Northern red oak (*Quercus rubra* L.) as a species suitable for the upcoming seasons with frequent dry periods

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Abstract

Northern red oak (*Quercus rubra* L.) has higher tolerance to dry periods and to lower soil nutrient content. It seems to be more resistant to tracheomycosis and therefore it should be considered as a promising species on selected forest sites. The research plots are situated in the Louny region with significant rainfall deficit; good model area for future expected climatic changes. New plantation of northern red oak and sessile oak on together 10 subplots with 500 plants were measured between 2015 and 2019. Results proved significant level ($\alpha = 0.05$) of better height growth of northern red oak as well as higher resistance to dry periods (lower mortality). Lang's Rain Factor proved to be a good indicator of difficult climatic condition during growing seasons and therefore could be used for realistic evaluation of possible success or failure of artificial regeneration.

Key words: climatic changes; regeneration; height growth; Lang's Rain Factor

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1. Introduction

Northern red oak is characterized by higher tolerance to dry sites, even the climatic conditions at the original sites of northern red oak include annual precipitation totals between 700 – 2030 mm. Annual average temperature of this area is between 4 and 16 °C (Sander 1990). In Europe, this species usually grows at altitudes of 250 – 800 m s.l. (Nagel 2015) with annual rainfall of only 500 – 550 mm per year (Nagel 2015; Burkardt 2018). The species shows higher resistance to low rainfall than sessile oak and pedunculate oak (Durand et al. 1983; Timbal & Dreyer 1994; Dressel & Jäger 2002). The physiological explanation for this tolerance is that northern red oak leaves have a higher tolerance to water scarcity, mainly because they have a higher stomata density on the leaf than domestic oaks (Timbal & Dreyer 1994) and species can thus respond more efficiently and quickly to water deficits. The species is also significantly more resistant to very low temperatures, with temperatures up to –30 °C or even –40 °C (Brus 2011). It is also resistant to late spring frosts as it sprouts later than domestic oaks (Jacamon 1987). On the other hand, this tree often tends to form forks, which is a consequence of the higher number of terminal buds and therefore it is necessary to take into

account this problem especially in young stands and possibly to pruning and form a crown of young oaks in time. Also in autumn, especially in the case of young trees, there is a risk of the crown breaking, as the dry leaves persist for long periods on the branches and can cause considerable damage if larger amounts of wet snow occur.

Northern red oak is reported in the literature as a species, which is suitable for arid and semiarid areas, as it copes well with the lack of precipitation. According to these characteristics, northern red oak is suitable for expected climatic changes bringing a different distribution of precipitation with probably less total annual amount. Its resistance to air pollution and higher resistance to frost is also known (Miltner & Kupka 2016). According to a survey of the health status of oak stands, it appears that northern red oak is a species that is minimally damaged due to tracheomycosis (Štefančík 2011a). Northern red oak is considered a tree species with relatively easy natural regeneration, but requires frequent silvicultural interventions (Štefančík 2011b). At the same time, it is suitable at sites of high risk of soil erosion and soil degradation (Miltner & Kupka 2016). Northern red oak has a high wood production (Kupka et al. 2018). However, its drought tolerance is more important nowadays, and

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hence better regeneration (both natural and artificial) in areas with more frequent dry periods.

Many authors report lower northern red oak requirements for nutrient content in the soil (Bauer 1953; Miltner et al. 2016). Northern red oak plantations are therefore more productive, especially at poorer sites. Northern red oak tolerates acidic sandy soils, but also performs well on heavier gley soils. It does not prefer calcium rich soils, although it seems that with age its tolerance to higher calcium content increases. Sites with high levels of groundwater are also unsuitable. In general, deeper soils slightly acidic with a minimum calcium content are suitable for northern red oak.

The root system of northern red oak is similar to that of domestic oaks. The young tree has a well-developed tap root, which in five years can reach a length of up to 70 cm, later forming a cordial root system (Bauer 1953; Nagel 2015). Later, significant lateral roots are formed, which extend to a considerable distance from the trunk, creating a solid root system that resists wind damage (Timbal & Kremer 1994; Réh & Réh 1997). Root system is growing throughout the whole growing season without interruption during summer period (Dickson 1994; Hubert 1994).

Further work has also shown the effect of light periodicity on the growth of seedlings (Guo et al. 2001). This study has shown that after the first year, when the plant needs more protection from full sunlight, from the second year its development is significantly better if it has sufficient light (Guo et al. 2001). This is important to keep in mind when planning the regeneration of this species, whether natural or artificial.

Appropriate density of mature stand is an important issue when applying management methods of shelterwood systems. Spetich et al. (2002) studied the influence of parent stand density on the growth of oak seedlings. The experiment was carried out with the plantation of two-year bare-root oak seedlings. At a basal area stocking of 0.8, at a collar root diameter of 6 mm, only one in 144 seedlings was fully vital after 11 years. Using thicker and older seedlings (collar root diameter of 22 mm), this ratio was one in five at the same stocking. A similarly beneficial effect on the growth of undergrowth or underplanting is the opening of the canopy by removing the secondary stand (Craig et al. 2014). Similar results were obtained by Hartman et al. (2005), which recommends reducing the crown canopy to 25% of the full canopy. After that he achieved the highest seedlings density of natural regeneration. Also, Dey (2014) emphasizes that in order to preserve the oak in the stands, care must be taken to maintain it at a level so that it can be naturally regenerated. Major et al. (2013) when assessing the natural renewal of northern red oak in the NW Germany found that the crown canopy is not the main limiting factor, but it is also an undergrowth with an average height of about 2 m, which influences the northern red oak regeneration. It is therefore recommended to remove this undergrowth

component after the seed year (Major et al. 2013). Also Hart et al. (2012) concluded that strong competition of red maple (*Acer rubrum*) makes it impossible to restore northern red oak and without maple reduction this species gradually disappears from stands in the eastern US. These findings are confirmed by another study that looked at the development of the species composition 30 years after final cutting (Gould et al. 2005). This study confirmed that oak seedlings have significantly higher aboveground biomass and greater leaf area index LAI than seedlings growing under the shade under the upper layer. Schweitzer & Dey (2011) also noted in their study that the manipulation of the crown canopy significantly influenced the species composition of the regeneration. Active intervention is required to keep the northern red oak in the new regeneration.

Another option for regenerating northern red oak is the clear-cutting. Meadows & Stanturf (1997) or Fan et al. (2015) state that the most successful natural regeneration of northern red oak can be achieved after clear-cutting. Shelterwood cutting or leaving seed trees will not ensure uniform regeneration over the entire area. Selective cutting is not suitable for this species. Also Aldrich et al. (2005) confirmed the long-term observation (since 1926) of the species composition of mixed oak stands that its gradual reduction takes place if no clearcut is performed in the stands. Collins & Battaglia (2002), who used a small scale, group like clearcuts with a radius of 7, 10, 14, 20, 29 and 40 m on which randomly spaced acorns sown under the hoe, also investigated the appropriate cutting size. The survival rate was 21–37% in the first year and only 8–26% in the second year. The size of germinated seedlings and the size of their assimilation apparatus in the first year after germination had a more significant effect on mortality than the size of the gap cutting. In terms of micro-relief, the survival rate was slightly higher for acorns planted on higher sites than on depressions. Here, too, the importance of light for the survival of oak seedlings is confirmed.

Also Elliott & Knoepp (2005) assessed the effect of different regeneration cuttings in oak stands this time on the physical condition of the soil and nutrient content. Their work also recommends the use of (small) gap cutting, rather than the shelterwood cutting, both in terms of the physical condition of the soil after the many travels of harvestors, and in terms of accessibility of the main soil nutrients.

Northern red oak is often cited as an example of an invasive species. Available literature suggests that its capacity for natural seed regeneration is site dependent (Healy et al. 1999). On poor sites, it becomes abundant and may have an invasive character, while on richer soils it is significantly less invasive (Henin & Vandekerckhove 2016).

The aim of this study is to assess the regeneration of northern red oak and its growth in the first years after planting under given climatic conditions of recent years

in an area characterized by longer dry periods. It also assesses the value of the Lang's rain factor to evaluate local climatic conditions.

2. Material and methods

The Louny region of northern Bohemia is made up mostly of areas lying in the rain shadow of the Ore Mountains with a significant rainfall deficit. It is therefore a model area in terms of expected climate change. Established research areas consist of 5 single-sub-areas for each species in a random arrangement in one site with a total area of 20×50 m. The surrounding edge of research area planted by the same species varies between 1 to 2 m to avoid side effect. Research plots are established near Holedeč and basic information are given in Table 1.

Table 1. The basic data on research plot.

Species	Forest site	Altitude [m a.s.l.]	Average size of plant [cm]
Red oak	1C5*	220	30
Sessile oak	1C5*	220	32

Note: * *Carpineto-Quercetum*.

Two-year seedlings of bare-rooted (1+1) were planted in spring 2015. Spacing of the seedlings were $1.3 \text{ m} \times 1.3 \text{ m}$. The area is fenced to eliminate the negative effects of game. The differences between the height of red oak and sessile oak seedlings were statistically insignificant. Established plots with planting of red oak seedlings were monitored and measured in autumn in the years 2015 – 2019. The total height and actual height increment with the precision of 1 cm were measured. Mortal-

ity and appearance vitality were evaluated. The average height of sessile oak and red oak were 44 cm and 45 cm respectively at the end of the year 2015.

The data was processed by statistical package STATISTICA. Non-parametric two-sample Kolmogorov-Smirnov test were applied on data sets to evaluate differences on significant level $\alpha = 0.05$ for $n_1 = n_2 = 250$.

The official meteorological data for the Ústí nad Labem region, where these areas are located, show the following annual aggregate data (Table 2).

3. Results

The first step in data processing was to evaluate climatic conditions which are definitively one of the key factor for survival rate and growth of new plantations. The graphs in Fig. 1 and 2 show the course of monthly temperatures and precipitation in individual years.

It is clear from the graphs that while the temperatures were very similar in these years, the volume of precipitation varied considerably from one year to the next and in particular 2018 and 2019 were very unfavourable in terms of precipitation. Although the red oak plantation were in good condition at that time and 3 – 4 years after planting, this unfavourable rainfall balance was reflected in them. Although precipitation in 2018 is higher than in 2016, temperatures are also higher, especially in spring (April May) and summer (July and August). In terms of precipitation, 2018 was therefore more favourable than 2016. However, the results on experimental plots with oak do not confirm this. It is therefore necessary to use

Table 2. Meteorological data in the Ústí nad Labem area.

Year	Average year temperature [°C]	Annual precipitation [mm]	Precipitation in large season [mm]	Temperature in large season [°C]	Precipitation in main season [mm]	Temperature in main season [°C]
2015	9.5	591	467	13.0	281	16.3
2016	8.9	655	467	14.0	373	16.5
2017	8.9	667	500	13.1	414	15.2
2018	9.7	438	260	15.9	231	16.9
2019 ¹	10.9	384	384	13.5	275	16.6

Note 1: data for 2019 include data for 1 – 10 only months

Note 2: in accordance with bioclimatology, the following periods are considered here:

- large growing season with monthly temperatures higher than 5 °C
- main growing season with monthly temperatures higher than 10 °C.

Fig. 1. Monthly precipitation in the research area in the period 2015 – 2019.

Fig. 2. Average month temperature in the research area in the period 2015 – 2019.

a different climatic characteristic, namely Lang's Rain Factor (LRF).

It takes into account the rainfall to temperature. Higher temperatures mean higher evapotranspiration and hence a higher need for precipitation to maintain the same vegetation conditions. The LRF value for the whole year is 73.60 for 2016, but only 45.15 for 2018, which is only 61.3% of the 2016 value. Even greater differences in these years are noticeable, considering only the growing season. In the large growing season, the values are 33.26 (2016) and 16.38 (2018) which represents only 49.2% of 2016. The same situation is for the main growing season where the LRF is 22.55 (2016) and 13.68 (2018) which is again only 60.7%. The figures are given more clearly in Table 3.

Table 3. Lang's Rain Factors for period of the years 2016 and 2018 for research area.

Year	Year LRF	Large growing LRF ¹	Main growing LRF ²
2016	73.60	33.16	22.55
2018	45.15	16.38	13.68

Note:

¹ – large growing (season) is the period with average day temperature higher than 5 °C;

² – main growing (season) is the period with average day temperature higher than 10 °C.

These unfavourable conditions were indeed reflected in the research plots, as shown in the following graphs. Even the relative mortality rate is lower for red oak in the first three years after planting (2015 – 2017), these dif-

ferences were not pronounced distinctly (Fig. 3). In 2018, however, there is a significant break (due to unfavourable climatic conditions), when the relative mortality of sessile oak reached almost 29%, while in red oak plantation it was only 11%, i.e. just over a third of the mortality of domestic oak.

Similar differences are also evident in the height development of plantations (see Fig. 4).

While the seedlings were nearly identical in height at the time of planting (2015), their development in the first two years after planting was not different on significant (level $\alpha = 0.05$; $D_2 = 0.089 < D_{2max} = 0.121$). Year 2018 markedly slowed down the growth of sessile oak due to unfavourable climatic conditions, while red oak growth decreased only slightly. From that year differences between these two species and this differences were statistically significant level ($\alpha = 0.05$; $D_2 = 0.132 > D_{2max} = 0.121$). The same picture could be recognised for height increment where the differences are significant even for level $\alpha = 0.01$ ($D_2 = 0.150 > D_{2max} = 0.146$). These differences persist till the last year (2019).

4. Discussion

Planting is in a semi-arid area at an altitude of 220 m. a.s.l. This is an area suitable for growing oak. Planting mortality in our plots was significantly lower in the first year (see Fig. 3), than reported by Jacobs et al. (2005),

Fig. 3. Mortality in new plantation of red oak and sessile oak.

Fig 4a. Height growth of red oak and sessile oak in the period of 2015 – 2019.

Fig 4b. Height increment of red oak and sessile oak.

where the mortality rate of unfertilised seedlings is up to 40%, while in our areas the mortality rate was 18% for sessile oak and 11% for red oak. This is in line with the recommendation of Oswalt et al. (2006) – sort out poor-quality seedlings before planting – which was also done in this case. This will save the cost of planting seedlings that do not have a high chance of survival.

No herbicide was used to reduce the weed, but only mechanical reduction was applied. The aim was to obtain data that are not affected by the application of chemicals, as some studies have pointed out (Demchik & Sharpe 2001; Schreffler & Sharpe 2003; Schuler & Robinson 2006).

The height growth of oak seedlings in our plots was very similar to the findings published so far (e.g. Spetich et al. 2002; Hartman et al. 2005; Craig et al. 2014) although some of them give data for the development of seedlings under mature stand and not in the open area, as in this case (see Fig. 4).

It is also clear from the graph in Fig. 4 that red oak grew better than sessile oak and from 2017 (2 years after planting) it started to reach statistically significantly higher average height than domestic sessile oak. This is even more evident in the adjacent graph of the same figure where the height increments are expressed. Since 2017, they are significantly higher than those of domestic oak.

The results proved the advantages of red oak plantations in terms of height growth and lower mortality in semi-arid and arid climatic conditions. They indicate the

shorter time for safe reforestation which could be important advantages in near future.

Climatic characteristics (precipitation and temperature) co-determine the success of afforestation. The LRF can serve as a suitable criterion for assessing local climatic conditions and their impact on the field performance of seedlings and hence for a more objective assessment of the quality of planting.

5. Conclusions

The results of surveys on research plots with sessile oak and red oak plantations confirmed that in areas with higher temperatures and lower precipitation as expressed by Lang's rain factor, red oak can be successfully grown, showing better resistance to dry climatic conditions than domestic oaks in both growth and field performance first years after planting. With regard to the current development of basic climatic characteristics, it is necessary to consider adaptation to these conditions also with regard to species composition changes in our forests.

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References

- Aldrich, P. R., Parker, G. R., Romero-Severson, J. et al., 2005: Confirmation of oak recruitment failure in Indiana old-growth forest: 75 years of data. *Forest Science*, 51: 406–416.
- Bauer, F., 1953: Northern red oak. Frankfurt am Main, Sauerländer, 108 p.
- Brus, R., 2011: Dendrology for Foresters. Ljubljana, Univerza v Ljubljani, Biotehniška fakulteta, 408 p.
- Burkardt, K., 2018: Kurzportrait Roteiche (*Quercus rubra* L.). Available at https://www.waldwissen.net/waldwirtschaft/waldbau/wuh_roteiche/index_DE (accessed May 6, 2018).
- Collins, B. S., Battaglia, L. L., 2002: Microenvironmental heterogeneity and *Quercus michauxii* regeneration in experimental gaps. *Forest Ecology and Management*, 155:279–290.
- Craig, J. M., Lhotka, J. M., Stringer, J. W., 2014: Evaluating Initial Responses of Natural and Underplanted Oak Reproduction and a Shade-Tolerant Competitor to Midstory Removal. *Forest Science*, 60:1164–1171.
- Demchik, M. C., Sharpe, W. E., 2001: Forest floor plant response to lime and fertilizer before and after partial cutting of a northern red oak stand on an extremely acidic soil in Pennsylvania, USA. *Forest Ecology and Management*, 144:239–244.
- Dey, D. C., 2014: Sustaining Oak Forests in Eastern North America: Regeneration and Recruitment, the Pillars of Sustainability. *Forest Science*, 60:926–942.
- Dickson, R. E., 1994: Height growth and polycyclism in northern red oak. In: Timbal, J., Kremer, A., Le Goff, N., Nepveu, G. (eds.): *Le chêne rouge d'Amérique*. INRA éditions, p. 131–140.
- Dressel, R., Jäger, E. J., 2002: Contributions to the biology of vascular plants of the Hercynian area. 5. *Quercus rubra* L. (northern red oak): life history and agriophytic spread in the Sächsische Schweiz National Park. *Hercynia*, 35:37–64.
- Durand, P., Gelpe, J., Lemoine, B., Riom, J., Timbal, J., 1983: The dieback of pedunculate oak in the Eastern Pyrenees. *Revue Forestière Française*, 5:367–386.
- Elliott, K. J., Knoepp, J. D., 2005: The effects of three regeneration harvest methods on plant diversity and soil characteristics in the southern Appalachians. *Forest Ecology and Management*, 211:296–317.
- Fan, Z. A., Yao, Q. I. B., Dey, D. C., Spetich, M. D., Ezell, A. B., Shifley, S. C. et al., 2015: Efficacy and associated factors of even- and uneven-aged management to promote oak regeneration in the Missouri Ozarks. *Forest Science*, 61:397–408.
- Gould, P. J., Steiner, K. C., Finley, J. C. et al., 2005: Development pathways following the harvest of oak-dominated stands. *Forest Science*, 51:76–90.
- Guo, Y. F., Shelton, M. G., Lockhart, B. R., 2001: Effects of light regimes on the growth of cherrybark oak seedlings. *Forest Science*, 47:270–277.
- Hart, J. L., Buchanan, M. L., Clark, S. L. et al., 2012: Canopy accession strategies and limeta-growth relationships in *Acer rubrum*. *Forest Ecology and Management*, 282:124–132.
- Hartman, J. R., Buckley, D. S., Sharik, T. L., 2005: Differential success of oak and red maple regeneration in oak and pine stands on intermediate-quality sites in northern Lower Michigan. *Forest Ecology and Management*, 216:77–90.
- Healy, W. M., Levis, A. M., Boose, E. F., 1999: Variation of red oak acorn production. *Forest Ecology and Management*, 116:1–11.
- Henin, J. M., Vandekerckhove, K., 2016: Belgium. In: Hasenauer, H., Gazda A., Konnerth M., Lapin K., Mohren G.M.J., Spiecker H. (Eds.): *Non-Native Tree Species for European Forests: Experiences, Risks and Opportunities*. In: FP 1403 NNEXT Country Reports, Joint Volume. Vienna, University of Natural Resources and Life Sciences, p. 20–31.
- Hubert, M., 1994: Tree shaping and pruning. In: Timbal, J., Kremer, A., Le Goff, N., Nepveu, G. (eds.): *Le chêne rouge d'Amérique*. INRA éditions, p. 247–253.
- Jacamon, M., 1987: *Dendrology Handbook*. Vol. II. Broadleaves. Paris, Ecole Nationale du Génie Rural, des Eaux et des Forêts, 256 p.
- Jacobs, D. F., Salifu, K. F., Seifert, J. R., 2005: Growth and nutritional response of hardwood seedlings to controlled-release fertilization at outplanting. *Forest Ecology and Management*, 214:28–39.
- Kupka, I., Baláš, M., Miltner S., 2018: Quantitative and qualitative evaluation of Northern red oak (*Quercus rubra* L.) in arid areas of North-Western Bohemia. *Journal of Forest Science*, 64:53–58.
- Major, K., C., Nosko, P., Kuehne, Ch., 2013: Regeneration dynamics of non-native northern red oak (*Quercus rubra* L.) populations as influenced by environmental factors: A case study in managed hardwood forests of southwestern Germany. *Forest Ecology and Management*, 291:144–153.
- Meadows, J. S., Stanturf, J. A., 1997: Silvicultural systems for southern bottomland hardwood forests. *Forest Ecology and Management*, 90:127–140.
- Miltner, S., Kupka, I., 2016: Silvicultural potential of northern red oak and its regeneration—Review. *Journal of Forest Science*, 62:145–152.
- Miltner, S., Kupka, I., Třeštík, M., 2016: Effects of Northern red oak (*Quercus rubra* L.) and sessile oak (*Quercus petraea* (Mattusch.) Liebl.) on the forest soil properties. *Lesnický časopis- Forest Journal*, 62:169–172.
- Nagel, R. V., 2015: Northern red oak. In: Vor, T., Spellmann, H., Bolte, A., Ammer, C. (eds.): *Potentials and risks of introduced tree species*. Göttingen, Göttinger Forstwissenschaften, p. 219–267.
- Oswalt, Ch. M., Clatterbuck, W. K., Houston, A. E., 2006: Impacts of deer herbivory and visual grading on the early performance of high-quality oak planting stock in Tennessee, USA. *Forest Ecology and Management*, 229:128–135.

- Réh, J., Réh, R., 1997: Dub červený (*Quercus rubra* L.), jeho vývoj struktura a rastové procesy vplyvom prebierok a možnosti využitia jeho dreva v drevozpracujúcom priemysle. Vedecké štúdie TU vo Zvoleně, č. 2/1997/A, Zvolen, TU, 71 p.
- Sander, I. L., 1990: Northern red oak (*Quercus rubra* L.). In: Burns, R. M. and Honkala, B. H. (eds.): Silvics of North America. Vol. 2. Hardwoods. Handbook no. 654. Washington, D. C., USDA, Forest Service, Department of Agriculture, p. 727–733.
- Schuler, J. L., Robison, D. J., 2006: Stand development and growth responses of 1 –and 3-year-old natural upland hardwoods to silvicultural treatments. *Forest Ecology and Management*, 232:124–134.
- Schreffler, A. M. et al., 2003: Effects of lime, fertilizer, and herbicide on forest soil and soil solution chemistry, hardwood regeneration, and hardwood growth following, shelterwood harvest. *Forest Ecology and Management*, 177:471–484.
- Schweitzer, C. J., Dey, D. C., 2011: Forest structure, composition and tree diversity response to a gradient of regeneration harvests in the mid-Cumberland Plateau escarpment region, USA. *Forest Ecology and Management*, 262:1729–1741.
- Spetich, M. A., Dey, D. C., Johnson, P. S., 2002: Competitive capacity of *Quercus rubra* L. planted in Arkansas Boston mountains. *Forest Science*, 48:504–517.
- Štefančík, I., 2011a: Štruktúra a vývoj porastov duba červeného (*Quercus rubra* L.) s rozdielnym funkčným zameraním, *Lesnícky časopis–Forestry Journal*, 57:32–41.
- Štefančík, I., 2011b: Výsledky výskumu neceloplošnej výchovy dubového porastu z prirodzenej obnovy, *Zprávy lesnického výzkumu*, 56:255–264.
- Timbal, J., Dreyer, E., 1994: Water consumption and drought resistance. In: Timbal, J., Kremer, A., Le Goff, N., Nepveu, G. (eds.): *Le chêne rouge d'Amérique*. INRA éditions, p. 85–90.
- Timbal, J., Kremer, A., 1994: Root system. In: Timbal, J., Kremer, A., Le Goff, N., Nepveu, G. (eds.): *Le chêne rouge d'Amérique*. INRA éditions, p. 48–51.