

Accelerated Height Growth Versus Mortality of *Quercus petraea* (Matt.) Liebl. in Hungary

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ABSTRACT

Background and Purpose: Due to climate change, it is important to know to what extent forests will be impacted by atmospheric changes. This study focuses on the height growth response of sessile oak (*Quercus petraea* (Matt.) Liebl.) to counteracting effects of fostering and interfering changes under contrasting climatic conditions with special attention to the xeric limit zone of this species.

Materials and Methods: Twenty-eight sites were selected along a climatic gradient from the humid region in southwest Hungary to the continental-semiarid region in northeast Hungary where neighbouring old and young sessile oak stands were available for pair-wise comparison of height growth. While these young stands developed entirely in the significantly changed atmospheric conditions, the older trees lived only a part of their life time in such changed environment. The Ellenberg quotient (EQ) was used for describing climate aridity. Stand top height in each pair of old and young stands was measured to calculate the relative stand top height using yield tables of sessile oak for Hungary. Additionally, stand densities of old stands were measured. To demonstrate the height growth differences of old and young stands their relative stand top heights were compared as functions of EQ and stand density.

Results: The relative top heights of the young stands were significantly higher than of the older stands, which means that the overall growing conditions were better in the last 30-35 years due to atmospheric changes than the mean conditions during the lifetime of old stands. Although extreme drought events associated with climate change caused reduced stand density due to periodic tree mortality at the xeric limit of sessile oak, the synergetic effect of all atmospheric changes was still sufficient enough to accelerate height growth.

Conclusions: There has been an acceleration of height growth during the last decades despite the increased frequency of droughts. It cannot be concluded that height growth acceleration will continue in the future since climate models show an increasing tendency of dry extremes in Hungary that may overrule the positive fostering effect of atmospheric changes.

Keywords: *Quercus petraea* (Matt.) Liebl., height growth, climate change, xeric limit, stand density, stand top height

INTRODUCTION

Multi-year drought periods since the beginning of the 1980s led to prolonged water deficits during the growing seasons in the Carpathian Basin [1, 2].

Droughts negatively influence the radial growth of trees [3, 4], reduce the vitality of trees [5], increase pest and disease invasions [6], and may lead to mortality [7], resulting in reduced stand density primarily at their xeric distributional limit [8].

Nevertheless, some studies suggest that forests may benefit from higher temperatures due to various compensating effects, such as fertilization through rising atmospheric CO₂ concentration and nitrogen deposition, or improving water use efficiency [9-11]. Data of the ICP Forests plot showed a positive relationship between higher temperature, CO₂ and N deposition, and the increase of volume increment [12]. The results of the project called RECOGNITION (Relationships Between Recent Changes of Growth and Nutrition of Norway

Spruce, Scots Pine and European Beech Forests in Europe) showed that there were significant increases in height growth rates in many parts of Northern Europe. Increasing growth rates were also reported in many forests in Hungary [13] and even beyond its natural range, which is probably related to the changing environments [14, 15].

Sessile oak (*Quercus petraea* (Matt.) Liebl.) forests are among the most important forest communities in the Carpathian Basin and one of the economically most important tree species in Hungary. The distributional area of the species extends from the most humid to arid areas in Hungary. Since the early 1980s, severe drought periods have triggered several mortality events of sessile oak [16, 17], especially in the northeastern part of the country. Therefore, it is a well-suited tree species for the analysis of the climatic background of decline and growth acceleration [18].

The largest 20% of trees, or a fixed number of 100 or 200 of the largest trees from the collective are called stand top height [11]. Among numerous dendrometrical parameters, stand top height is considered to be the most indicative factor for the stand's productivity [11, 19] which is less dependent on stand density and thinning [11]. Moreover, height growth is suitable for examining the effect of climate change [20].

The rate of tree height growth can be most precisely determined by measuring the trees of experimental stands in the frame of a long-term forest yield monitoring. In doing so, the growth rate of the same trees in time can be compared with the growth rate of the specified age found in the yield tables of sessile oak [21].

Any plots of the long-term forest yield monitoring near the xeric limit of sessile oak were affected by tree mortality during the last decades. Therefore, the growth of the same tree stock could not be analysed, but instead the current height of neighbouring old and young stands was compared. This way, we did not try to determine the exact quantity, but the direction of the change in height growth.

The comparison of the height growth performance of neighbouring old and young stands grown on the same

site conditions enables the understanding of how the changing climate, the fertilization effect of the CO₂-enriched atmosphere and nitrogen deposition influenced the height growth of trees. Since climate change became more rapid in the 1980s, the growth of young (30-35 years old) stands reflects the effect of atmospheric changes to a great extent. While these young stands developed entirely in the changed atmospheric conditions, the older trees lived only a part of their lifetime (with slower growth potential) in this changed environment. Consequently, the growth of the neighbouring old stands could serve as a comparison of the growth of young stands.

In this approach 28 stands along a climatic gradient were examined using a pair-wise comparison of the height growth of neighbouring old and young stands.

Our research questions were the following:

- 1) Has the height growth of sessile oak been accelerated or slowed down due to the counteracting effects of fostering and interfering atmospheric changes?
- 2) Is there a difference in height growth between the humid and more arid areas during the last three decades?
- 3) Is the height growth suppressed at the xeric limit of sessile oak, where frequent drought periods triggered mortality in the last decades?

MATERIALS AND METHODS

Study Area

The investigated 28 sessile oak sites are situated along the climatic gradient from the humid region in southwest Hungary to the continental-semiarid region in northeast Hungary (Figure 1).

The sites where neighbouring old (>50 old years) and young (<50 old years) stands were available for the pair-wise comparison of growth were selected. The mean age difference of the old and young stands was 61 years. The site

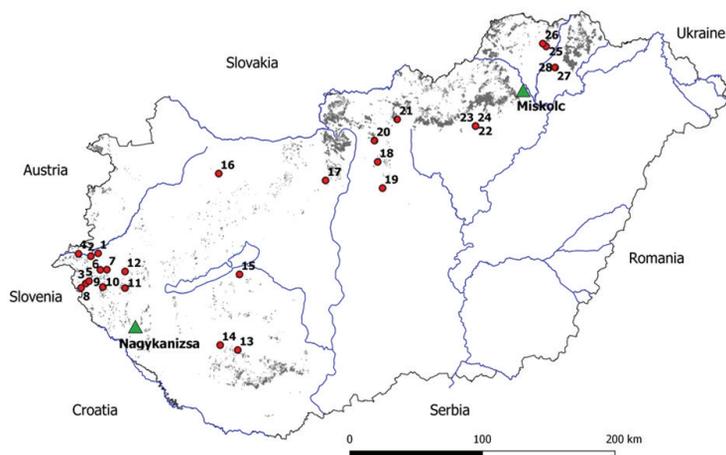


FIGURE 1. Selected sessile oak stands (circles), meteorological stations (triangles) and the distribution of sessile oak (grey) in Hungary.

conditions of the neighbouring stands could be considered similar. All selected stands are in zonal position with low topographic variability, and are situated on deep loamy soils (Table 1).

In Hungary there has been a gradual change from oceanic to continental influence on the climate which is modified by a mediterranean effect towards the southwest part of the country. This is reflected, for example, in the difference of summer precipitation sums by comparing the meteorological data of two official stations located in the Southwest (Nagykanizsa) and Northeast (Miskolc) of Hungary (Figure 1). A clear warming trend (0.46-0.52°C/decade) during the last three decades can be observed for summer temperatures, whereas contrasting trends (-4.3 mm/decade for Nagykanizsa and +18.8 mm/decade for Miskolc) are visible in the amount of summer precipitation (Figure 2).

Meteorological Data

To analyse the response of growth to climate change, the annual gridded data of the Ellenberg quotient (EQ) were obtained from the CARPATCLIM Database [22] for the period 1961-2010. The EQ has a good potential for describing the aridity limitation of forest stands in Hungary [23] and was thus used to describe the climate of the selected sites with a spatial resolution of 10 km (Equation 1, [24]).

$$EQ = \frac{T_{july}}{P_{annual}} \quad (1)$$

where T_{july} is mean temperature of July, and P_{annual} is annual precipitation sum.

TABLE 1. Site and stand characteristics.

Stand No.	Ellenberg quotient (EQ)	Soil type	Old stand				Young stand		
			Age (years)	Top height (m)	Relative top height (%)	Relative stand density (%)	Age (years)	Top height (m)	Relative top height (%)
1	28	Gleyic Luvisol	109	31.5	118	94	26	13.5	126
2	27.8	Gleyic Luvisol	62	23.1	109	90	25	13.6	132
3	26.9	Gleyic Luvisol	94	29.1	114	95	27	14.7	132
4	27.6	Gleyic Luvisol	122	30.6	114	92	32	16	122
5	27.2	Gleyic Luvisol	104	32.4	123	85	31	14.9	117
6	26.1	Gleyic Luvisol	94	31.8	125	92	28	15.5	135
7	26.1	Cutanic Luvisol	93	31.3	123	84	35	19.3	137
8	28	Cutanic Luvisol	99	31.7	122	94	26	15.8	148
9	27	Cutanic Luvisol	126	35.4	129	98	31	17.5	138
10	26.8	Cutanic Luvisol	125	34.7	127	101	26	15.7	147
11	26.4	Cutanic Luvisol	114	35.5	132	105	30	18.5	150
12	29.6	Cutanic Luvisol	115	34.6	128	81	32	15.5	119
13	28.6	Cutanic Luvisol	101	31.9	122	89	25	16.7	162
14	29	Cutanic Luvisol	51	25	133	90	26	17	159
15	31.9	Cambisol (Humic)	79	24.3	102	69	45	18.3	106
16	30.3	Cambisol (Humic)	96	26.3	102	98	25	12.8	124
17	35.8	Cambisol (Humic)	98	22.4	87	73	46	17.4	99
18	34.9	Cambisol (Humic)	116	26.2	97	68	25	12.6	122
19	35.6	Cambisol (Humic)	64	21	98	79	30	14.3	116
20	35.1	Cambisol (Humic)	79	20.5	86	62	31	12	92
21	32.5	Cambisol (Humic)	70	22.7	101	77	25	12.7	123
22	36.2	Luvic Chernozem	60	18.7	90	65	34	13.1	95
23	36.6	Luvic Chernozem	98	16.6	64	62	33	12.9	96
24	31.8	Luvic Chernozem	105	22.6	86	80	31	12.5	98
25	34.1	Luvic Chernozem	64	23	107	83	29	15.8	133
26	34.3	Luvic Chernozem	67	20.5	93	89	29	15.5	130
27	38	Luvic Chernozem	77	18.4	78	71	26	12.4	112
28	37	Luvic Chernozem	71	19.9	88	75	41	16.3	102

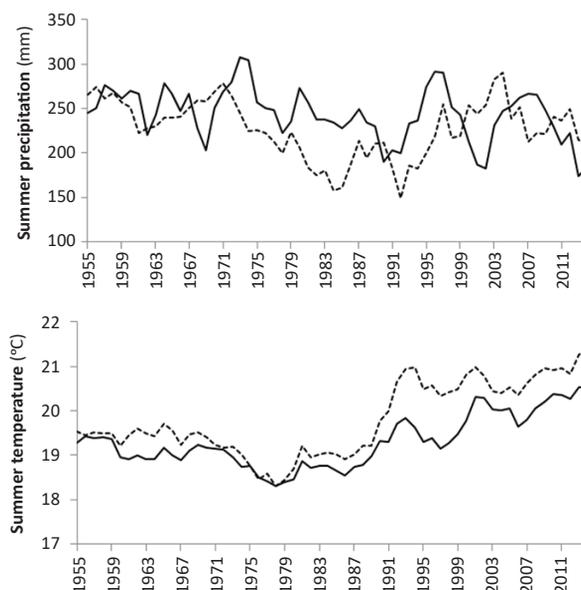


FIGURE 2. Trends in summer (J-J-A) precipitation and temperature for Nagykanizsa (solid line) and Miskolc (dotted line) meteorological stations for 1955-2016; curves are smoothed by 5-years moving average.

Topographical differences may cause differences in micro-climate conditions between the gridded data and the study sites. For that reason, special care was paid to select flat, zonal sites that might help to reduce the bias.

Stand Height Analysis

In each pair of old and young stands stand top height was measured to calculate the relative stand top height using the yield tables of sessile oak in Hungary [21].

The height of the visually highest 25 trees of each stand was measured using a TruPulse 200 laser instrument (Laser Technology, Inc., Colorado 80112 USA), after which the stand top height was considered as the mean value of the highest eight trees. Relative stand top height was calculated as the ratio of the current stand top height and the age-dependent height value of the average yield class (III). This refers to the overall height growth performance of the stands up to the given age [25]. To illustrate the height growth differences of the old and young stands their relative stand top heights were compared as functions of the EQ. To test if the stand top height values differ a one-way t-test was used. Additionally, the ratio of relative top heights was presented to show the differences of height growths of the young and old stands.

Relative Stand Density

Current stand density (trees·ha⁻¹) was estimated for old stands, after which relative stand density (Equation 2, [8]) was calculated to evaluate forest decline as a function of the EQ:

$$D_{rel\%} = \left(\frac{D_{cu}}{D_{fu}} \right) \quad (2)$$

where: $D_{rel\%}$ is relative stand density, D_{cu} is current stand density, and D_{fu} is fully stocked density (depending on the average stand diameter).

RESULTS AND DISCUSSIONS

Using the average yield class (III) of sessile oak as a reference allowed the analysis of the effect of climate change on the relative stand top heights which are decreasing with increasing aridity, i.e. higher Ellenberg quotient (Figure 3).

While the highest stand top heights are characteristic on areas where the climate is humid and the soil conditions are the most favourable (EQ<30), the lowest top heights can be found in the driest sites (EQ>35) where moisture availability limits growth. Interestingly, the top heights are lower in more humid areas (EQ<29) due to less favourable soil conditions (Gleyic Luvisol) (Table 1).

The pair-wise comparison of the results showed that the relative top heights of the young stands were significantly higher than of the older stands ($t=7.04$, $p<0.01$), which means that the overall growing conditions were better in the last 30-35 years than the mean conditions during the lifetime of the old stands (Figure 3). The ratio of relative stand heights of the young and old stands were above unity in 26 stands with a mean value of 1.15 (Figure 4).

Surprisingly, the height growth of sessile oak has accelerated even towards the dry sites. Furthermore, the young stands have an increasing growing tendency (around +15% compared to the old stands). Since the growth of the old stands used as a reference has probably increased in the last decades, the real increase in the height of the young stand is higher than 15% as well.

According to our results, the height growth was accelerated even in dry regions although there was significant mortality (mainly middle-aged and old stands) in these regions due to extreme droughts during the last decades [8]. In a recent study (for further details see [18]) we have already determined the relative stand density for 17 old

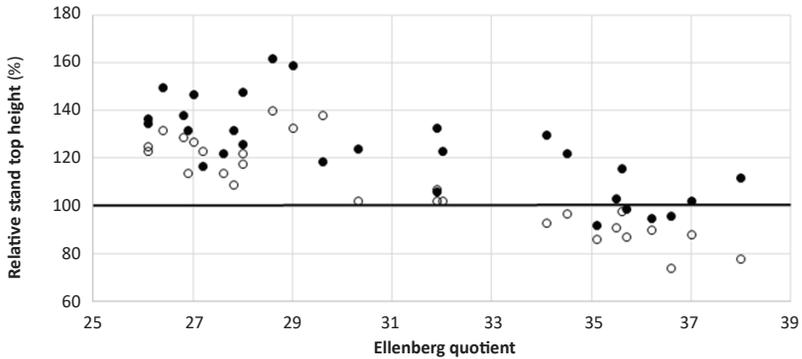


FIGURE 3. Relative stand top height of old (white circles) and young (black circles) stands as a function of Ellenberg quotient.

stands of this present study. We completed the available data with the measurement of the relative stand density in the missing 11 sites applying the same methodology. The comparison of the relative density and relative top height of the stands revealed that a significant difference of the relative stand density of sessile oak has emerged between humid and dry sites (Figure 5).

As a result of forest decline in dry sites, the relative density reduced to 60-70%, while it remained at about 90% in humid regions. The parallel processes of declining relative stand density and accelerated height growth in dry sites are seemingly contradictory but not implausible progressions in forest ecosystems.

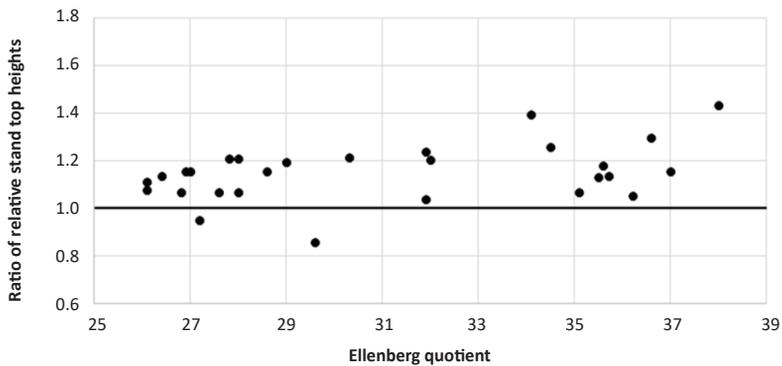


FIGURE 4. The ratio of relative top heights of young and old stands as a function of Ellenberg quotient.

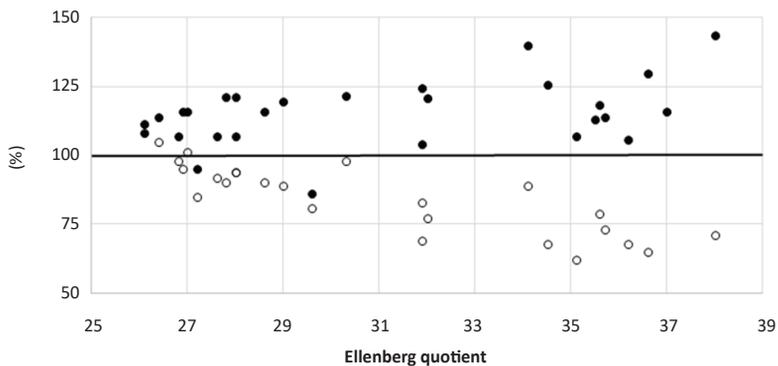


FIGURE 5. The ratio (in %) of relative top heights of young and old stands (black circles) and relative stand density of old stands (white circles) as a function of Ellenberg quotient.

CONCLUSIONS

Although extreme drought events associated with climate change caused periodic mortality at the xeric distributional limit of sessile oak, the effects of all atmospheric changes generated accelerate height growth.

Furthermore, our results do not support the fact that the excess nitrogen deposition fosters growth of trees primarily and only on low nitrogenous soil with sufficient water supply [11], since the height growth of trees on nitrogenous soil in humid climate is not greater than that of on humus-rich soils in drier climate.

Although there was an acceleration of growth in the last decades despite the increased frequency of droughts, this does not mean that growth acceleration will continue to be characteristic in the future since climate models show an increasing tendency of dry extremes in Hungary [26] which may overrule the positive effect of atmospheric changes.

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