Productivity and life length of oak (Quercus robur L.) artificial crop in the Northern Ergeny, Kalmykia

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Abstract. The paper deals with the current state, productivity and durability of oak tree (Quercus robur L.) stand in the Northern Ergeny (Kalmykia, Russia). The best forest-growing conditions are formed on light alluvial-deluvial soils of river terraces during the first years of plant life as well as in large depressions of placers with dark-colored soils and the horizon below onemeter. Large deep gulches of Ergeny partially overgrown with natural tree and shrub vegetation play the most important role for massive (continuous) afforestation in the territory of Kalmykia. When cultivating forest stands under these conditions, the most productive and durable breed is the pedunculate oak. Seed generation of oak can develop according to I-III class of forest appraisal index (the forest density stored up to this age is 160-190 m³ ha⁻¹) and survive to 80-100 years and in the case of timely cutting – to form a stable coppice stand. Effective methods of cultivation of viable plantings on placers are: formation of a long-term reserve of soil moisture, creation of pure plantations of medium density from relatively shade-tolerant tree species and large shrubs frequent removal of dead wood and unpromising trees, formation of a shadowy underbrush or undergrowth in rapidly dilapidated stands.

1. Introduction
Steppe afforestation in the semi-desert zone of the European territory of Russia lasts for more than 150 years and it is characterized by extremely low productivity [1]. Some scientists think that the reason of the early break of forest crop in steppe is the global change of the climate [2-4]. Long-term practice has been shown that in forest and steppe lands, with the exception of poor Sands and wetlands, the most stable ones forests are formed with the main tree species (Quercus robur L.). Meanwhile, the artificial plantations of differently aged oaks (particularly the young) are inhibited due to the dry climate, unsuitable soil and groundwater conditions, violation of soil processing, excessive planting rates, the use of sophisticated mixing schemes and not zoned seed, late high-intensity thinning, and damage of crops by insects [1, 5, 6]. Therefore, the search for optimal methods and ways of growing long-term steppe plantations is still a challenge in the globe [7-16]. Particularly acute disputes arise in the assessment of the value of the type of mixing of the type of mixing value of tree species and the width of the aisles when laying plantations, since the use of...
complex multi-breed mixing schemes requires frequent high – cost and time-consuming cutting care, and the use of wide aisles (5.0-6.0 m) – life-long agrotechnical care [14].

In more difficult conditions – on the southern black soil and dark chestnut soils of upland with inaccessible groundwater – allow for the establishment of both pure and mixed stands of oak with defined satellites. More difficult conditions (the southern black soil and dark chestnut soils of upland with inaccessible groundwater) allow the establishment of both pure and mixed stands of oak with defined satellites [12]. In beams, on river terraces and in floodplains of the steppe zone – preference is given to mixed cultures. Due to a ‘good quality’ Crops are mainly grown on wood-shadow and combined types. Of accompanying species beneficial effect on oak have maples, *Acer platanoides*, *A. campestre*, *A. tataricum*, *Pyrus communis*, *Tilia cordata*, *Pinus pallasiana*, *Morus nigrum*. Mixed oak crops have higher productivity and sustainability.

Among the shrub species ‘activators’ growth of oak are sumac, honeysuckle, Euonymus can be mentioned. Even a small admixture of these species in oak forests with their uniform placement on the area of the soil, which ensures its looseness and better preservation of moisture in the upper soil layer (up to 30 cm), where the bulk of the root systems of trees and shrubs take place.

For elder plants, mixed oak crops are characterized by higher productivity, biological stability, and marketability of stands [12] compared to pure ones. Besides, mixed crops consider the 2.5-3.0 m width of the row spacing in oak cultures.

Other researchers, based on the study of the growth and condition of old-age plantations of state forest strips, ‘industrial oak forests’ on zonal soils of arid dry steppe and semi-desert, have concluded that mixed cultures cultivation causes greater risk of ‘silencing’ oak satellites [14]. Therefore, selection and placement excluding an inhibitory effect on the oak forest formation is quite difficult. Forest vegetation conditions of steppes are very heterogeneous, and the accompanying breed should have rarely compatible properties. On the one hand, it should be less drought-resistant than oak (fall out of the composition, anticipating the crisis of its moisture supply). On the other hand, it can grow a little slower than oak, economically use soil moisture, and be high enough, shade-tolerant and possibly longer to remain on the forest area, providing shading trunks and soil. Apparently, in the most difficult conditions this function can be performed only by itself, but highly differentiated oak forest stand.

On the southern black soil and chestnut soil types, in the most arid parts of the South of the Russian plain, we may dilute pure oak cultures, and even can raise flat areas and light-slopes with light-chestnut soils of large and medium shrubs plantations [14].

The most old-aged trees survived to our time had been laid 1930-1950s years when creating state forest protective belt sand oak groves of industrial importance, and also in the 1970s – during the period of short-term recovery of forest reclamation works in the country. Since so far, a number of aspects of afforestation in arid conditions remain controversial, the plantations have an exceptional cognitive value, both from the point of view of assessing the forest patchiness of lands, and the prospects for the application of certain tree species and forestry techniques.

The purpose of the research is to assess the current state, productivity and durability of the stand of oak tree (*Quercus robur* L.) on various ecotopes and to determine the effectiveness of methods of their cultivation.

2. Materials and methods
The work was carried out in June 2017 on six permanent trial plots laid by employees of Arshan-Zelmenkiy research branch of the Institute of Forest Science of Russian Academy of Science on various ecotopes in the Northern Ergeny (the Ergeninskaya Upland in the borders of Sarpinskiy district of Kalmykia, Russian Federation) – Watershed state forest protective belts Volgograd-Elista-Cherkessk, Arshan-Gojur and Tegya gulches, Arshan-Zelmen Forest Dacha. The viability and durability of stands were determined by the appearance of the crown (the state of the top, the presence of dry twigs, growth of shoots), the presence of secondary twigs and water shoots on the trunks, the nature and condition of the ground cover (forest environment), compared with the investigated plantations of a higher age. The condition of the forest stand was determined using the scale of the life
condition of the trees based on the characteristics of the tree crown (1 – healthy tree, 2 – weakened tree, 3 – severely weakened tree, 4 – dying tree, 5 – fresh dead standing tree, 6 – old dead standing tree). The first three categories were grouped as ‘health and weakened’, the last three ones were grouped as ‘dry out’ (table 1, columns 12, 13).

For the measurement of the influence of silvicultural factor on the growth and development of the forest stand the technology of creation and maintenance of silvicultural care in plantation was studied. For this purpose the year, definite time and the way of creation of the plantation were under investigation (table 1, columns 2, 3). Also the way of soil preparation, the category of planting area, the scheme of mixing and wood species distribution, culture and age of the planting material as well as the time, periodicity, intensity and types of environmental harvesting (reconnaissance reports, plans of silvicultural practice, taxation plots description, management plan area). Also the amount of regenerating and non-regenerating blocks was calculated.

For the detailed condition survey and productivity definition of the artificial stands the sampling area was determined in that part of the division, which can characterize the average measures of the whole plantation(table 1, columns 1, 2). The sampling areas had squared shape along full width of the line or on the assumption that the whole scheme of wood species mixing could be determined on the sampling area. The determination of the sampling area was done using surveying compass, while the angles and property lines were peg down. The soil continuum and nether vert of the sampling areas were characterized. The amount of the rows was calculated and the width of the row spacing was measured.

The presence of destructive insects and mechanical defects of the trees were registered. Then the complete enumeration of the trees on the sampling area based on two centimeters steps of the width with measurement of the diameter on the height of 1.3 meter was done using measuring stick. For the each step the average height of the tree was measured by the electron altimeter. After the measurement the heights were plotted and the plot was used for the determination of the average height of the plantation. The average diameter of the plantation was calculated by the sum of basal areas using special tables of the Forest reference book (in Russian’Lesnaya vspomogatelnaya kniga’) (table 1, columns 8-11).

The measurement of naturally regenerated forest was done using enumerative method on the areas with dimensions of 4 square meters. The amount of viable undergrowth was calculated individually on the each registration plot based on the plant species and height groups (till 0.6 m, 0.6-1.5 m, higher than 1.5 m). Three most typical trees for the each height group and for the each species of wood were cut at the root collar. The age of them was measured by calculating of the layers and the height was measured within the accuracy of 1 centimeter. The measurement of the underwood natural regeneration was done in its presence. The measurement of natural regeneration was done by calculating of the amount of the undergrowth in thousands per hectare. After that it was divided by the groups of height. The pattern of seedage distribution was described by the plot area (proportional, differential, block forest planting, grouped forest planting). The underwood was also characterized by the amount, age, average diameter and height.

On the sampling areas also the thickness and composition of the plant litter as well as the types (the main edificators and indicators), abundance and degree of coverage of the area of herbage cover were studied. The degree of coverage was determined by eye in tenths. In case that forest live cover is almost consisted of Gramineae the concept ‘degree of cover’ can be changed to ‘degree of grassing-down’. The method of V.G. Nesterov was used for the estimation of participation of the definite species of herbaceous plant in composition of plant cover. This method is based on the scale of O. Drude with division to the 5 classes: 1 – full (the species of plant covers no less than 0.5 of the whole land plot area), 2 – partial (the species of plant covers 0.2-0.1 of the whole land plot area), 3 – occurs sporadically, 4 – occurs accidentally, 5 – occurs on rare occasions.

The data collected in the course of investigations were operated by the standard forest estimation methods. For the each indicator plot the main taxation indicators which could characterize the plantation (composition, average height and diameter, bonitetas (forest appraisal index), crop density,
crown closure, stock volume) were calculated (table 1, columns 4-11). Some of the indicators were measured in the field (the average height and diameter). The forest appraisal index was determined by the special scale of M.M. Orlov (table 1, column 5). The calculation of crop density and stock volume was done by supplementary volumetric and single-tree assortment tables (forest reference book) (table 1, columns 6, 7).

The sound procedure of the biologically active depth was done to the deepness of 10 meters on the sampling areas. The configuration of the potting soil was studied and reported (the type of soil, depth of cumulo layer, color, humidity, granulometric texture, structure, the presence of the plant roots, inclusions, new growth, salts, the nature of the conversion to the next soil horizon etc) using the generally accepted method. Soil samples for laboratory tests were selected from each genetic horizon. Soil samples were transferred to the sample bottles; the numbers of the bottles and the depth of samplings were marked in laboratory records.

3. Results and discussion

Northern Ergeni is a semi-desert with an average precipitation of 285 mm per year with predominance in the warm season – often in the form of short-term showers. Evaporation exceeds 700 mm year⁻¹, and the duration of the frost-free period is 170-190 days during a year. Roast, dry summer is gradually replaced in the winter with frequent thaws and unstable snow cover with an average height of about 10 cm. An important feature of the climate is the high dynamism of seasonal and annual precipitation. The coefficient of variation of the latter during the life cycle of the stand exceeds 60%. The terrain is heavily dissected by a hollow-dolomite-girder net. Plakors and slopes with developed microlief and deep occurrence of the aquifer are covered with light-chestnut complex sandy-loamy soils with feather grass and wormwood. Tertiary terraces of ‘wet’ beams with light soils on alluvial-deluvial deposits, with grassy and motley grasses and aquifer at a depth of 1.5-5.0 m, wedged into the floodplain and thalwegs of gulches.

Surface runoff and groundwater are mainly formed by melting and subsequent drainage and infiltration of snow water. In the surface run, rainfall plays a smaller role than the snow cover, since it falls out unevenly, mainly in the warm half of the year. Due to the uneven distribution of moisture along the relief elements, the middle sections of the gulches turn out to be the most provided moisture, then pre-basalt depressions. The lower parts of the gulches receive moisture not only from surface runoff, but also from groundwater. The slopes and watersheds of Ergeni are provided with the least amount of moisture. The microlief, which affects snow accumulation and accumulation of melt and rainwater, causes different humidification of individual, even very small areas, so the soils and vegetation cover of the watersheds and slopes differ in significant variegation. The difference between moistening of individual, sometimes very small areas is very significant.

In the state forest belt of Volgograd-Elista-Cherkessk (experienced plot of the Arshan-Zelmen branch of the Institute of Forest Science) the state of the stands was very different. On elevated areas there was a retreat of forest-forming species (pedunculate oak (Quercus robur L.), green ash (Fraxinus lanceolata Borkh.), elm squat (Ulmus pumila L.). They were replaced by undergrowth species (tatar maple (Acer tataricum L.), tannery (Cotinus coggygria Scop.), alycha (Prunus cerasifera Ehrh.), and irgulidae (Amelanchier ovalis Medik.), forming on 1/3-1/2 less high, but healthy plantations. The islets of full-length pedunculate oak stands 14-15 m in height and 20-26 cm in diameter with the undergrowth were preserved only within shallow enclosed depressions. The best condition are moderately thinned (900-1000 trunks ha⁻¹), clean oak forests with a row spacing of about 3 m (table 1, area 5). In the plantation with row spacing of 1.5 m (adjacent slide) and without timely thinning, a relatively small, stunted tree stand was formed.

The relief on trial plot 5 is flat, with no apparent slope to either side. The soil is dark-colored, up to 60 cm light loamy, moist, saturated with thin roots. From the depth of 40 cm the color becomes lighter (turns yellow). From 60 cm the composition of deposits is heavier, drier, the color is lighter, there are roots with a diameter of about 5 mm (illuvial horizon of the soil). At the depth of 75 cm there is a parent rock – yellow loess-like light loam, with 85 cm in it there are grains of carbonates. The horizon
of carbonate accumulation lies at a depth of 110 cm, and the aquifer lies below 10 m. The soil layer is 0-110 cm and is a layer of active moisture circulation – feeding the oak and its satellites.

Table 1. The taxation indicators of artificial pedunculate oak plantations in the Northern Ergeny (the Ergenskaya Upland in the borders of Sarpinskiy district of Kalmykia, Russian Federation).

| Numbers of Trialareas | Location | Age (years) | Compositiona | Bonitas (forest appraisal index) | Completeness | Stock (m³ ha⁻¹) | Height average (m) | Height max (m) | Diameter average (cm) | Diameter max (cm) | Condition – healthy and weakened (%) | Condition – drying and shriveled (%) |
|-----------------------|----------|-------------|--------------|-------------------------------|--------------|-----------------|--------------------|---------------|-------------------|-----------------|-------------------------------------|------------------------------------|
| 1                     | Arshan-Gojurgulch | 65 | 10O IV | 0.6 | 50 | 13 | 16 | 26 | 48 | 99 | 1 |
| 2                     | Arshan-Gojur gulch, Arshan-Zelmen Forest Dacha | 65 | 10O + Wp I | 0.9 | 190 | 20 | 24 | 35 | 66 | 84 | 12 |
| 3                     | Tegya gulch | 65 | 10O III | 0.9 | 158 | 14 | 17 | 28 | 20 | 28 | 85 | 15 |
| 4                     | Watershed state forest protective belt Volgograd-Elista-Cherkessk | 65 | 10O IV | 0.4 | 45 | 12 | 17 | 20 | 38 | 98 | 2 |
| 5                     | Arshan-Gojurgulch | 75 | 10Oc+ Mt III | 1.0 | 180 | 18 | 24 | 35 | 66 | 84 | 16 |

Note: O and Oc – oak seed and oak coppice (Quercus robur L.), Wp – white poplar (Populus alba L.), Mt – maple tree (Acer negundo L.).

The stand of oak (65 years, III bonitas, reserve about 160 m³ ha⁻¹) of medium quality is in a satisfactory condition. Closure of his canopy is 0.7-0.8. Crowns are openwork with a considerable number of dead branches. The shrunken trees are 10-15% and many old stumps. The soil and trunks of oak (up to a height of 5-6 m) are resembling of an underbrush made of plum (Prunus cerasifera EHRH.), irgulidae (Amelanchier ovalis Medik.), tatar maple (Acer tataricum L.) and golden currant (Ribes aureum Pursh). However, the positive influence of underbrush is offset by its competition for moisture. In the ‘windows’ of the canopy there is a semen of oak trees 0.4-1.0 m high, but it has no prospect of reaching the upper tier.

The plantation is dead-armed with the presence of litter from a half-decomposed litter. It preserves the forest environment and pedunculate oak can live for about 10 more years. However, there is a need for selective sanitary cutting with focal thinning of undergrowth.
Of particular interest is the arboretum, created in the adjacent to the test area 5 lowering about 40 years ago in the form of single rows of pedunculate oak (*Quercus robur* L.), ash green (*Fraxinus lanceolata* Borkh.), maple (*Acer platanoides* L.), finely chopped (*Tilia cordata* Mill.), aspen (*Populus tremula* L.), alternating with the scenes of bushes (maples of Tatar (*Acer tataricum* L.), irgi ordinary (*Amelanchier ovalis* Medik.), skimpy tannery (*Cotinus coggygria* Scop.), golden currant (*Ribes aureum* Pursh), branching tamarix (*Tamarix gallica* L.). The planting is healthy, closed, dead-armed. The trees of linden, maple and ash are not much inferior to oak in development and deserve a wider application when creating plantations in the depressions of placers (in the intrazonal conditions of the Ergenin Upland). The natural renewal of maple and ash occurs intensely at the edges and in the wider windows of the forest canopy. Irga and Tatar maple in the thickened plantations have the appearance of low (5-6 m) slender trees.

Plantations in the Arshan-Gojur and Tegya gulches (table 1, areas 1-4 and 6) are created in the belt of transit of groundwater from under the placers and slopes into gulches in similar conditions – on light cohesive-sandy-loamy humus soils, but with different availability of ground moisture.

The best growth and condition at age 65 have a clean and unedged pedunculate oak culture with 1.5-meter rows (table 1, area 3), created on the outskirts of the village of Gojur. They are located on the western (right-bank) terrace of the Khamkhurka River with an elevation above the floodplain to 3 m and groundwater at a depth of 1.5-2.0 m. We have there semihydromorphic soil with a loamy loam (15 cm) at a depth of about 1 m, lying on gray wet sand. Humus horizon lasts to a depth of 50-55 cm. In the cover there is an almost pure association of the cilice stalk with a height of 0.8-1.2 m.

The average height of the stand is about 20 m (1 bonitas), the average diameter is 28 cm. The trunks are not very shallow, cleaned from boughs to a height of 8-12 m. The stock of wood is about 190 m$^3$ha$^{-1}$. However, the planting is severely eroded by unauthorized logging. Its viability is weakened by the increased illumination of the sub-crane space. There is a tendency to accelerate the death of trees, which will lead to the decay of the ecotype within no more than 10 years.

In the same conditions, the local ecotype of the white poplar (*Populus alba* L.) grows well and forms durable plantings. A healthy appearance and potential longevity also show the pear (*Pyrus communis* L.).

In similar conditions – on sandy loam soil with a slightly deeper groundwater occurrence, on the outskirts of Gujur settlement, there is a healthy sprout planting of oak (table 1, area 6, Arshan-Zelmen forest dacha). It was formed on the site of the crops cut down in 1943 by the occupation forces, supposedly planted in 1878. At 75 years, the height of trees, mainly in coppice nests, is 18-24 m; the average diameter is 35 cm. The trunks are mainly wood-burning with a spreading openwork crown at an altitude of 5-7 m and thick branches. The canopy closure is about 0.6-0.7. The undergrowth is formed of rare patches of ash-tree-leaved maple (*Acer negundo* L.) and birch bark (*Ulmus minor* Mill.) with a height of 4-6 m. Self-seeding of oak appears regularly, but there is no undergrowth. A certain harm to the seed renewal of oak is caused by uncontrolled grazing of cattle, which, in the severe climatic conditions of Kalmykia, is not characterized by food selectivity. The soil cover is alive and consists almost entirely of a crumbling ladies’ bedstraw (*Galium odoratum* (L.) Scop.).

Planting is viable and can survive for more than a decade. Its cumulative durability will significantly exceed 100 years.

In a similar soil and soil conditions, but significantly higher on the slope of the right bank of the Khamkhurka terrace, there is another 65-year-old oak plantation (table 1, area 2). It was formed from pure cultures with 3-meter rows and naturalized to the state of a natural forest ecosystem. The plantation has also been repeatedly cut by felling, but at the present time it is loosely closed, evenly distributed over the area stand with a height of 20-25 m (1 bonitas) and an average diameter of about 30 cm with an undergrowth of maple ash-tree (*Acer negundo* L.) – 4.0-4.5 m and a ground cover made of a crumbling ladies’ bedstraw (*Galium odoratum* (L.) Scop.). The quality of the trunks is average. Live crowns are at an altitude of 7-10 m, rather spreading, openwork. On the illuminated part of the trunks there are water shoots and thin secondary branches – the result of early thinning of the stand, but it can live for more than a decade. The elm (*Ulmus pumila* L.), which is located on the periphery
of the plantation, also has the appearance of healthy trees with the size of trunks often exceeding the oak.

The well-being of this plantation provides a ground flow of moisture, wedged out from under the slope of a high plateau with light surface deposits. This is evidenced by the presence on the slope – 4-5 m above the pedunculate oak – of five rows of pine (Pinus sylvestris L.) at the age of about 40 years. Wide (about 5 m) row spacing did not ensure their closure, but most trees look healthy, reached a height of 12-13 m, diameter of the trunks 16-17 cm with a current height increase of 25-30 cm.

On light soils of gulch terraces with an aquifer deeper than 4-5 m (table 1, areas 1 and 4), the contact of the root system of trees with a border of backed moisture occurs with a large delay. Pedunculate Oak crops grow slowly and thin out strongly. Wide (6 m and more) aisles and long-term soil care (test area 4) did not accelerate their development, but led to an excessive growth of the crown and to a decrease in of the trunks marketability. Excessive illumination leads to the development of water shoots on them and dredging the soil with steppe grasses. The oak appears to be relatively healthy in the closed biogroups formed in the terrain relief depressions (test area 1). 60-65-year-old plantations are at different stages of decay. There is no self-seeding of oak. The average height of the parent stand does not exceed 12-13 m (IV bonitas), the timber stock – 50 m ha⁻¹.

4. Conclusion

There is a considerable area of forest lands on the semi-arid territory of the Ergeninskaya Upland. Its main part is located in the dry-girder systems on the way of transit of underground fresh water drain into the hydrographic network and at the watersheds – in closed relief depressions.

The best forest-growing conditions are formed on light allevial-deluvial soils of river terraces with fresh ground water already accessible for root system during the first years of plant life as well as in large depressions of placers with dark-colored soils and the horizon of the accumulation of carbonates below 1 m. Large deep gulches of Ergeny (Malaya Tinguta, Arshan-Zelmen, Gashun and others) partially overgrown with natural tree and shrub vegetation (elm (Ulmus pumila L.), willow (Salix fragilis L.), aspen (Populus tremula L.), white and black poplar (Populus alba L. and P. nigra L.), tamarix (Tamarix gallica L.), loch (Elaeagnus angustifolia L.), thorn (Prunus spinosa L.), hawthorn (Crataegus monogyna JACQ.)) play the most important role for massive (continuous) afforestation in the territory of Kalmykia. In view of the uniqueness of such places for treeless areas of Kalmykia, some of them are currently assigned the status of specially protected natural areas (for example, ‘Bayrachniy Les’ near Gojur village, Sarpinskiy district of the Republic of Kalmykia, Russian Federation) with the corresponding mode of management.

When cultivating forest stands under these conditions, the most productive and durable breed is the pedunculate oak (perhaps its late form is preferable). Seed generation of oak can develop according to I-III class of bonitas and survive to 80-100 years and in the case of timely cutting – to form a stable coppice stand. If necessary, these areas can be occupied by gardens, vineyards, walnut groves (the first apple orchards appeared here in the middle of the XIX century). In the conditions of micro depressions the cultures of small-leaved linden (Tilia cordata MILL.), maple-leaf (Acer platanoides L.), pear-tree (Pyrus communis L.) and irgi (Amelanchier ovalis Medik.) are also promising.

The early closing and early opening of the forest canopy caused by the deep occurrence of the aquifer, a rare planting or unsystematic felling of trees reduces the longevity of the oak groves in the semi-desert. Apparently, the occurrence of an aquifer under a co-incipient deposition of girder terraces deeper than 4-5 m is the limiting for the formation of durable plantations of this species. The presence in the thinning plantations of non-competitive shading undergrowth increases the durability.

Effective methods of cultivation of viable plantings on placers are: formation of a long-term reserve of soil moisture (deep preliminary soaking of soil), creation of pure plantations of medium density from relatively shade-tolerant tree species and large shrubs frequent removal of dead wood and unpromising trees, formation of a shadowy underbrush or undergrowth in rapidly dilapidated stands.

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