Growth and productivity of red oak (Q.Rubra L.) forest cultures in the North-West Caucasus

Ekaterina Kulakova[1*] and *Nelli* Kartashova[1]

[1] Voronezh State University of Forestry and Technologies named after G.F. Morozov, 8 Timiryazeva Street, 394087, Voronezh, Russian Federation

Abstract: The paper presents the results of the study of red oak (Q. rubra L.) cultures located on the territory of «Kurjip district forestry» of the Republic of Adygea (western part of the North Caucasus). The characteristic of red oak is given as a tree species, less demanding to soil conditions in comparison with other forest-forming species and possessing high decorative properties, due to which it is used for solitary plantings, as hedges along highways, arrays in parks, squares and other objects of landscape architecture. It combines well both in pure plantings and in combination with petiole oak, hornbeam and aspen. Red oak can grow on sandy loam and loamy podzolic soils without stagnant moisture, mainly on the banks of rivers, it grows worse on calcareous soil. The tree species due to well-developed root system is resistant to wind, also characterized by good resistance to damage by entomo- and phyto-pests. The growth and productivity of red oak and related species were analyzed in the work, and the graphs of growth progress by height and diameter of crops were plotted. It was found that in more favorable growing conditions red oak is not inferior to petiole oak in growth and productivity. **Keywords:** North-West Caucasus, Forest Cultures, Red Oak, Common Oak, Non-Native Species, Growth, Productivity.

1 Introduction

The Forest Code of the Russian Federation provides for the improvement of the composition, resource and ecological potential of forests. Introduction is a significant factor in increasing the productivity and species diversity of forest ecosystems. One of the fastest growing oak species - red oak - is of interest for the study region. Red oak (Q. rubra L.) is a North American introduction, which was brought to Europe at the end of the XVII century and became widespread on the European continent. And everywhere this species shows itself as a fast-growing tree species. It has been cultivated in forestry in the Northwest Caucasus since the sixties of the XX century and has not been studied to the end [1-5].

Red oak is the most widespread North American oak in culture. It is found in cultivation in the Leningrad Region, Moscow Region, Rostov Region and the North Caucasus. It is a tree species that reaches a height of 20-40 m with quite strong wood and high decorative properties. Compared to petiole oak, it is less demanding to soil fertility.

* Corresponding author: kulakova_92@list.ru

Forest ecosystems are projected to change dramatically under the impact of climate change, in particular due to expected declines in the distribution of key tree species. Adaptation of forests is both necessary and urgent. In addition to native tree species, introduced species are used for adaptation, in particular red oak, which is one of the dominant species based on its biological and ecological characteristics. An important condition for adaptation of any introduced species in the secondary habitat is its resistance to various unfavorable environmental factors. Let us consider several of them: winter hardiness, drought resistance, gas endurance.

According to a number of authors, adult red oak trees are not damaged by low temperatures, and in its natural habitat it tolerates low temperatures down to -38°C (Fowels, 1963), in Germany -41°C, and in Russia down to -45°C (Kryukov and Belyaev, 1981). Nevertheless, young plants are often damaged by low temperatures. In A.V. Smorodin's research from 1994 to 1996, significant damage to red oak seedlings of various origins was recorded (Smorodin, 2000). In the experiment on testing different oak species, red oak and downy oak were the most damaged (16.9-17.2%) [6-15].

The second important factor is drought resistance through water regime indicator. According to the water regime indicator, during the second most stressful period of vegetation in the temperature gradient of 20-36°C, drought resistance was determined in introduced and native species (Maltsev, 1954, Smorodin, 2000). Drought resistance consists of the ability of plants to tolerate dehydration and overheating (Genkel, 1978). As shown by analysis of variance, there are no differences between species, and the irreversible limit of dehydration (lethal water deficit) is 1.3-2.0 times lower in exotics than in native species. Red oak is better adapted to temperate climate, so its productivity is higher in these conditions. In extreme conditions, under prolonged exposure to unfavorable factors, it undergoes destruction more than local species, the intensity of its growth processes is equalized and even inferior to local species.

Therefore, it is advisable to introduce red oak into forestry in the North Caucasus mainly only in mountainous and foothill zones, where there are no long-term soil and air droughts and dry winds [16-30].

The third factor is the red oak's gas endurance. Red oak is successfully used in landscaping in the cities of Krasnodar Krai, and the emissions from numerous cars do not have a depressing effect on its growth processes. Red oak is the most resistant to smoke emissions (Höfker, 1924). In terms of resistance to sulfur dioxide gas, northern oak is inferior to white acacia in Bulgaria (Prokopyev, 1957), and superior to it in Austria (Egger, 1966). According to chamber tests, northern oak is among other oaks very resistant (Antipov, 1979). In Germany it is resistant to smoke in the industrial area of Rhine-Westphalia (Bauer, 1953). It is recommended for use in smoky and gassy areas (Sobosky, 1967).

Resistance of red oak to salt accumulation is probably insignificant. There are no recorded cases of growing on saline soils in the study region. Its resistance to salt accumulations in soil is not mentioned in the literature. It is only known to avoid carbonate content in soil (Cairn, 1939). The presence of 4.2% limestone in the root-inhabited layer of soil up to 60 cm and 12-34% from the depth of 60-80 cm is relatively harmless for it (Kleiber, 1954), but the concentration of 7.2% in the upper 30 cm layer is fatal, so it is recommended to plant it on soils with carbonate layer deeper than 30 cm (Timbal, Galpe, 1989). Speaking about resistance of red oak to pests and diseases, it is higher than that of local species. Pests of local oaks do not cause it any noticeable harm. It has absolute immunity to powdery mildew.

Under the conditions of the North Caucasus, red oak is a rather light-loving species, requiring lateral shading and not tolerating overhead shading. In a fruit-bearing plantation under favorable conditions, self-seeding appears almost everywhere. In a 30-year old

plantation 5-7 year old self-seeding was found. Trees of boreal oak in a timely not thinned plantation with dense planting and wide row spacing, bending, occupy all light niches. Consequently, adult trees are quite light-loving.

One of the main signs of successful adaptation of an introduced species is the preservation of reproductive capacity and the formation of good quality seeds. Red oak in the Northwest Caucasus blooms in the third decade of April, later than the early and earlier than the late form of petiole oak. Its reproductive process is insufficiently studied. Most authors believe that the exotum enters the reproductive phase from 20-30 years of age (Hutiev, 1975; Demyanov, 1978) and only in old-growth stands from 11-14 years of age (Prikladovskaya, 1979; Sirotkin, Uglyanets, 1990). Red oak bears fruit almost annually (after one year) and abundantly, while petiole oak fruits once every 5-7 years (Alentyev, 1990). Up to 60 kg can be harvested from a freestanding tree, and up to 1000 kg/ha of acorns can be harvested from a formed FLSU. Red oak is propagated by seeds and shoots from the stump (up to 15 or more shoots reaching 2.5-4.0 m in the 3rd year).

It is worth noting that species diversity is increasing due to human economic activity. The role of Quercus species in forest communities is important not only in the North Caucasus, but also in other regions of the Russian Federation (Bolotov, Shcheglov, Belyaev, 2014). It is one of the main forest forming species. Oak forests are represented mainly by petiole oak (Q.robur L.), rock oak (Q. retgaea L.). In the lower belt of oak forests up to 700 m above sea level and along river valleys, the petiole oak grows, and at higher altitudes (mountain belt) - rock oak (Zhurikhin, Zhurikhina , 2013). Red oak (Q. Rubra L.), an adventive species, has taken good root in the climatic conditions of the study region. Red oak has been planted since the 1960s during artificial afforestation, and later it actively spread itself, sometimes displacing native species (Kotovsky, 2018).Objective: To analyze the growth and productivity of forest cultures of Kurjip district forestry of the Republic of Adygea with predominance of red oak and associated tree species.

2 Materials and Methods

The research was conducted on the territory of the Maikop forestry, Kurjipsky district forestry of the Republic of Adygea. It is on the territory of this forestry district that numerous red oak cultures grow. It should be noted that plots with optimal forest conditions for oak growth - fresh oaks forest (D2) - were selected for the study. The undergrowth includes hazel, elderberry, hawthorn and Caucasian hawthorn. The research is based on the method of comparison and analysis (Kulakova, 2015, 2019). Soil cover is represented by gray forest soils, in some places there are sod carbonate soils on limestone and dolomite.

The research is based on the method of sample areas. The sample plots were laid taking into account the requirements of OST 56-69-83. 5 permanent trial plots (PTPs) of 0.25 ha each were laid. Before laying the sample plots, a reconnaissance survey of plantations was conducted to determine their general condition (Kalinichenko, 2000). The main taxation indicators of the stand - age, height, tree stem diameter, fullness and stock - were determined at the PTPs. A complete enumeration of trees was carried out with distribution by species, thickness levels and condition categories.

The thickness stage size was determined depending on the average diameter of the tree: thus, for diameters from 6.1 to 16 cm the step was taken as 2 cm, for average diameters of 16.1 and more - 4 cm. A measuring fork was used to measure the trunk diameter at a height of 1.3 m, a SUUNTO PM-5/1520PC altimeter was used to determine the height, and an age drill was used to determine the age. The taxation characteristics of red oak cultivars are presented in Table 1.

Table 1. Characterization of red oak forest cultures of Kurdjipsky forestry area

№ permanent trial plots (PTPs)	№ quarter / stratum	The composition of the forest plantations	Age, Years	Height, m	Dbh, cm	Guality classes / Fullness	Stock, m^3/ha	Increment, m^3/year
1	5/5	6 Red Oak	32	12	12	I / 0,7	88	2,75
		4 Common Oak		13	14		59	1,84
2	5/32	6 Red Oak	32	12	12	I / 0,7	2	0,06
		4 Common Oak		13	14		2	0,06
3	5/37	6 Red Oak	32	12	12	I / 0,7	5	0,2
		4 Common Oak		13	14		3	0,16
4	5/38	6 Red Oak	32	12	12	I / 0,7	3	0,16
		4 Common Oak		13	14		2	0,06
5	5/14	5 Red Oak	50	17	20	II / 0,8	75,43	1,51
		2 Common Oak		17	20		26,12	0,52
		1 Caucasian hornbeam		15	16		3,50	0,07
		2 Aspen		20	28		38,98	0,78

3 Results and discussion

The growth rate of artificial plantations (forest crops) is reflected in the value of their average growth through the stock. The maximum value of growth was found in red oak stands (Quarter 5, Stratum 5) - at the age of 32 years the average growth is 2.75 m3/ha per year, and the minimum value was observed in Quarter 5, Stratum 32, where by the age of 32 years the increment growth is 0.06 m3/ha per year. It should be noted that at the same stand completeness (0.7-0.8) and forest cultures age there is a noticeable variability (within one order of magnitude) in both raw wood stock and current wood increment from 0.06 to 2.75 m3/ha/year, which most likely reflects the influence of the limiting factor of soil fertility. The influence of soil-vegetation conditions is clearly manifested in the plantation on PTPs N 2, established on low power-carbonate soils formed on limestone and dolomite.

Moreover, the growth intensity of red oak is a complex reaction to the influence of not only external, but also internal factors, and the study of this reaction in different growing conditions gives an idea of its integral stability and productivity in this region and can be a prerequisite for the success of its culture.

The growth characteristics of red oak were studied in an experiment laid in 1995 against the background of local species of common oak, sessile oak, Hartwith oak, and downy oak. In the first year, the survival rate of the introduced species was 98%, while that of the native species ranged from 80 to 96%. The amount of growth was observed to be 1.1-1.4 times greater, and in terms of height it surpassed the native species by 2.1-3.9 times. In the drought year 1996, exotum height increments were significantly inferior (by 47-93%) to local species, and in terms of diameter it exceeded it by 1.4-1.8 times (Smorodin, 1999, 2000).

The drought in 1998 did not affect the current growth of red oak (it was higher than that of native species) and did not affect its size (in height it exceeded native species by 1.5-1.8 times and in diameter by 1.2-1.5 times). Its consequences had an unfavorable outcome for the exotum, its current growth in the following year decreased 3.8 times in height and 1.5 times in diameter.

Analyzing the obtained data, we see that the common oak has a slight advantage over the red oak in terms of height and diameter. The advantage of common oak over red oak in height was only 8 % and in diameter 15 %. At fullness 0.7-0.8 and I - II class of bonitet the total stock of artificial plantations is in the range from 4 to 147 m3. The minimum value of the stock is observed in red oak forest cultures established on low power-carbonate soils formed on limestone and dolomite. With the improvement of soil fertility the stock of plantations increases. As soil fertility increases, the stock of artificial plantations.

Thus, in the most productive plantations on gray forest soils, average models of red oak and petiole oak were taken to determine the course of growth.

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Figures 1 and 2 show the growth progress of forest culturesops in terms of height and diameter.

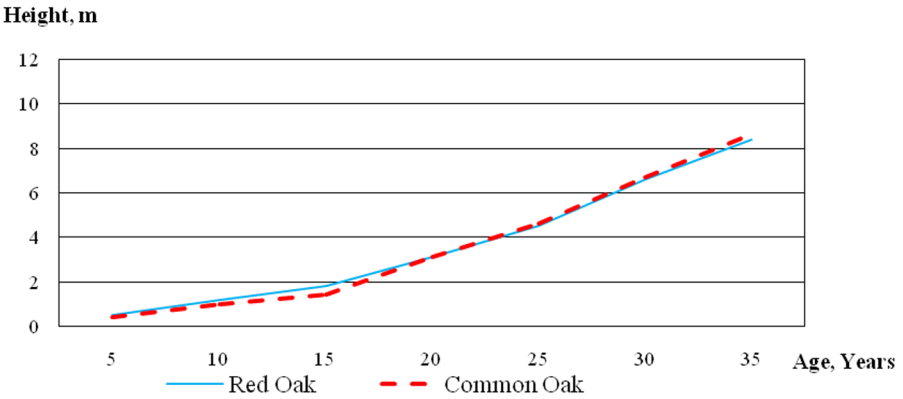


Fig. 1. Height growth rate of forest cultures

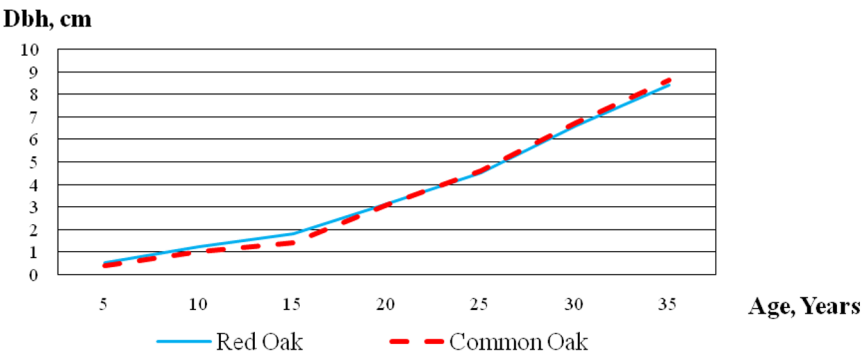


Fig. 2. Forest cultures growth rate by diameter

Analyzing the data of Figures 1 and 2, we can see that the height growth of red oak and common oak up to 15 years of age is approximately the same, and from 20 years of age a slight advantage of common oak can be traced. In terms of diameter from the age of 5 years, there is a clear advantage of common oak over red oak..

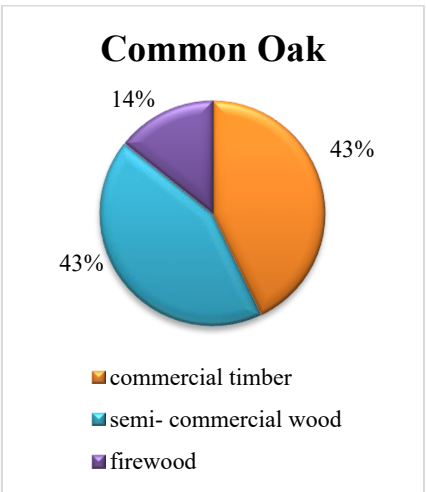
Under the canopy there is a lot of different-aged undergrowth and acorns are present. Leaves are tough, with fallen leaves lying in a dense layer on the soil. Acorns may serve as food for birds and animals, making this species likely to be distributed in remote areas (Spetich, 2022).

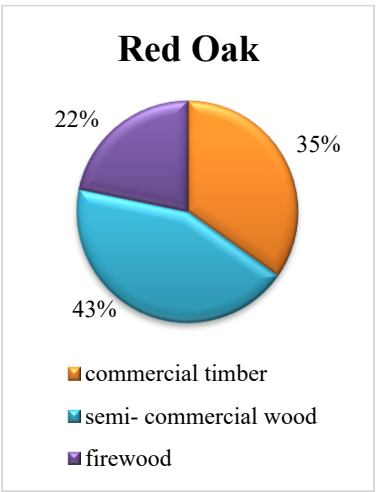
Using taxation materials on permanent trial plots in the red oak stands, qualitative assessment of the studied crops with distribution of trees into commercial timber, semi-commercial wood and firewood was carried out. Commodity structure of red oak forest cultures of Kurdjip district forestry is given in Table 2.

Table 2. Commodity structure of forest cultures of red oak in Kurdjipsky district lesnichestvo

№ quarter / stratum	The composition of the forest plantations	tree species	Trees classified			Growing stock, m3/ha
			commercial timber	semi-commercial wood	firewood	
5/14	5 Red Oak 2 Common Oak 1 Caucasian hornbeam 2 Aspen	Red Oak	8	10	5	75,428
		Common Oak	6	6	2	26,12
		Caucasian hornbeam	0	4	1	3,504
		Aspen	0	6	6	38,98

Quarter № 5, stratum № 14, is represented by mixed crops of red oak, petiole oak and admixture of Caucasian hornbeam and aspen. The commodity structure was analyzed by target species. Commercial timber, semi- commercial wood of common oak accounted for 86 % and of red oak - 78 %. The woody ones make up 14 and 22 %, respectively. Analysis of Caucasian hornbeam trees revealed that the majority of stands are represented by semi-commercial wood (80%) and firewood - 20% (Figure 3).





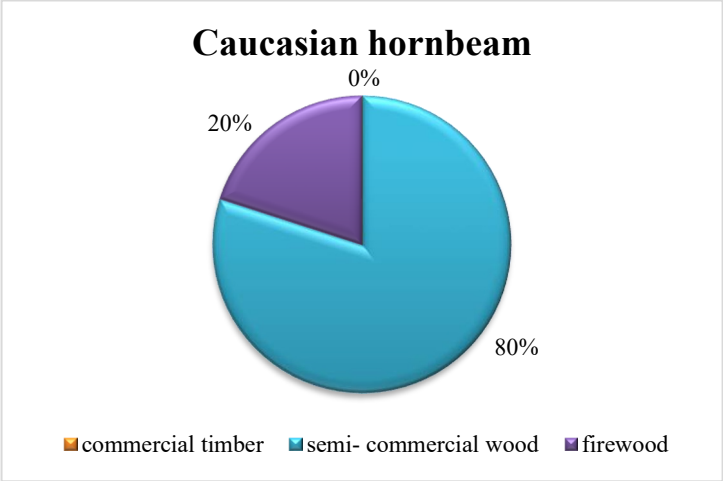


Fig. 3. Commodity structure of red oak forest cultures (quarter 5, stratum 14)

Having studied the marketable structure of 50 years old red oak forest cultures, it was established that red oak has a clear advantage over common oak and other related species due to a higher number of commercial timber and semi- commercial wood.

4 Conclusions

Adventive species of red oak (Q. Rubra L.), successfully introduced in the conditions of the North-West Caucasus, has a number of significant advantages in comparison with the native ones. It is characterized by relatively fast growth, unpretentiousness to soils, resistance to diseases and environmental changes, besides, it emits phytoncides.

Under cultivation conditions outside its natural range, red oak almost always outperforms native species under good water availability. At the age of 50 years, red oak is superior to common oak in terms of productivity. The rapid growth of red oak allows to reduce the age of thinning, which provides additional forest income. Rapid growth and short cutting turnover allows to get economic effect from cultivation of red oak in contrast to common oak.

Red oak in the conditions of the North-West Caucasus is fully adapted, and therefore it can be recommended for use in forestry, forest amelioration and green building.

For landscaping purposes, red oak can be used throughout the entire territory of the Northwest Caucasus with more than 500 mm of precipitation per year. It should be introduced into alleys, group plantings of urban landscaping objects, as well as into recreational plantings around cities and other settlements.

Cultures of red oak of the Maikop lesnichestvo, Kurjipsky district forestry in the conditions of fresh oak forests are able to form highly productive plantations, not inferior to the development of common oak.

When establishing crops on soils poorer in mineral nutrition, red oak can be used, as it is less demanding on fertility and can grow even on acidic soils.

Red oak has higher growth intensity (height, diameter) than common oak and other oak species. Its current growth rate was almost always higher than that of native species, but during or after droughts native species dominated, which did not affect the leadership of introduced species in terms of total and average annual growth.

In forestry it can be used to increase productivity and qualitative composition of plantations, to obtain ameliorative and recreational effect mainly in foothill and mountain zones of oak and beech forests on black soil, gray and brown forest soils.

It is advisable to introduce it in fresh and wet growing conditions in unforested areas and for the reconstruction of low-value oak and hornbeam forests, on soils not suitable for native oak trees.

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