Research paper

Acorn production of pedunculate oak in northeast of Ukraine

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Abstract. We analysed the quantity and quality of *Quercus robu*r L. acorns after years with a very poor yield under the canopy of natural oak stands of various compositions, ages and stock densities in the northeastern part of Ukraine. We determined the mass of 1,000 healthy and damaged acorns of the current year. The levels of variability were estimated for the number and mass of acorns under the canopy of the studied stands. The dependences of the number of acorns on the age of oak stands and their stock density were studied. The total number of acorns under the canopy of natural oak stands was 9,900–19,000 seeds per hectare with a total mass of 26.8–54.1 kg per hectare in 2020 and 8,600–17,200 seeds per hectare with a total mass of 22.7–48.4 kg per hectare in 2021. The proportion of damaged acorns was about 70% both in 2020 and 2021. The largest number of acorns was concentrated under healthy trees (without signs of decline) that had a well-developed crown and, therefore, received more sunlight and heat. The identified quantitative and qualitative estimates and acorn spreading pattern need to be considered when selecting sites for further natural seed regeneration in old-aged oak stands.

Key words: *Quercus robur*, acorn yield, acorn mass, fructification, stand parameters.

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Introduction

Pedunculate oak (*Quercus robur* L.) is the main forest-forming species in the northeastern part of Ukraine. Oak stands occupy 46% (about 284,000 hectares) of the total forest area of the region (Rumiantsev *et al*., 2018; Tkach *et al*., 2019, 2020). Within the northern part of the Kharkiv region, oak stands cover an area of almost 108,000 hectares (38% of the region's forest area).

It is known (Auchmoody *et al*., 1993; Gvozdyak *et al*., 1993; Healy *et al*., 1999; Slepykh & Korshikov, 2017; Gradečki-Poštenjak *et al*., 2018; Gavranović Markić *et al*., 2022) that the success of natural and man-made regeneration of oak forests largely depends on healthy (germinative)

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acorns available in sufficient quantities. Successful natural regeneration of oak stands occurs only in mast years with high acorn production (Krynytskyi *et al.*, 2006; Didenko, 2008a; Martiník *et al.*, 2014; Tkach *et al.*, 2014).

However, oak belongs to the tree species that have heavy seeds and do not bear fruit annually, i.e. it is characterized by fructification periodicity (alternation of mast and non-mast years). According to some authors (Klimo *et al.*, 2008; Majboroda, 2010; Gradečki-Poštenjak *et al.*, 2011; Prévosto *et al.*, 2015; Tkach *et al.*, 2015), the average periodicity of pedunculate oak fructification is five years. A similar fructification periodicity has also been confirmed for other oak species in European and North American forests (Downs & McQuilken, 1944; Sharp & Chisman, 1961; Shaw, 1968; Goodrum *et al.*, 1971; Sork, 1993; Koenig *et al.*, 1994, 1996; Bellocq *et al.*, 2005; Klimo *et al.*, 2008; Gradečki-Poštenjak *et al.*, 2011).

The abundance and frequency of oak fructification as well as the success of natural regeneration depend on many abiotic (climatic influences primarily) (Kelly, 1994; Koenig *et al.*, 1996, 2010; Gradečki-Poštenjak *et al.*, 2018), biotic (damage by various pests, diseases and browsing animals) (Downs & McQuilkin, 1944; Beck & Olson, 1968; Chalupa, 1973; Meshkova & Didenko, 2014; Gradečki-Poštenjak *et al.*, 2018) and anthropogenic (forest management) factors (Sork, 1993; Dey, 1995; Healy *et al.*, 1999; Matić *et al.*, 1999; Klimo *et al.*, 2008; Martiník *et al.*, 2014; Dobrovolný *et al.*, 2017).

Stand characteristics, such as site type, stand origin, composition, age, stock density, phenological form, Kraft class, and crown projection area are particularly essential for the expected acorn yield and, accordingly, for the future cultivation of valuable timber (Beck & Olson, 1968; Chalupa, 1973; Sork, 1993; Dey, 1995; Matić *et al.*, 1999; Wright *et al.*, 2005; Paine & Beck, 2007; Didenko, 2008a; Didenko, 2008b; Klimo *et al.*, 2008; Martiník *et al.*, 2014; Dobrovolný *et al.*, 2017, Slepykh & Korshikov, 2017). For the northeastern part of Ukraine, these issues have been covered in scientific works only in fragments (Didenko, 2008a; Didenko, 2008b) and therefore are very relevant now.

The aim of the study was to find out the dependence of the quantity and quality of acorns, as well as their weight and spread pattern, on mensuration characteristics of oak stands (age, composition and stock density) for the selection of plots of old-aged oak trees with a focus on their natural seed regeneration in the future.

Material and Methods

The research was conducted in natural pedunculated oak stands within the forest-steppe part of the Kharkiv region in the State Enterprise "Kharkiv Forest Research Station" during 2020–2021. The study region is located in the northeastern part of Ukraine (Figure 1).

The studied stands were allocated for regeneration felling, so the mensuration characteristics of the stands were taken from the materials of the Kharkiv Forest Research Station. The study covered stands aged 100–150 years, which were split into two groups: those aged 100–120 (four research plots) and those aged 121–150 years (four research plots). The stock density ranged from 0.6 to 0.9 for the stands in the first group and from 0.5 to 0.8 for the stands in the second group. The oak proportion in the first layer of the stands was 80–90% (Table 1).

In accordance with the Ukrainian forestry and ecological classification (Ostapenko & Tkach, 2002), the forest type of the studied stands is fresh fertile maple-lime oak forest, which corresponds to the fifth category in the European classification of forest types (European Environment Agency, 2007), namely mesophytic deciduous forest (related to medium rich soils of the nemoral forest zone; forest composition is mixed and made up of a relatively large

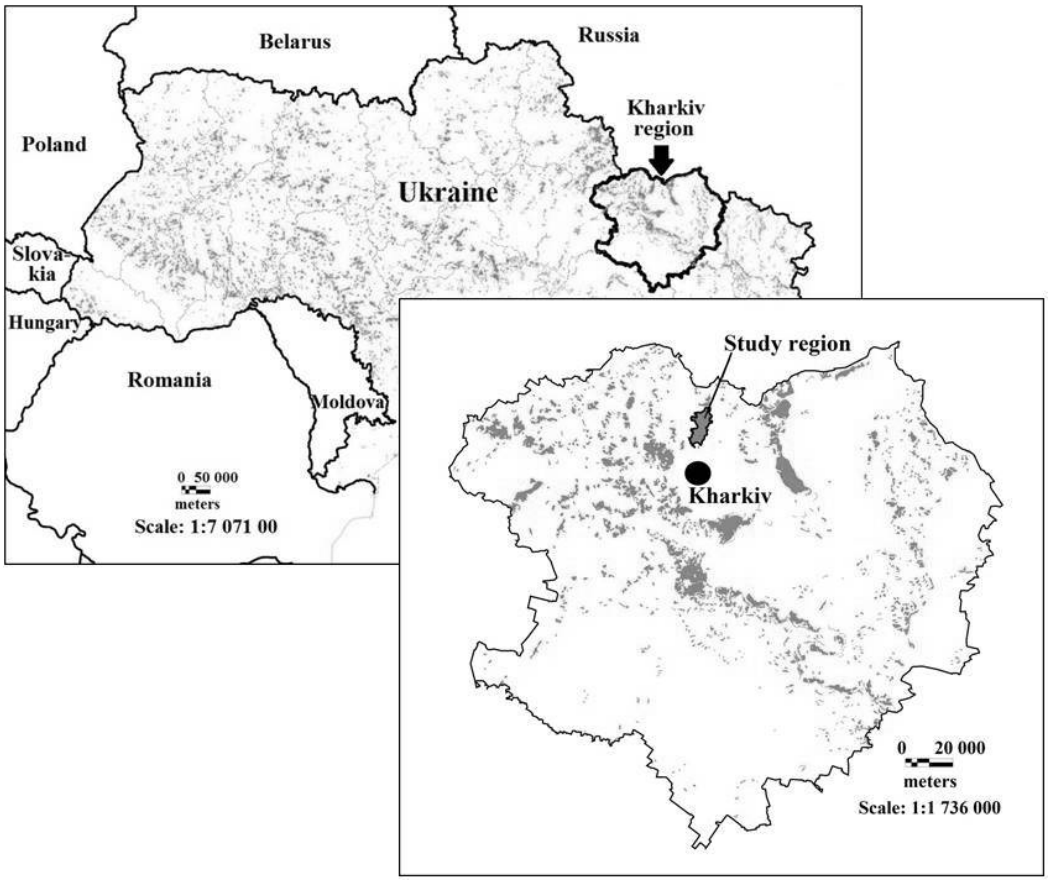


Figure 1. Map of oak forests (grey) in the Kharkiv region and location of the study area.

Table 1. Mensuration characteristics of the studied oak stands and their coordinates.

Research plot	Characteristics of shelterwood				Location of plot	
	Composition [%]	Age [year]	Stock density	Stock [$m^3 \cdot ha^{-1}$]	Latitude	Longitude
Stands aged 101–120						
1	Oak 90%– N-Maple 10%	115	0.6	260	36°16′44″	50°06′04″
2	Oak 90%– F-Maple 10%–Ash	110	0.7	240	36°20′31″	50°06′27″
3	Oak 80%– N-Maple 20%	103	0.8	290	36°18′56″	50°10′48″
4	Oak 90%– F-Maple 10%	105	0.9	330	36°19′33″	50°10′45″
Stands aged 121–150						
5	Oak 90%– N-Maple 10%	135	0.5	230	36°17′53″	50°05′51″
6	Oak 90%– N-Maple 10%– Ash	145	0.6	270	36°18′59″	50°11′06″
7	Oak 90%– N-Maple 10%	130	0.7	320	36°18′57″	50°11′08″
8	Oak 80%– Lime 10%– N-Maple 10%	125	0.8	325	36°17′29″	50°05′54″

Note: Oak = pedunculate oak (*Quercus robur* L.); N-Maple = Norway maple (*Acer platanoides* L.); F-Maple = field maple (*Acer campestre* L.); Lime = small-leaved lime (*Tilia cordata* Mill.); Ash = common ash (*Fraxinus excelsior* L.).

number of broadleaved deciduous trees: *Carpinus betulus* L., *Quercus petraea* (Matt.) Liebl., *Quercus robur* L., *Fraxinus excelsior* L., *Acer platanoides* L. and *Tilia cordata* Mill.

The climate of the study region is moderately continental. The average air temperature varies from +21 °C in summer to -7 °C in winter. The growing season is on average 190 ± 5 days. The average annual rainfall is 492 mm, of which 280 mm falls in the growth season (Kharkiv Regional State Administration, 2021). In general, the conditions are favorable for growing highly productive and resilient oak stands.

We determined acorn production using seed traps (metal square frames (1 × 1 m) on 0.5 m high legs with a collection bag) placed directly on the soil surface. We fabricated the seed traps specifically to collect acorns. The traps (1 m^2) were placed in early September (and were left until the end of October) every 5 or 10 m along five transects (parallel lines). The distance between the transects ranged from 10 to 15 m, depending on the stand area. Thus, 50 traps were established on each research plot. A total of 400 traps were placed within eight research plots. This technique was used by Didenko (2008a, 2008b) for the study in the oak forests within the Left-Bank Forest-Steppe in Ukraine (Kharkiv region) and by Martiník *et al.* (2014) and Dobrovolný *et al.* (2017) in floodplain oak forests in the Czech Republic and Croatia.

Acorns were collected from the traps every two weeks and then divided into two quality categories: "healthy acorns" and "damaged acorns" (Beck & Olson, 1968; Didenko, 2008a; Didenko, 2008b; Meshkova & Didenko, 2014). Acorns without visible signs of damage were classified as "healthy acorns". Acorns with bore holes from *Curculio glandium* Marsham and *Cydia splendana* Hübner as well as those damaged by rodents or birds and having gnaw marks were classified as "damaged acorns".

The number of collected acorns was expressed as the number of seeds per 1 m^2 and then converted into 1 hectare. The weight of 1,000 acorns in each of the quality categories at each plot was determined. In cases of insufficient number of acorns in the plots, the weight was determined for 100 acorns and then converted into 1,000 acorns. The acorn weight was determined in the laboratory on digital scales in grams, followed by conversion into kilograms.

Acorn number data samples were processed using variation statistics and the Microsoft Excel suite. Variations in the num-

Table 2. Scale of rough estimation of flowering and fructification of oak stands according to V. Kapper (Kapper, 1930).

Points of flowering and fructification	Description
0	Flowering and fructification are absent
1	Very poor flowering or very poor fructification (few flowers or fruits on trees growing on the edges or outside stands and very few on those growing within stands)
2	Poor flowering and poor fructification (very satisfactory and even flowering or fructification of trees growing on the edges or outside stands and poor flowering or fructification within stands)
3	Normal flowering or normal fructification (substantial flowering or fructification of trees growing on the edges or outside stands and good flowering or fructification in middle-aged and mature stands)
4	Good flowering or good fructification (abundant flowering or fructification of trees growing on the edges or outside stands and good flowering or fructification in middle-aged and mature stands)
5	Very good flowering or very good fructification (abundant flowering or fructification of trees growing on the edges or outside stands as well as in middle-aged and mature stands)

ber and weight of acorns were assessed by the Mamaev's scale (Mamaev, 1972). To do this, we calculated the coefficient of variation (*CV*, %), which represents the standard deviation of the variable to the mean of sample data (Watson, 1969). In accordance with the Mamaev's scale, the following levels of variability of the variables were identified: very low (*CV* <7%), low (*CV* = 8–12%), medium (*CV* = 13–20%), increased (*CV* = 21–30%), high (*CV* = 31–40%) and very high (*CV* > 40%).

Fructification success for oak stands was evaluated by the Kapper's scale (Kapper, 1930), which is presented in Table. 2. According to the evaluation, a very poor fructification (1 point) by the Kapper' scale (Kapper, 1930) was identified both in 2020 and 2021.

Results

In fresh fertile maple-lime oak forest (mesophytic deciduous forest) after years with very poor yield there were 9,900–19,000 acorns per hectare with a total weight of 26.8–54.1 kg per hectare in 2020 and 8,600–17,200 acorns per hectare with a total weight of 22.7–48.4 kg per hectare in 2021 (Table 3).

Table 3. The quantity and weight of oak acorns under the canopy of the studied oak stands.

Research plot	Characteristics	2020			2021		
		Healthy acorns	Damaged acorns	Total	Healthy acorns	Damaged acorns	Total
1	Number of acorns per hectare (numerator)/Percent (denominator)	3,200 31	7,100 69	10,300 100	3,100 30	7,400 70	10,500 100
	Kg of acorns per hectare	8.6	18.2	26.8	8.4	18.6	27.0
	Weight of 1,000 oaks [kg]	2.68	2.57	5.25	2.71	2.51	5.22
2	Number of acorns per hectare (numerator)/Percent (denominator)	4,700 36	8,300 64	13,000 100	4,200 31	9,300 69	13,500 100
	Kg of acorns per hectare	13.1	20.6	33.7	12.1	25.8	37.9
	Weight of 1,000 oaks [kg]	2.78	2.48	5.26	2.87	2.77	5.64
3	Number of acorns per hectare (numerator)/Percent (denominator)	3,400 32	7,200 68	10,600 100	4,300 37	7,300 63	11,600 100
	Kg of acorns per hectare	10.1	19.4	29.5	11.3	18.8	30.1
	Weight of 1,000 oaks [kg]	2.98	2.69	5.67	2.62	2.57	5.19
4	Number of acorns per hectare (numerator)/Percent (denominator)	3,100 31	6,800 69	9,900 100	3,200 33	6,600 67	9,800 100
	Kg of acorns per hectare	8.9	18.8	27.7	8.9	18.2	27.1
	Weight of 1,000 oaks [kg]	2.88	2.77	5.65	2.79	2.76	5.55
5	Number of acorns per hectare (numerator) / Percent (denominator)	4,400 29	10,700 71	15,100 100	3,500 27	9,400 73	12,900 100
	Kg of acorns per hectare	13.1	30.7	43.8	9.3	24.3	33.6
	Weight of 1,000 oaks [kg]	2.98	2.87	5.85	2.67	2.59	5.26
6	Number of acorns per hectare (numerator)/Percent (denominator)	5,400 28	13,600 72	19,000 100	4,300 25	12,900 75	17,200 100
	Kg of acorns per hectare	15.6	38.5	54.1	12.3	36.1	48.4
	Weight of 1,000 oaks [kg]	2.89	2.83	5.72	2.87	2.80	5.67

Research plot	Characteristics	2020			2021		
		Healthy acorns	Damaged acorns	Total	Healthy acorns	Damaged acorns	Total
7	Number of acorns per hectare (numerator)/Percent (denominator)	3,700 29	9,200 71	12,900 100	3,500 30	8,100 70	11,600 100
	Kg of acorns per hectare	10.6	25.6	36.2	9.9	22.2	32.1
	Weight of 1,000 oaks [kg]	2.86	2.78	5.64	2.84	2.74	5.58
8	Number of acorns per hectare (numerator)/Percent (denominator)	2,700 25	7,900 75	10,600 100	2,200 26	6,400 74	8,600 100
	Kg of acorns per hectare	7.7	21.1	28.8	5.9	16.8	22.7
	Weight of 1,000 oaks [kg]	2.87	2.67	5.54	2.67	2.62	5.29

It was found that 121–150-year-old stands had higher yields of acorns both in 2020 and in 2021 compared to stands aged 101–120. For example, acorn quantities under the canopy of 121–150-year-old natural oak stands were on average 24% higher in 2020 and 10% higher in 2021 compared to 101–120-year-old stands (Table 3). The level of variability for the total number of acorns was characterized by the Mamaev's scale (Mamaev, 1972) as medium for 101–120-year-old natural oak stands (*CV* = 13–14%) and increased for 121–150-year-old natural oak stands (*CV* = 25–28%) (Table 4).

Table 4. Number of acorns per hectare in oak stands by study years.

Statistical value	Study year	
	2020	2021
Stands aged 101–120		
Minimum	9,900	9,800
Maximum	13,000	13,500
Average	11,000	11,400
Standard error	1,400	1,610
Coefficient of variation (CV) [%]	13	14
Stands aged 121–150		
Minimum	10,600	8,600
Maximum	19,000	17,200
Average	14,400	12,600
Standard error	3,570	3,570
Coefficient of variation (CV) [%]	25	28

The average number of acorns per 1 m^2 under the canopy of 101–120-year-old natural oak stands was 1.0–1.3 in 2020 and 2021, while under the canopy of 121–150-year-old natural oak stands it was 1.1–1.9 and 0.9–1.7, respectively (Table 5). The largest numbers were recorded in 101–120-year-old natural oak stands with a stock density of 0.7 and in 121–150-year-old stands with a stock density of 0.6. The level of variability for the number of acorns per 1 m^2 was characterized as very high according to the Mamaev's scale (Mamaev, 1972) for all studied stands (*CV* = 58–113%).

The study showed that acorns were unevenly distributed over the study area and were spotted on the plots. It is indicative that the largest numbers of acorns were concentrated under the canopy of trees, which had good health (without signs of decline) and well-developed crowns and, respectively, received more heat and light. However, the percentage of such trees in the studied stands was insignificant (up to 10% of the total number).

The proportion of healthy acorns varied from 25% to 36% in 2020 and from 25% to 37% in 2021 (Table 3). In 2020, the largest proportion of healthy acorns of 36% was recorded under the canopy of a 105-year-old oak stand of vegetative origin with a stock density of 0.7 (research plot 2). In 2021, the largest proportion of healthy acorns – 37% – was found under the canopy of a 103-year-old oak stand of vegetative origin with a stock density of 0.8 (re-

Table 5. Number of acorns per m² on research plots by study years.

Research plot	Study year	Statistical value				
		Minimum	Maximum	Average	Standard error	Coefficient of variation (CV) [%]
1	2020	0	4	1.0	1.11	106
	2021	0	6	1.1	1.20	113
2	2020	0	5	1.3	1.22	94
	2021	0	6	1.3	1.15	86
3	2020	0	3	1.1	1.00	94
	2021	0	3	1.2	0.93	80
4	2020	0	3	1.0	0.88	88
	2021	0	3	1.0	0.80	81
5	2020	0	6	1.5	1.25	82
	2021	0	3	1.3	0.78	61
6	2020	0	5	1.9	1.27	67
	2021	0	5	1.7	0.99	58
7	2020	0	5	1.3	1.23	95
	2021	0	3	1.2	1.00	86
8	2020	0	4	1.1	0.91	86
	2021	0	3	0.9	0.73	85

search plot 3). On average, the proportion of healthy acorns in 2020 and 2021 was only 30%. Accordingly, the proportion of damaged acorns ranged from 64% to 75% in 2020 and from 63% to 75% in 2021. The average proportion of damaged acorns in both 2020 and 2021 was about 70% (Figure 2). Therefore, in years with very poor yields (1 point (Kapper 1930)) the number of oak seedlings under the canopy of stands will be insufficient for a successful natural regeneration of this species.

Research results indicate that the average weight of 1,000 healthy acorns in 121–150-year-old natural oak stands was 2% greater in 2020 and 1% greater in 2021

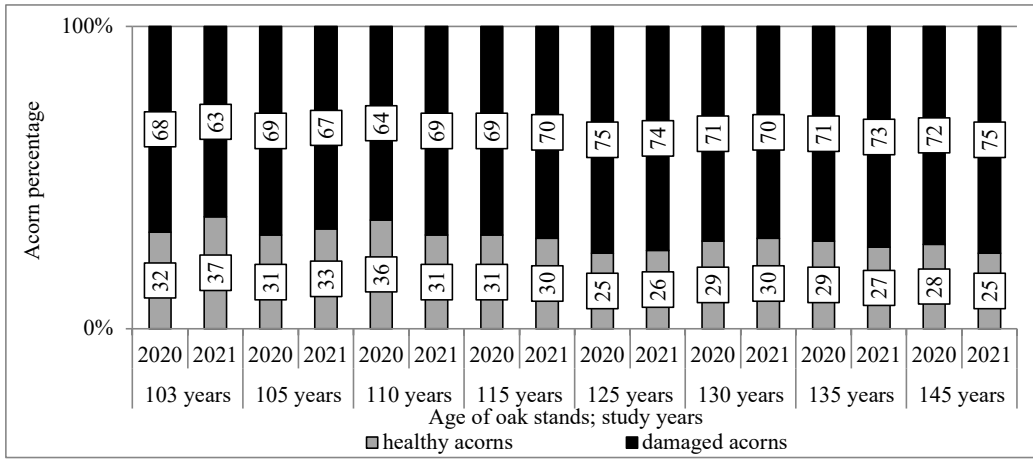


Figure 2. Proportion of healthy and damaged acorns in oak stands in 2020 and 2021.

compared to 101–120-year-old stands. The weight of 1,000 damaged acorns was by 6% and 1% greater, respectively (Tables 3, 6). The level of variability for the weight of 1,000 acorns in terms of their quality was very low according to the Mamaev's scale (Mamaev, 1972) for all studied stands (*CV* = 2–6%).

Table 6. Weight (kg per hectare) of 1,000 acorns in oak stands by study years.

Statistical value	Study year			
	2020		2021	
	Healthy acorns	Damaged acorns	Healthy acorns	Damaged acorns
Stands aged 101–120				
Minimum	2.68	2.48	2.62	2.51
Maximum	2.98	2.77	2.87	2.77
Average	2.83	2.63	2.75	2.73
Standard error	0.13	0.13	0.11	0.13
Coefficient of variation [%]	5	5	4	5
Stands aged 121–150				
Minimum	2.86	2.67	2.67	2.59
Maximum	2.98	2.87	2.87	2.80
Average	2.90	2.79	2.76	2.75
Standard error	0.05	0.09	0.11	0.10
Coefficient of variation [%]	2	3	4	4

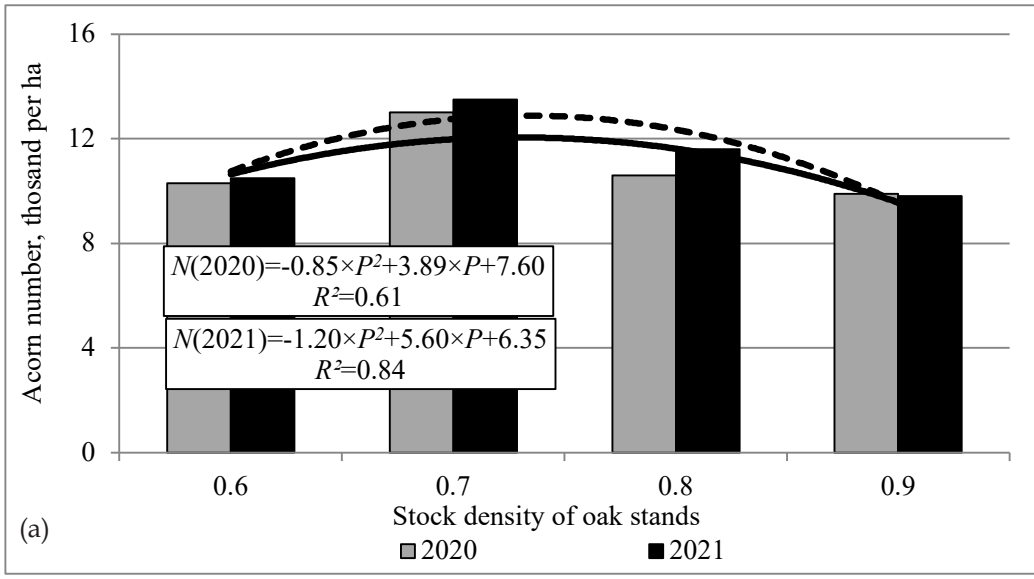
It was noted that for oak stands aged 101–120, the largest number of current year's acorns was found in the stands with a stock density of 0.7. There, the acorn numbers amounted to 13,000 per hectare in 2020 and 13,500 per hectare in 2021 (Figure 3). The numbers were 21% and 22% less in the stands with a stock density of 0.6, 18% and 14% less in the stands with a stock density of 0.8, and 24% and 27% less in the stands with a stock density of 0.9, respectively. These regularities are well described by polynomial equations of the second order (R^2 = 0.61 and 0.84).

Under the canopy of 121–150-year-old natural oak stands, the largest number of current year's acorns was recorded in stands with a stock density of 0.6: 19,000 acorns per hectare in 2020 and 17,200 acorns per hectare in 2021. In the stands with a stock density of 0.5, the numbers were 21% and 25% less, respectively. For the stock density of 0.7 the acorn numbers were 32% and 33% less and for the stock density of 0.8, 44% and 50% less, respectively. These regularities are well described by polynomial equations of the second order (R^2 = 0.75 and 0.80). It should be noted that we did not find any dependences of acorn number, weight and quality on the oak proportion in the mother stand composition.

Discussion

The results have shown certain regularities in acorn production of pedunculated oak in the northeastern part of Ukraine (Kharkiv region). It was found that the number and weight of acorns as well as their quality significantly depended on the age and stock density of oak stands. Instead, the oak proportion in a mother stand did not affect the quantity, weight and condition of acorns.

In the region, the studied years (2020 and 2021) were characterized by very poor



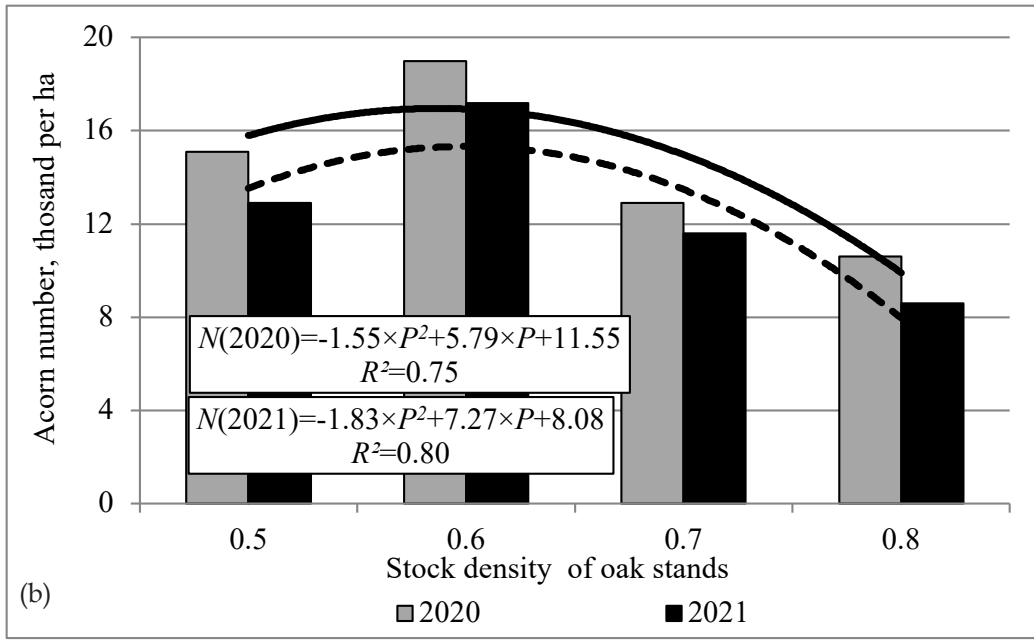


Figure 3. Quantity of acorns in oak stands with different stock densities by study years: (a) – stands aged 101–120; (b) – stands aged 121–150 (*N* – number of acorns per hectare, *P* – stock density, solid line – 2020, dashed line – 2021).

yield of acorns (1 point by Kapper's scale). Prior to that, during 2007–2015, there were five years (2007, 2009, 2011, 2012 and 2014) with very poor or poor fructification of oak in the study region (Tkach *et al.*, 2015) and, therefore, very poor acorn yield (1–2 points by Kapper's scale). There was also one year (2008) with normal acorn yield (3 points by Kapper's scale). Very good or good acorn yield (4–5 points by Kapper's scale) was recorded over three years in that period (2010, 2013 and 2015), with the highest yield in 2013. We can say that the mast years for pedunculate oak in that period have occurred every three to four years without a certain frequency.

Thus, taking into account related findings (Krynytskyi *et al.*, 2006; Didenko, 2008a; Tkach *et al.*, 2014), which indicate the successful natural seed regeneration of pedunculate oak stands only in years with good or very good acorn yield, we come to the conclusion that in the last 15 years only three years could be appropriate for the successful regeneration of oak stands in the study area. Martiník *et al.* (2014) and Dobrovolný *et al.* (2017) came to the same conclusion from the results obtained in floodplain oak forests in the Czech Republic and Croatia.

Foresters, in order to promote oak fructification, take steps to reduce the stock density of stands and ensure that more light and heat enter the tree crowns (Dey, 1995; Matić *et al.*, 1999; Krynytskyi *et al.*, 2006; Klimo *et al.*, 2008; Martiník *et al.*, 2014; Tkach *et al.*, 2014; Dobrovolný *et al.*, 2017). Matić *et al.* (1999) and Klimo *et al.* (2008) recommend growing stands with a sparse canopy from a young age so that by the time they reach maturity they have a sufficient number of vital trees with wide, healthy and well-lighted crowns. The same opinion was expressed by Dey (1995) based on research in oak forests in the eastern United States. Our results also show that greater numbers of acorns were recorded under the canopy of more sparse oak stands with a stock density of 0.6–0.7 as compared to the stands with the density of 0.8–0.9. The reason is that sparse stands create more favorable conditions for better fructification of oak: tree crowns receive more light and are provided with more heat, especially from the southwestern, southern and southeastern facing sides.

Krynytskyi *et al.* (2006) also indicated the successful fructification of pedunculated oak in the Lviv region in Ukraine in old-aged oak stands (over 200 years old) with a stock density of 0.6. In addition, the study showed that the largest number of healthy acorns were concentrated under the wide crowns of vital model oak trees without signs of decline and damage by pests and diseases, on the southern and eastern crown sides. On these sides, acorns had larger size and, consequently, greater mass.

Korpel *et al.* (1991) also emphasized that dominant trees in the first forest layer gain more heat and light and fruictify more frequently and more abundantly than trees of lower Kraft classes. In addition, trees growing at stand margins bear fruit more often and more abundantly than trees inside a stand (Shvidenko & Danilova, 2001). Goodrum *et al.* (1971) and Sharp & Chisman (1961) came to similar conclusions in previous studies. Later this was concluded also by Dey (1995), Röhrig *et al.* (2006) and Dobrovolný *et al.* (2017).

According to Martiník *et al.* (2014), the average number of acorns in pedunculated oak stands in the Czech Republic in years with abundant crop was 82 per m^2 in 2009 and 66 per m^2 in 2011. Under open canopies and under single trees (seed trees left after felling), the density of acorns was 118 and 124 seeds per m^2, respectively. Under fully closed canopy, acorn number was much lower. The findings by Dobrovolný *et al.* (2017) in two plots in the Czech Republic and two plots in Croatia in oak stands varied by ages, compositions and stock densities did not reveal a significant difference in the quantitative and qualitative characteristics of acorns. The number

of acorns in the research plots after a year with a medium seed production ranged from 2 to 17 seeds per m^2 and was lower than the number of acorns in a mast year (20–50 acorns per m^2) (Dey, 1995; Röhrig *et al.*, 2006).

According to Didenko (2008b), after a year with a poor crop (fructification success is 2 points by the Kapper's scale) under the canopy of 100–180-year-old natural oak stands with 50–100% of oak in the first layer, only 6,800–16,900 sound acorns per hectare were recorded. The author noted a decrease in the number of acorns under the canopy of oak stands with the decrease of the oak proportion in the composition. The acorn quantity increased with the age of the stands. Instead, our research did not confirm the conclusion regarding the decrease in the number of acorns under the canopy of oak stands as the oak proportion in their composition decreases, but the increase in the number of acorns with the age of the stands was confirmed. However, it should be interesting to investigate further the fructification intensity in stands with various oak percentages in composition (within 50–100%) with the same stock density. Other results (Didenko, 2008a) indicated that after a year with very good fructification (fructification success was 5 points by the Kapper's scale) under the canopy of 180–190-year-old natural oak stands with 90% of pedunculated oak in the first layer, more than 400,000 acorns per hectare have appeared with a mass of almost 700 kg per hectare. The proportion of acorns from previous years was 26%; sound acorns were 68%, and unsound acorns accounted for 6%.

Studies of fructification in red oak (*Quercus rubra* L.) stands in the northern United States are also consistent with our results. Thus, Healy *et al.* (1999) showed that during the eleven-year observation period (1986–1996), a greater density of acorns (18 seeds per m^2) was recorded under the canopy of sparser stands compared to stands with a higher closure of the first layer (13 seeds per m^2). Conversely, a study by Bellocq *et al.* (2005) did not reveal differences in the number of red oak acorns under the canopy of stands of varying densities.

Many researchers (Dey, 1995; Sander, 1990; Beck, 1993; Krynytskyi *et al.*, 2006; Meshkova & Didenko, 2014) indicate a significant proportion of acorns damaged by pests, diseases and mammals. In years with very poor and poor yields, insects can damage 50 to 80% of acorns (Sander, 1990; Beck, 1993; Dey, 1995). According to Meshkova & Didenko (2014), up to 67% of acorns can be damaged by *Curculio glandium* and *Cydia splendana* and up to 1% by rodents in the Left-Bank Forest-Steppe of Ukraine (Kharkiv region). A study by Krynytskyi *et al.* (2006) in the Right-Bank Forest-Steppe in Ukraine (Lviv region) indicated that up to 50% of acorns can be damaged by *Curculio glandium* and *Cydia splendana*, up to 8% by saprophytic fungi (fungi from the genera *Rhizopus, Mucor, Trichoderma* and *Phenicillium*) and up to 35% by parasitic fungi (fungi from the genera *Fuzarium, Phomopsis, Ciboria* and *Alternaria*). Therefore, preventive control of harmful microorganisms and insects can be one of the ways to preserve a larger number of healthy acorns under the canopy of oak forests in order to further use them to ensure the natural seed regeneration of valuable oak forests (Downs & McQuilken, 1944).

Conclusions

In the years with very poor yield, the number of acorns under the canopy of natural pedunculated oak stands was up to 19,000 seeds per hectare with a total mass of about 54 kg per hectare in 2020 and up to 17,000 seeds per hectare with a total mass of about 48 kg per hectare in 2021. However, the proportion of damaged acorns was up to 70%, so the successful natural regeneration of oak forests could not be expected.

The results indicate the dependence of the number and weight of acorns as well

as their quality on the age of oak stands and their stock density. On the other hand, no dependence of these characteristics on the oak proportion in the mother stand composition was found. The largest numbers of acorns were concentrated in more sparse stands under healthy trees (without signs of decline) with well-developed crowns, which, therefore, received more heat and light. However, the proportion of such trees in the stands was insignificant.

The identified quantitative and qualitative estimates and the pattern of acorn spreading should be taken into account when selecting sites for further natural regeneration by seeding in old-aged pedunculated oak stands. Preference should be given to stands older than 100 years with a stock density of 0.6–0.7 and at least 80% of oak in the composition.

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