing of shoots growth, as well as its beginning were not limited by this factor.

It was found that the number and frequency of precipitation did not significantly affect the dynamics of shoots growth in the result of the research. This was evidenced by low coefficients of correlation. The beginning of the growth culmination did not depend on the amount of precipitation according to the graph shown in Fig. 4. It was in 2015, when the culmination happened in the second decade of May – the first decade of June, with a small. amount of rainfall in that period. And slowing down of the first wave of growth occurred just in the period with a lot of rainfall. In 2016, there was much more rainfall in general, but the largest number of them occurred in the period of slowing down of the first wave of growth. Year of 2017 was much drier than the previous two, but this did not affect the intensity of the amount of growth. Thus, the maximum amount of growth in plants was observed regardless of the presence or absence of spring-summer precipitation.

Based on conducted researches, it was planned to develop scientific approaches and to propose real ways to increase phytomelioration efficiency of woodlands using *Th. plicata*, to generalize knowledge about this species and to give an assessment of its introduction and possibilities of use in green construction of the Right-Bank Forest-Steppe of Ukraine.

CONCLUSIONS

Conducted researches showed that *Th. plicata* plants is characterized by high growth energy. And the climatic conditions of the Right-Bank Forest-Steppe of Ukraine are quite favorable for successful vegetation of the plants of this species.

Vegetation period of *Th. plicata* is 151 ± 3 days. This cycle of the development is coincident with the duration of the vegetation period in the area under research. The beginning of *Th. plicata* vegetation is observed in the III decade of March – I decade of April starting with formation of generative organs. Growth of vegetative shoots begins in the second decade of April.

Temperature regime of the environment of all ecological factors has the greatest impact on shoots growth. Humidity and precipitation did not reveal a significant pattern of influence. Seasonal growth of shoots is related to air temperature during the vegetation period and humidity fluctuations. In total there are two waves of shoots growth – in May and August.

Based on conducted researches, it was planned to develop scientific approaches and to propose real ways to increase phytomelioration efficiency of woodlands using *Th. plicata*, to generalize knowledge about this species and to give an assessment of its introduction and possibilities of use in green construction of the Right-Bank Forest-Steppe of Ukraine.

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