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IMPACT OF TEMPERATURE AND WETNESS OF SUMMER MONTHS ON AUTUMN VEGETATIVE PHENOLOGICAL PHASES OF SELECTED SPECIES IN *FAGETO-QUERCETUM* IN THE YEARS 2011–2015

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Abstract

ŠKVARENINOVÁ JANA, BABÁLOVÁ DARINA, VALACH JÁN, SNOPKOVÁ ZORA. 2017. Impact of Temperature and Wetness of Summer Months on Autumn Vegetative Phenological Phases of Selected Species in Fageto-Quercetum in the Years 2011–2015. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 65(3): 939–946.

The work presents the result of the drought impact on the onset and the development of autumn phenological phases of tree species (*Quercus robur* L., *Carpinus betulus* L., *Prunus avium* L.) in the central part of Slovakia. The selected autumn phenological phases of tree species were observed in the years from 2011 to 2015. From meteorological parameters we examined precipitation, number of tropical days, and their periods from June to August. We revealed distinct differences in air temperature and precipitation between the years, which affected the onset of individual phenological phases. Based on the calculations of the Thornthwaite moisture index and climatic water balance, the year 2014 was wet (except for June) with the shortest periods of tropical days. The extreme drought and the longest 13-day period of tropical days in the year 2015 shifted leaf colouring of hornbeam and cherry tree by 16 and 22 days earlier and the leaf fall by 5 and 16 days earlier than the average of the period from 2011 to 2015. Oak was the least sensitive to the weather extremes, which was documented by a balanced course of the phenological phases with the lowest variation. The 5-year-long average onset of the autumn phenophases of oak and hornbeam was shifted by 1–4 days later and of cherry tree by 4 days earlier than the 25-year-long average.

Keywords: weather extremes, phenology, autumn phenological phases, Slovakia, forest-tree species

INTRODUCTION

Water and forests represent elements important for the life on our planet. In the time of the current global climate change, the attention is paid to the conditions and further development of forest ecosystems. Worldwide increasing frequency of drought can be considered as one of the demonstrations of climate change (Perkins *et al.,* 2012; Ďurský *et al.,* 2006). Its long-term impact threatens biodiversity, changes site characteristics and eventually also the range of tree species. According to Wilhite and Glanz (1985), we recognise meteorological drought as a deficit of atmospheric precipitation and the period with increased evaporation and transpiration; agricultural drought, when the biomass production is reduced and the physiological processes of plants and agricultural crops are affected by water stress; and hydrological drought, when the deficit of atmospheric precipitation is reflected in the water cycle of the region. The intensity and the rate of drought impact on the organisms differ at levels of individuals, populations, communities, and ecosystems.

Resilience is an important characteristic of organisms in relation to water deficit, as it represents the ability to tolerate stress or recover from stress (Hodgson *et al.,* 2015). Visible drought impacts are leaf colouring, wilting, and foliage loss, and eventually the decrease of biomass production, and reduction of production and non-production functions of forest ecosystems (Solberg, 2004). Drought directly affects plant water balance, tissue hydration and consequently other physiological processes. The increasing temperature and water stress cause worsening of health conditions and even die-back of forest stands worldwide (Allen *et al.,* 2010; Mezei *et al.,* 2014), consisting mainly of tree species with shallow root systems (Netzer *et al.,* 2016; Peuke *et al.,* 2002).

In the last years, increased mortality of native tree species was observed in Europe after summer periods of drought (Tsopelas *et al.,* 2004; Breda *et al.,* 2006; Dobbertin and Rigling, 2006). Local conditions and biotic factors (insects, fungi) play an important role because they can intensify the impact of drought (Allen and Breshears, 1998; Foden *et al.,* 2007). We need to realise that tree species mortality, as well as changes in structure and functioning of ecosystems are not caused by one period with water deficit, but by cumulated long-term impacts of low frequency and high intensity, or high frequency and low intensity (Van Mantgem *et al.,* 2009; Škvarenina *et al.,* 2009). Ecosystems with greater biodiversity and communities consisting of several age categories are more resistant to drought (Archaux and Wolters, 2006).

The weather extremes with high air temperatures and periods of drought during vegetation season have been observed in the last years. The main aim of our work was to point out to weather extremes by phenological reactions.

MATERIAL AND METHODS

In the years between 2011 and 2015, we performed phenological observations of selected phenological phases of pedunculate oak (*Quercus robur* L.), common hornbeam (*Carpinus betulus* L.) and wild cherry (*Prunus avium* L.) in the central part of Slovakia – Zvolen valley. The locality is situated at elevations between 290 and 320 m a.s.l. with the prevailing north-western aspect. The area belongs to a warm up to a slightly warm climatic region, at the border between the zone of a slightly warm moist district and a slightly warm and slightly wet hilly up to upland district (Lapin *et al.,* 2002). The meteorological data was taken from the meteorological station Sliač which is located in 313 m a.s.l. and is approximately 3 km away from tree observed species. The phenological observations were performed according to the methodology of the Slovak Hydrometeorological Institute (Anonymous, 1984). The onset of the phenological phase was observed within a group of 10 individuals of the particular tree species (10% occurrence). To compare the phenological phases, a set of so called BBCH codes was prepared at an international level, which we applied also in our study of the phenological phases. We observed the following phenological phases:

- *leaf colouring LC – BBCH 92* (first yellow leaves occur),
- *leaf fall LF – BBCH 93* (yellow leaves fall even in still air).

In the statistical data processing of the onset of the phenophases in the individual years we used absolute numbers of days in the year (so-called Julian days).

From the meteorological parameters we evaluated the number of tropical days from June to August, when the maximum daily air temperature exceeded 30 °C. We also determined the periods of tropical days, i.e. the number of consecutive days with the air temperature ≥30 °C. When analysing water regime we focused on maximum lengths of dry periods in individual months. We determined the thresholds following the work of Slovak Hydrometeorological Institute (Kolektív, 1991), which stated the criteria of precipitation amount for drought in several groups (1 mm, 3 mm, 5 mm) based on the long-term observation series in different orographic conditions. We also counted the number of days with heavy precipitation events that exceeded 20 mm. We used the Thornthwaite moisture index (TMI) and the climatic water balance (CWB) of Sliač station as drought indicators.

The Thornthwaite moisture index was calculated following Thornthwaite and Mathere (1955)

$$TMI = 100\,((P/PE) - 1)$$

TMI ....Thornthwaite moisture index,
P..........precipitation (mm),
PE ....potential evapotranspiration (mm)

Climatic water balance

$$CWB = P - PE$$

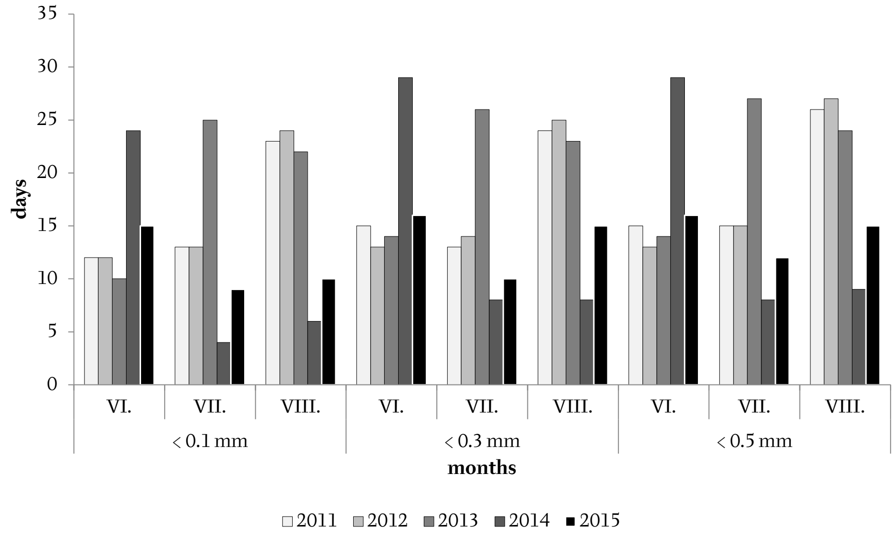
CWB (mm),
P....... precipitation (mm),
PE .... potential evapotranspiration (mm)

while PE was calculated following Ivanov (Novák 1995):

$$PE = 0.0018\,(25 + T)^2 \,.\, (100 - RH)$$

T....... air temperature (°C),
RH ... relative air humidity (%).

The onset of the autumn phenological phases in the last 5 years was compared with their onset during the 25-year-long period from 1991 to 2015. The statistical significance was estimated at 99 % level.



1: *Drought periods from June to August in the years between 2011 and 2015 determined based on the precipitation amount*

I: *Selected precipitation characteristics of the growing seasons in the years from 2011 to 2015*

Years	Month rainfall sum / Max. daily rainfall sum (mm)			Number of days with rainfall >20 mm		
	VI.	VII.	VIII.	VI.	VII.	VIII.
2011	149.2/34.5	142.9/55	25.3/9.4	3	3	0
2012	98.5/28.8	108.1/23.5	11.5/5.1	1	1	0
2013	102.9/36.1	13.3/8.2	101/61.6	2	0	1
2014	43/28	171.3/41.8	111.5/28.2	1	4	2
2015	25.9/10.2	120.8/37	31.2/16.5	0	3	0

II: *Indicators of drought and water balance in the years from 2011 to 2015 (-drought, + water surplus)*

Years	Climatic water balance			Thornthwaite moisture index		
	VI.	VII.	VIII.	VI.	VII.	VIII.
2011	44	46	–87	42	47	–77
2012	–12	–10	–137	–11	–9	–93
2013	12	–132	–43	13	–91	–30
2014	–103	60	37	–71	54	50
2015	–105	–42	–99	–80	–26	–76

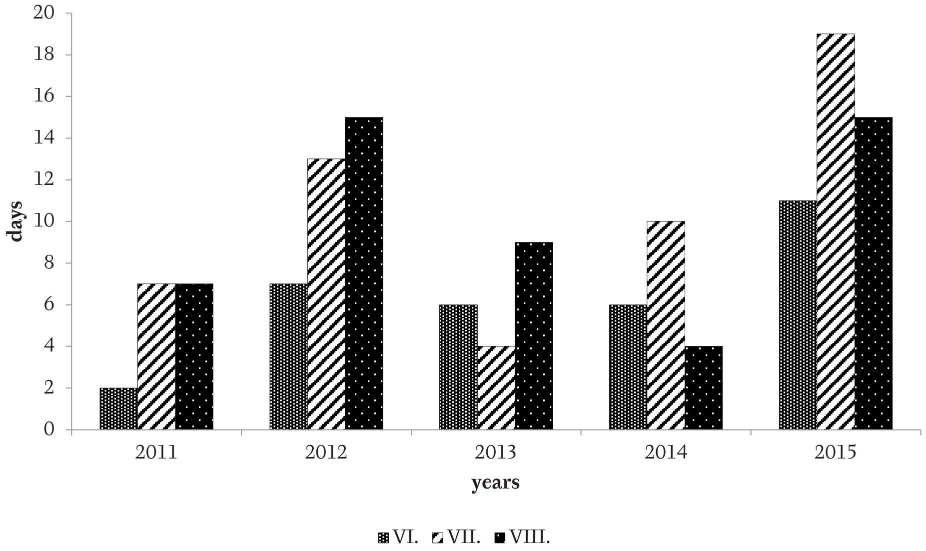
RESULTS AND DISCUSSION

When analysing the impact of the weather extremes on the phenological phases of the tree species we examined the temporal course of two meteorological elements – precipitation and air temperature. Distinct differences of precipitation can be seen between the individual years. The longest drought periods with the precipitation totals below 5 mm were in June 2014 and in July 2013, when the number of days with precipitation below 5 mm reached 22–28 days (Fig. 1). The water deficit in these years is also reflected in the monthly precipitation totals (Tab. I), the analysis of the climatic water balance, and the Thornthwaite moisture index (Tab. II). The highest amount of precipitation in July and August was also recorded in the year 2014, which created the supplies of usable soil water that ensured uninterrupted processes of photosynthesis and respiration. The year 2015 represented an extreme of the examined period, since in the months from June to August drought was confirmed by all evaluated precipitation characteristics. The year 2015 was the driest within the last 25 years.

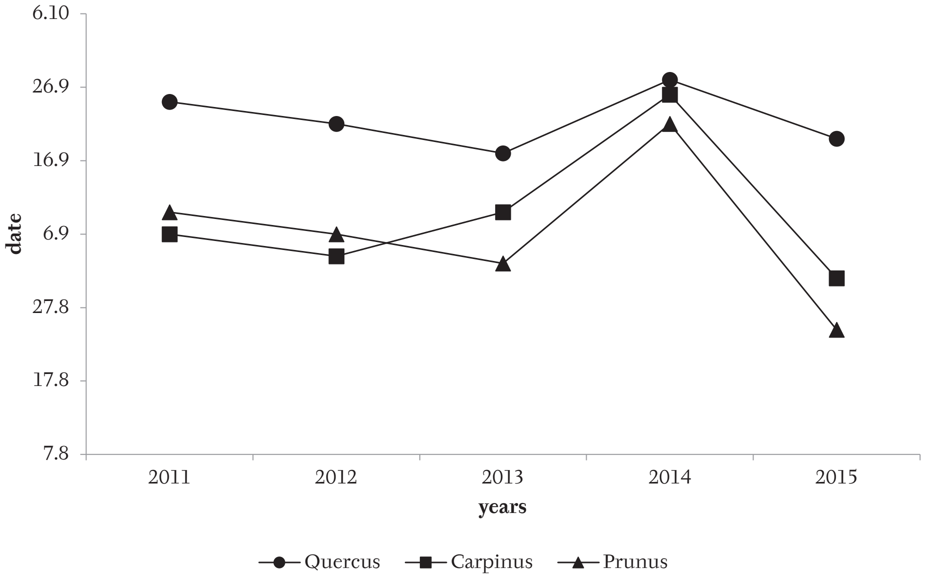
Apart from precipitation, drought intensity is also determined by air temperature. Precipitation deficit is often linked to high long-lasting temperatures. They were most apparent in the years 2013 and 2015 (Tab. III) when we recorded maximum daily air temperatures exceeding long term 50-years absolute maximum. These were outreached in June 2013, 2014 and in August 2013 and 2015. If we compare the period of tropical days in those years with the period between 1987 and 2012 (Škvareninová, III: *Selected temperature characteristics of the growing seasons in the years 2011–2015*

Years	T max (°C)			Max. period of tropical days		
	VI.	VII.	VIII.	VI.	VII.	VIII.
2011	30.7	34.5	35	0	7	6
2012	34.2	36.7	35.5	6	11	7
2013	**35.8**	36.9	**37.8**	6	12	12
2014	**35.8**	32.7	31.7	6	3	3
2015	34.4	37.4	**37**	11	9	**13**
1961–2010*	35.6	37.8	36.8	-	-	-

* absolute maximum air temperature (1961–2010)



2: *Number of tropical days from June to August in the years 2011–2015*



3: *Onset of leaf colouring of selected tree species in the years from 2011 to 2015*

2013) at the same locality, we see that in the year 2015 the absolute 13-day-long record of tropical periods was recorded since 1987. In that year we also recorded the highest number of tropical days in each summer month (Fig. 2). Similarly 14-days long hot wave and the highest daily maximum 40 °C were observed in Hosinec and Řež stations in Czech republic in August 2015 (Crhová *et al.*, 2016).

The lack of water and long-lasting high air temperatures stress tree species, which is often manifested by an early onset of some autumn phenological phases. The year 2015 was characterised by an earlier onset of leaf colouring of the monitored tree species (Fig. 3). The greatest differences were recorded for the common hornbeam and wild cherry, which leaves started to colour 16 and 22 days earlier than the 5-year average, and 17 and 20 days earlier than the 25-year average of the phenophase due to the weather extremes. The similar phenological reactions to the extreme temperatures of tree species were observed in Czech republic in 2015 (Hájková *et al.*, 2016). The earlier onset of leaf colouring was observed on the most of tree species. The onset of leaf colouring of pedunculate oak was observed 6 days earlier in the same altitude than the Sliač station what corresponds to our observations (1 day earlier). The advance in the onset of leaf colouring of pedunculate oak was not so significant then on others tree species. The difference is nonsignificant in compare with others tree species in Czech republic.

Schieber *et al.* (2009) confirmed the significant relationship between the onset of leaf colouring and precipitation amount in the summer periods (from May to August). The authors found high correlation for hornbeam ($r^2 = -0.81$). The weather in the summer period of the year 2014 represented by high precipitation totals and short periods of tropical days caused the delay in leaf colouring of all tree species by 3 to 12 days in comparison with the average from the last 5 years and by 7–8 days in comparison to the average onset in the years from 1991 to 2015.

Sensitive responses to weather extremes in the summer months were recorded in the case of wild cherry, for which the coefficient of variation reached the highest values in both time periods (Tab. IV). This tree species is more demanding on soil moisture. Moisture deficit and longer periods of tropical days during the last 5 years shifted its average onset of leaf colouring by 4 days earlier. The lowest coefficient of variation of leaf colouring was found for pedunculate oak (s_x%=1.26). From the point of the demands on soil moisture, this tree species belongs to mesophytes (Pagan, 1992) and is able to adapt to different soil moisture conditions. Its deep root system enables the tree species to utilise the water from deeper soil layers, which was reflected by a balanced course of the onset of the phenophase in the analysed period and its low deviations from the long-term average. Menzel (2003) reported positive correlation between August and September mean temperature and leaf colouring and Delpierre *et al.*, (2009) found that leaf colouring process started earlier and was sensitive to higher temperature for pedunculate oak in France. In the case of oak and hornbeam we observed the delay of the phenophase in the last five years. We compared our values for pedunculate oak with similar values (Braslavská and Kamenský, 2002) from Slovakia and the years 1986–2000. The work confirmed that in spite of the inter-annual variation comprising both negative and positive deviations from the 15-year average, the phenophase shifted to later periods by 7 days, which can be a signal of climate change. Similar results were published by Slovíková and Bednářová (2014), who presented the negative impact of the delay of autumn phenophases on tree species vitality.

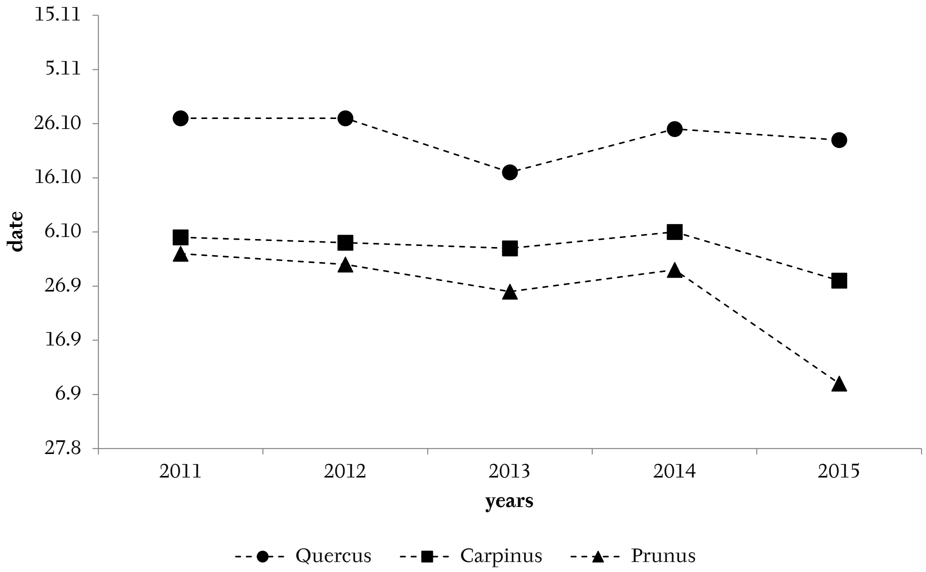
Leaf fall responds to temperature and precipitation conditions in summer months, as well as the weather pattern in autumn after leaf colouring. Wind and heavy rain can significantly accelerate this phenophase. The onset of leaf fall in individual years is presented in Fig. 4. In the year 2015, extreme drought and the longest periods of tropical days caused the shift of the leaf fall of hornbeam and cherry by 5 and 16 days earlier than the average from the years 2011–2015. In comparison with the long-term average, the cherry leaves fell 20 days earlier (Tab. V). The phenophase of this tree species had the greatest variation (3.54%). The impact of drought was significant on leaf fall of oak neither in Zvolen basin (–1 day) nor in Czech republic (–3 days) with long-term average (Hájková *et al.*, 2016). Juknys *et al.* (2012) documented the relationship between moisture and water conditions, temperature and leaf fall. They found that decrease in soil moisture caused by a simultaneous rise in temperature and decrease in precipitation lead to earlier leaf fall. Early leaf fall of tree species due to drought was

IV: *Statistical characteristics of the phenological phase of leaf colouring, phenophase shifts (+ earlier, – later, * significant trend p<0.01)*

Wood species	$Ø_1$ 2011–2015	min	max	s_x%	$Ø_2$ 1991–2015	s_x%	$Ø_2$ trend	Δ (Q_2–Q_1)
Quercus robur	22.9.	18.9. 2013	28.9. 2014	1.26	21.9.	2.15	0.75*	–1
Carpinus betulus	23.9.	1.9. 2015	26.9. 2014	1.49	19.9.	4.07	0.51*	–4
Prunus avium	10.9.	25.8. 2015	22.9. 2014	4.01	14.9.	6.47	0.55*	+4

also documented by Štefančík (1995). He found that if an extreme drought and long-lasting high temperatures exceeding 30 °C occurred during the growing season, still green beech leaves were falling already in August. Similarly, Breda *et al.* (2006) was found prematurely shed non-senescent green leaves during dry and warm summer of 2003 in *Fagus sylvatica*.

We recorded the latest leaf fall of hornbeam and cherry in the year 2011, when the values of the drought indicators in June and July were highly positive. In spite of the longer periods of tropical days, we did not record an earlier onset of the phenophase. In the case of oak, the onset of leaf fall was balanced in both monitored periods, which is documented by the lowest values of the coefficient of variation. Vilhar *et al.* (2014) were found only weak sensitivity of leaf fall to air temperature and to soil water conditions for oak. It was found for single months without clear seasonal pattern.



4: *Onset of leaf fall of selected tree species in the years 2011–2015*

V: *Statistical characteristics of the phenological phases of leaf fall, phenophase shifts (+ earlier, – later, * significant trend p < 0.01)*

Wood species	Ø$_1$ 2011–2015	min	max	s_x%	Ø$_2$ 1991–2015	s_x%	Ø$_2$ trend	Δ (Q_2–Q_1)
Quercus robur	25.10.	18.10. 2013	28.10. 2012	1.15	21.10.	2.59	0.59*	-4
Carpinus betulus	3.10.	28.9. 2015	6.10. 2011	1.39	30.9.	3.19	0.36	-3
Prunus avium	25.9.	9.9. 2015	3.10. 2011	3.54	29.9.	6.69	0.58*	+4

CONCLUSION

The contribution presents the results of the impact of the weather extremes on the onset of autumn phenological phases of selected tree species (*Quercus robur* L., *Carpinus betulus* L., *Prunus avium* L.) in the central part of Slovakia at elevations between 290 and 320 m a.s.l. In the years from 2011 to 2015, we recorded 10% occurrence of leaf colouring and leaf fall on 10 trees of each tree species. To determine temperature and humidity conditions of this period we used the Thornthwaite moisture index and the climatic water balance. The year 2014 was characterised by the most abundant precipitation, which created the supplies of the usable soil water for continuous photosynthesis and respiration of the tree species. In that year, leaf colouring of all monitored tree species was delayed by 3 to 12 days in comparison to the 5-year average and by 7 to 8 days in comparison to its average onset in the years from 1991 to 2015. The year 2015 represented a distinct extreme of the evaluated period, since in the months from June to August drought was confirmed by all examined precipitation characteristics. The absolute 13-day-long record of the tropical period was observed in that year since 1987. Wild cherry responded to this extreme most sensitively, as its autumn phenophases started by 20 days earlier than its 25-year average onset. Pedunculate oak had the lowest variation of both phenophases, when their onset was shifted only by 1 and 2 days earlier, and hence, it can best withstand weather extremes and adapt to gradual changes of environmental conditions at the given site.

The average onset of the phenophases of oak and hornbeam in the analysed period was delayed by 1 and 4 days in comparison to the long-term average onset, while in the case of cherry, the phenophases started by 4 days earlier. Wild cherry reacted to the weather extremes in the summer months most sensitively, which was reflected by the greatest variation of the autumn phenological phases.

Phenological observations serve as bio-indicators of environmental changes and as one of the main indicators of species resistance to weather extremes. Their importance lies in the clarification of the relationships with regard to the climate development, mainly for making the assumptions of the changes in tree species ranges in relation to key meteorological elements.

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