Basic principles and technologies for planted forests and nature-oriented forests in arid conditions

Alexander Manaenkov[1*]

[1]Federal Scientific Centre of Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences, 97, Universitetskiy Prospekt, 400062, Volgograd, Russian Federation

Abstract. Expanding the area of protective forests and forests in arid regions is an affordable and effective means of solving climate and food security in Russia. The purpose of this work is to systematize the achievements of science and practice in the field of forest land reclamation, aimed at increasing the effectiveness of work, productivity and functional durability of forest crops on sands and zonal soils of dry sub-humid and semi-arid regions. The main reason for the treelessness of arid plains, the concept of "forestability of land," principles and criteria for its assessment, and patterns of geographic dynamics are discussed. Consistently presented afforestation methods, principles and techniques for creating and growing sustainable tree stands.

1 Introduction

Expanding the area of forest plantations and increasing forest resources in arid regions is a generally recognized accessible, effective and long-lasting means of preventing and eliminating the consequences of degradation and desertification of agricultural landscapes, solving environmental, social, utilitarian and other problems [1-4].

On the territory of Russia, potentially low-productive sandy lands of river valleys [5] and arable lands in the steppe zone, subject to water and wind erosion, remain major objects of forest reclamation and solving problems within the framework of the country's Climate Doctrine. It is also inconvenient on plains and slopes of watershed hills in dry steppe and semi-desert with zonal soils that are not saline in toxic concentrations. Its effectiveness is largely determined by an objective assessment of the forest suitability of land, forest cultural conditions and the use of adaptive technologies for creating, growing and maintaining plantings, the main task of which is the formation of a favorable water regime of the rhizosphere at all stages of their growth and functioning [6]. Those. the use of techniques that ensure the accumulation, conservation and economical consumption of moisture.

According to modern concepts, the main reason for the treelessness of arid plains is the high dynamics of atmospheric humidification and moisture reserves in the root layer (ROL), its critical decrease and death of the tree stand in dry years. At the same time, the

* Corresponding author: manaenkov1@yandex.ru

amplitude of annual, seasonal and monthly amounts of atmospheric precipitation, and, consequently, the probability of a decrease in the stock of root-accessible soil moisture to a critical level increases with the increase in continental climate and the heavier granulometric composition of the rhizosphere. A significant influence on the frequency of dangerous years is exerted by the relief, specific features of soil conditions and forest plantations, which can increase or decrease the forest suitability of land and determine the effectiveness of agrotechnical, silvicultural and silvicultural practices [7-9].

Extensive literature [10-14] and original research materials [15-20] allow us to say that forest suitability of land is a biogeographical phenomenon. It is formed from the geographical and biological (biocenotic) potentials of forest formation.

Geographic potential is determined by the size of the productive part of the annual amount of precipitation, its stability over time, water-holding capacity and soil fertility of the rhizosphere. Within close-water areas and arable lands, where the tree stand receives additional water supply from groundwater, retained snow, and adjacent fields, forest suitability is also influenced by the amount of moisture subsidies from these sources.

The biological potential of forest formation is the intensity of deforestation and the resistance of the tree stand to soil moisture deficiency, which increases with the increase in the biological efficiency of the soil solution [17].

Closed, rapidly growing young animals consume the greatest amount of moisture and mineral nutrition [22]. After the culmination of growth and decrease in density, forest stands become less demanding on growing conditions. Therefore, in the broad practice of afforestation and reforestation, it is advisable to understand the forest suitability of land as the ability of the soil of the potential rhizosphere, under certain conditions of moistening and physical evaporation of moisture, to satisfy the need for water-mineral nutrition of young animals of a particular species during the period of their rapid growth with a closed state of the forest canopy. Those. during the period of maximum moisture consumption by the tree stand with a maximum of its unproductive consumption.

In space, the forest suitability of land can be represented as a gradient multi-vector field with increasing indifference of the edaphic vector of forest formation in the direction of increasing climate aridity, increasing oligotrophy, xerophyticity and age of the tree stand. Those. With increasing aridity and decreasing demands of plantings on environmental conditions, the forest suitability of different soils becomes closer. Therefore, it must be assessed differentiatedly – as applied, at a minimum, to groups of breeds that are similar in biology.

In areas with precipitation rates of 350-500 mm/year, massive afforestation of sandy lands with pine crops has become widespread (Pinus sylvestrisL.AndPinus nigrasubsp. Pallasiana (Lamb.)Holmboe). At a lower rate - clump-spike - along low-water depressions. Pine, especially common pine, tolerates low fertility of sands [21-26, etc.]. Its tree stands economically consume soil and ground moisture and do not cause significant deformation of the water-salt regime of the arenas [8, 27-30, etc.]. Massive plantings have the best water regime. They lose moisture less through physical evaporation than strip and rocker ones [14].

On open and lightly overgrown, deeply moistened sands, the main attention is paid to protecting young plants from notching, blowing out and falling asleep with aeol using mechanical and biological windbreaks (fences of dead plants, rows of shells, and other psammophytes). On overgrown sands, agricultural techniques are used to loosen the top layer, eliminate competitors and form a buffer reserve of soil moisture, provided that the necessary anti-deflation stability of the forested area is maintained.

As the aridity of the climate, the cohesion of surface sediments and the density of vegetation cover increase, the width of the strips and the duration of the main tillage increase. And if there is an underlying layer of hard quartz parent sand close to the surface and other screens for downward growth of roots, deep (up to 70 cm or more) loosening of the soil is carried out [24, 25 32-35].

Pine crops take root better when seedlings are planted as soon as possible after the soil thaws [25]. On gently undulating and hilly sands with sparse grass stand, the use of combined machines such as MLU-1, MPP-1, combining soil cultivation with furrows and planting of seedlings, has significant promise [36-38]. The width of ribbons of mineralized soil (furrows with dumps) is increased from forest-steppe to dry-steppe and semi-desert regions from 1.0-1.4 m to 1.8-2.0 m.

The depth of planting seedlings in the soil is adjusted depending on their size and local conditions. Deep planting (to the middle of the covered part of the stem [25, 34]) prevents the danger of their death from rapid physical desiccation of the rhizosphere, shallow planting – from covering the plants with sand “overhead”. Only seedlings with a well-developed fraction of small (suction) roots that was preserved during digging are used, avoiding drying them out.

As arid conditions increase, the duration of the period of agrotechnical care also increases. They are carried out mainly in the first half of the growing season as needed, starting from the 1st-2nd year of life until the crowns begin to close between the rows [34, 37, 39].

When machine planted, 2-year-old pine seedlings with an open root system take root better. The advantage in survival rate of containerized planting material has not been reliably established [41-43]. Enclosed in a container, the root system of plants is distinguished by conservative development - it is delayed from the beginning of growth, and during spring planting in dry conditions and in dry years, the danger of rapid drying out of the sand deeper than the horizon of its placement increases.

The effectiveness of silvicultural work is increased by early (in the 3rd-4th year in rows and 6th-8th in row-spacings) closure of crowns and deep (1.5-2.0 m or more) rooting of young trees [25, 43, 44]. With increasing poverty (dryness and mineral content) of habitats, the growth energy of pine decreases [20, 45]. Acceleration of forest formation is ensured by adequate conditions by increasing planting density and placing planting sites, which does not exclude the mechanization of agrotechnical and silvicultural work [14. 46, 47].

The optimal planting density of pine crops depends on both zonal and edaphic conditions [24, 48-50, etc.], as well as target priorities [51, 52]. On automorphic sands of the steppe zone it is in the range of 4-15 thousand/ha [24, 25, 53]. Increasing the fertility of the rhizosphere and the availability of accessible groundwater makes it possible to narrow this range towards its decrease.

As the precipitation rate decreases, the productivity and durability of closed tree stands decrease, the advantage finally goes to monocultures: on quartz sands -Pinus sylvestris, polymineral –Pinus nigrasubsp. pallasiana[18, 55]. On poor dry sands, undergrowth species do not contribute to their development. They grow slowly and die early. On rich varieties, they create a danger of “choking out” young pines. The growth of pine crops is stimulated only by soil-improving species on poor sands with close groundwater, where it is limited only by the low mineral supply of the soil [55].

The moisture supply of crops is gradually decreasing from sufficient (during the period of agrotechnical maintenance) to acutely deficient(after the closure of the crowns, the cessation of care and the utilization of the buffer reserve of soil moisture). Moisture deficiency, especially during drought, during this period causes inhibition of growth, abundant shedding of needles, thinning, and often severe weakening and subsequent death of young animals [17, 25, 56, 57]. On poor sands, the crisis state of plantings can persist for many years [14, 58]. For the rich, the high fertility of the CS accelerates their recovery from the crisis and provokes a repeated increase in the mass of needles. The need for moisture and the intensity of deforestation of such plantings again sharply increases, which reduces their drought resistance, current growth and can cause additional thinning or drying out of the tree stand [17, 29, 59, 60].

However, on rich (thick layered) sands, preliminary maintenance of the soil in a clean steam and weed-free state in open crops allows the formation of a large starting reserve of available moisture. Additional consumption of this moisture ensures high survival rate of plantings, accelerates growth and differentiation of the tree stand, and increases its productivity. By dampening the destructive effects of dry years, it increases the duration of the period of rapid growth of young pine trees by 5-10 years and increases the durability of plantings [18, 57].

On the contrary, thin soils and moisture-intensive layers located on the surface and at shallow depths from it reduce the effectiveness of summer precipitation, worsen the water regime and forest suitability of sandy lands. The pine root system, concentrating in them, slowly develops deeper. In a dry state, buried layers also prevent downward growth of roots [26, 35, 54, 61-63]. On such sands, pine plantations are short-lived. As a rule, they die from lack of moisture in the 1st or 2nd decade.

The spread deep into pine roots is also limited by parent quartz sand with its hardness above 1.8-2.0 MPa [25], as well as soil layers with a Cl content of more than 0.01% [64]. When they occur closer than 1 m from the surface, sandy soils are unsuitable for pine afforestation without physical reclamation (sanding, deep loosening, etc.) [65].

In full pine plantations on automorphic sands, the main moisture turnover occurs in the root-saturated layer about 2 m thick [66-68]. The annual budget of soil moisture in this layer depends on geographical, edaphic, biocenotic conditions, but mainly on the annual rate of atmospheric moisture (the depth of regular wetting by precipitation). With increasing aridity of conditions, this dependence increases and at the border with semi-desert it can reach almost 100%. The granulometric composition of the soil (moisture capacity) causes significant differences in the reserve of soil moisture only in moisture-rich years. They can make up more than 40% of its productive part, and in abnormally dry years they decrease to 2-3%.

A two- to three-fold reduction in the mass of needles by thinning increases the annual supply of moisture from the atmosphere to the soil by only 2-7%, but at the same time, the intensity of its consumption is significantly reduced and the stability of the moisture supply of the tree stand is almost doubled [7, 8].

Thus, with a decrease in the long-term norm of atmospheric precipitation, the forest vegetation efficiency of various types of sands approaches and shifts to relatively low-moisture differences [14, 69], where the CL has the most stable moisture charge over the years [7]. Calculations show that within the southern Russian Plain on loam, sustainable growth of young pine stands is ensured only when their norm is over 520-570 mm/year, on sandy loam - 470-520, and on loose sand - 400-420 mm/year [15]. In the dry steppe, single-phase sediments with a physical clay content of 3-5% become the most suitable for forests [17, 20]. When the rate of atmospheric precipitation is less than 350 mm/year in loose (physical clay less than 3%) quartz sands, the soil solution is insufficient for the formation of closed plantations [7, 70].

In arid conditions, the growth of pine forests is greatly influenced by groundwater (GW), the availability of which depends on the depth of its occurrence, the particle size distribution and hardness of sediments, the presence of screens from dry and saline horizons [25, 71], as well as on the potential and pressure of moisture [25, 71]. 72, 73], the degree of its mineralization [30]. Thus, on hummocky quartz sands of the northern semi-desert, HS with a mineralization of 0.5-1.5 g/l is considered accessible to pine at a depth of 1.0-2.5 m [26, 74], 0.6...0.7-3 .5 m (on the lower sections of the hillock slopes) [38]. On single-phase quartz sands of the steppe zone - 3.0-3.3 m (8, 75), on polymineral (more impermeable) sands - up to 5-6 m [14, 76], 6-7 m [77]. And for poplar and oak, groundwater with mineralization up to 4-6 and 15-18 g/l is available at a depth of up to 6-8 m or more [28, 78, 79].

Roots near the HS level absorb moisture 1000 times more intensely than those located in higher and drier soil layers [80], which increases the water-mineral supply of tree stands. On poor steppe sands, the quality of pine plantations increases by 1-2 classes [26], and it becomes possible to expand the range of species used. On sandy loam soils and polymineral sands, complete plantings are also formed by sedge (Populus nigraL.), pedunculate oak (Quercus roburL.), Robinia (RobiniaL.) and other breeds [28, 78, 81].

When consuming mineralized water, there is a danger of densification of dissolved salts, and the longevity of plantings is limited by the period of reaching their maximum concentration for the rock [30]. Under these conditions, crops are planted after deep and prolonged moistening of the soil by precipitation in small areas, alternating them with non-forested areas. Relatively wide row spacing, planting spacing, frequent agrotechnical maintenance are used, and clearing and thinning fellings ensure uniformly sparse placement of trees with loosely closed crowns, reducing the intensity of desiccation of ground moisture.

The forest suitability of sands is also reduced by the very close occurrence of GW due to the low thickness of the CS and large seasonal and long-term fluctuations in its level. A high rise in GW during the warm period leads to an additional reduction in the thickness of the rhizosphere, oxygen and mineral starvation of trees and can cause their death (8, 14, 82).

When ground moisture is inaccessible or limited, a reliable means of increasing the drought resistance of young pine trees is considered to be timely thinning aimed at thinning - removing excess needles, and reducing the destructive activity of the tree stand [25, 27; 59, 83, 84]. And belated logging in dense stands on poor sands can also lead to a deterioration in their condition [58, 59].

Under the same climate, the frequency and intensity of logging increases as the granulometric composition of the sand becomes heavier [60]. The maximum effect is achieved when cutting is carried out on the eve of dry years [59], but due to the rapid restoration of needle mass, it is short-lived [26, 43, 85].

On steppe automorphic sands, the drought resistance of pine plantations that have successfully survived the moisture crisis increases with age due to the development of the root system, early culmination and a decrease in tree growth, a decrease in the transpiration activity of needles, and they live up to 60-90 years or more.

Forest fires, pests and diseases cause great damage to pine plantations in the steppe zone. The problem of their protection and protection is more acute than in forest areas and has its own specifics [86-88]. Thus, the main practical task of farming in pine forests is to reduce the weakening effect on tree stands of dry years. In non-closed crops, this is timely and high-quality agrotechnical management; in closed young stands, thinning in the period before the culmination of their growth in height, aimed at reducing the density of the tree stand, the mass of transpiring needles and the supply of forest combustible materials. A prerequisite for the implementation of these measures is the preservation of the density of the crowns of edge trees as a barrier to the penetration of steppe vegetation under the canopy of plantings, the grass burning front, and also as a shelter and source of food for wild animals [8, 89]. In arid areas, it is necessary to reduce the time it takes to detect and suppress fires, pest proliferation and the development of root pathologies.

On the territory of dry steppe and semi-desert, non-saline and slightly saline loamy soils on the plains and slopes of watershed uplands are also promising objects for the creation of environmental and recreational forests and wide forest belts [90-92]. With a large deficit of atmospheric moisture, the patterns of dynamics of the water regime of forest stands established on sands can be traced even more clearly [6, 9, 93-95].

On heavy soils with inaccessible groundwater and a precipitation amount of 300-500 mm/year, the potential viability of the tree stand is limited by the unfavorable location of plantings in the relief, the high content and close to the surface occurrence of the carbonate accumulation horizon, as well as the presence of undergrowth, other competitors for moisture, and increased density upper tier [96]. Under these conditions, island protective forests and wide protective forest belts should be created not as massifs of homogeneous structure, but as a combination of forest and meadow-steppe ecosystems. It is advisable to allocate the best areas in terms of forest growth conditions for the cultivation of long-lived tall species, while those less suitable for forests should be allocated for shrub thickets and steppe grasses. Closed depressions with stagnant flooding should be left in their natural state. Preference should be given to afforestation of depressions and shady slopes with pure shrub-free crops of valuable deciduous species capable of forming and maintaining a moderately open forest canopy for a long time. The modes of their creation and education must have their own modifications depending on the terrain, dry climate and the duration of the period with stable snow cover. Reducing the latter is equivalent to reducing the annual norm of atmospheric precipitation.

In general, the technique of cultivating forest plantations should include such mandatory techniques as the selection of the most suitable forest areas, moisture-accumulating basic tillage, the creation of compositionally pure plantings of relatively shade-tolerant (dense-crowned) and drought-resistant species of medium density, agrotechnical care before the closure of the crowns, as well as frequent intensive thinning of young stands, promoting the conservation of the forest environment in thinning middle-aged and ripening stands.

In depressions, the main tillage can be limited to 1-2 years and carried out according to the black fallow system with plantation plowing. Relatively wide (3.5-4.0 m) row spacing, frequent agrotechnical maintenance, and early, relatively intensive clearing in young stands are advisable. Established plantations require repeated careful sanitary-selective cuttings of predominantly grassroots type (i.e., a gradual expansion of the tree feeding area while maintaining a high density of the forest canopy). A significant deterioration in the moisture supply and condition of plantings here should be prevented by installing simple hydraulic structures (dams).

Afforestation of flat areas of flats, slopes and gently undulating plains should be aimed at creating reclamation plantings of low marketability for 2-3 years and deeper basic soil cultivation, ensuring the destruction of the carbonate horizon and the formation of a large starting moisture reserve. Narrower (2.5-3.0 m) row spacing is advisable to speed up the closure of crops and reduce the period of agrotechnical care. The feeding area of trees should be expanded by less intensive than in depressions, uniformly selective clearing and thinning fellings, gradually forming loosely closed plantations of low trees with a spreading crown.

In the entire range of conditions of the dry steppe of the EPR, on dark-colored soils of the semi-desert, plantings of pedunculate oak and common ash have the most stable growth and longevity (Fraxinus excelsior L.), field maple (Acer campestre L.) and other breeds. On light chestnut soils – large and medium-sized shrubs: Acer tataricum L., Amelanchier Medik., Cotinus coggygria Scop., Elaeagnus angustifolia L., Lonicera tatarica L. etc. On the undulating plains of Western Siberia with chestnut soil Plants that are pure or with a small admixture of non-aggressive species grow better and remain viable longer of Ulmus laevis Pall. and Pinus sylvestris (on relatively light soils),and on dark chestnut ones – Pinus sylvestris, Larix sibirica Ledeb., Betula pendula Roth, Populus × sibirica G.V. Krylov and Populus balsamifera L. In the crops on the southern chernozems of this region, pure stands of both deciduous and coniferous species have stable growth and great vitality, which form more durable and commercially valuable plantings. The feasibility of creating wide strips of small-leaved elm, as well as using it as a companion to birch, poplar, and elm, requires additional study [97].

Within areas of washed away, blown soils and on steep slopes reserved for forest crops, special methods of basic soil cultivation should be used, aimed at preserving their residual fertility, erosion resistance and moisture accumulation. Mostly oligotrophic breeds are used [98-100].

Increasing the durability of previously created viable plantings is ensured by eliminating competitors of the main species for moisture: living ground cover, shrubs, and accompanying species.

In field-protective afforestation, an effective means of improving the water regime of plantings is to create them in the form of 2–3-row forest strips (FZLP), in which the tree stand receives additional nutrition due to the accumulation of snow, as well as from the soil of adjacent fields [101, 102].

The main technological methods for planting and growing them are also moisture-accumulating basic tillage, snow retention, and the creation of pure plantations from the most densely crowned trees and shrubs adapted to local conditions. The placement of planting places (choice of row spacing and planting/sowing spacing) provides conditions for the accumulation of snow mass throughout the entire diameter of the forest belt, mechanization of agrotechnical management until the crowns close between the rows and thinning (clearing and selective sanitary felling).

When crossing extensive depressions, it is advisable to replace xerophytes with more moisture-loving species.

On non-saline and slightly saline soils with shallow groundwater up to 5-7 m, screened by difficult-to-root-impermeable sediments, it is advisable to perforate them with boreholes.

On lands with increased salinity and complexity of zonal soils, the main processing system is replaced by a 1-3-year steam system using planking or longline plowing [103].

The average depth of snow cover and the supply of snow in the feeding zone of the forest stand of the FZLP are mainly determined by the amount of solid precipitation (r = 0.72 and 0.77), density, height of the forest stand and row spacing. In forest belts with shrubs, snow deposition is negatively affected by an increase in the number of rows, tree height and row spacing.

Shrubbery and single-row, weakly blown forest strips made of dense-crown species accumulate snow most effectively and work “for themselves.” Narrow curtains and single rows of bushes, covered with snow, act as semi hidden mechanical protection. Their creation increases and stabilizes the snow height on inters trip fields.

The best combined models are 3-row PZLP from an edge row of shrubs and two moderately open rows of trees.

Snow deposition in 2-3-row non-shrub forest belts increases with the expansion of row spacing to 3.0-3.5 m with the density of the middle-aged elm tree stand up to 600-800, birch - 900-1000, pine >1000 trees per hectare. Excessive compaction and growth in the height of the tree stand of these strips lead to a redistribution of the snow mass in favor of the edges and adjacent areas of the fields. When creating a 2-row PZLPs, it is necessary to slightly increase the row spacing and increase the density of the rows.

PZLP from elm and other dense-crown species should be created mainly in 2-rows, from birch and larch - in 3-rows. 2- and 3-row pine PZLPs can be effective when optimizing the density of their rows. The low-hanging crowns of edge trees of this species successfully replace rows of shrubs for a long period of time.

Raising the living crown of edge trees causes snow to blow out, sodding of the soil in the forest belt, and worsens the water regime of the forest stand.

In the PZLP from bio groups of trees, the best conditions for snow deposition occur when they are moderately dense. The clumps of bushes form chains of snow mounds 1.5-2.5 m high with a wide base.

The most stable spring reserves of soil moisture over the years are formed and replenished due to rains in shrub less 2-3-row PZLPs with relatively wide row spacing, and they are spent more economically in moderately dense simple and combined plantings of pine and birch [104].

Acknowledgments

The work was carried out on the topic of State task No. 122020100309-0 "Theoretical foundations, basic principles and technologies for improving the efficiency of protective afforestation and integrated phytomelioration on degraded, disturbed and low-productive lands of the arid zone of Russia."

References

1. The main UN document on environment and development (Rio de Janeiro, 1992) - “Agenda days for the 21st century” (unsed; ria-92).https://studfile.net/preview/7771424/page:7/(1992G.).
2. K. Kulik [et al.], The strategy of protective forestation development in Russian Federation for a period till 2020 year. VNIALMI. – Volgograd, 2008. – 34 p. (2008)
3. Decree of the President of the Russian Federation of October 26, 2023 No. 812 “On approval of the Climate Doctrine of the Russian Federation” Publication number: 0001202310260009.(2023).
4. R. Edelgeriev [and others], Global climate and soil cover in Russia. **Vol. 3**. pp. 430-453, (2021).
5. A. Manaenkov, Bulletin of PSTU. Ser.: Forest. Ecology, Nature management. Development of the foundations of steppe and protective afforestation: theoretical, applied aspects and tasks in modern conditions, No. 2 (30). pp. 5-23 (2016).
6. A. Manaenkov, N. Zyuz, Bulletin of the Russian Academy of Agricultural Sciences. Landscape and economic indication of sandy lands in arid regions. No. 2. pp. 53-55 (1997).
7. A.Manaenkov, Methodology and standards for assessing the forest suitability of lands for massive afforestation in the unstable moisture belt of the EPR. 35 s. (2001).
8. A.Manaenkov, Forest reclamation of arid zone arenas. 420 p. (2014).
9. A. Manaenkov, NEWS SPb LTA. Patterns of water regime, growth and durability of artificial tree stands in arid conditions. **Vol**. **221.** pp. 91-106 (2017).
10. P.Pogrebnyak, Fundamentals of forest typology. 456 p. (1955).
11. D. Vorobiev, Methodology of forest typological research. 388 p. (1967).
12. A. Bellegarde, Steppe afforestation. 336 pp. (1971).
13. E. Migunova, Forest typology, school of V.V. Dokuchaev and questions of geography. Sec. 2.2. 302 pp. (2009).
14. N. Voronkov, Moisture circulation and moisture supply of pine plantations. 184 p. (1973).
15. A. Manaenkov, Method for assessing the forest suitability of lands in the zone of unstable moisture, in mat. owls Forest stationary research: methods, results, prospects, Moscow, Academy of Sciences of the Russian Federation, September 2001, pp. 148-150 (2001).

16. A. Manaenkov, Lesn. household On the prospects for the development of forest typology. No. 5. – pp. 27-29 (2005).
17. A. Manaenkov, Forestry. Features of the water regime of the root layer and drought resistance of pine crops. No. 2. – pp. 52-61 (2009).
18. A. Manaenkov, G. Surkhaev, I. Surkhaev, Lesn. household Features of afforestation of sandy lands of the Terek-Kuma interfluve with pine crops. No. 5. pp. 36-38 (2010).
19. A. Manaenkov, Forest reclamation of arid zone arenas. 2nd ed. reworked and additional 428 pp. (2018).
20. A. Manaenkov, On the forest suitability of lands in the arid zone, in Sat. conference Forestry: current problems and ways to solve them, Nizhny Novgorod, November 25, 2022 under the general. ed. N. N. Besschetnova. pp. 166-171 (2022).
21. G. Morozov, Selected works in 2 volumes, 1970. The doctrine of the forest. **Vol. 1**. P. 27-458 (1970).
22. V. Veselovsky, On the growth of pine grown on the Don sands. 162 p. (1921).
23. V. Dubyansky, Sands of the Middle Don and their use in agriculture and forestry. 231 p. (1949).
24. V. Mironov, Ecology of conifers during artificial afforestation. 232 p. (1977).
25. N. Zyuz, Pine cultures on the sands of the Southeast. 155 p. (1990).
26. A, Gael, L. Smirnova, Sands and sandy soils. 252 p. (1999).
27. N. Svetlishchev, Lesn. household Load of trunks per unit area in pine crops, No. 9. pp. 21-22 (1965).
28. N. Kulik, Water regime of sands of the arid zone. 280 p. (1979).
29. N. Zyuz, M. Lobacheva, On the drought resistance of pine on various soil substrates (data from growing season experience), in collection. tr. VNIALMI Problems of integrated development of sands and melioration of pastures. **Vol. 2 (82).** pp. 16-20 (1984).
30. V. Petrov, Agroforestry science in the twentieth century. Forest reclamation of arid areas. pp. 162-198 (2001).
31. V. Mironov, N. Voronkov, N. Zyuz, To justify the depth of plowing of sandy soils for pine crops in the steppe zone, in collection. tr. VNIILM, p. 63-71 (1965).
32. V. Mironov, Afforestation of the sands of the Southeast. 168 p. (1970).
33. V. Vinogradov, Development of sands. 272 p. (1980).
34. N. Zyuz, Agroforestry and soil fertility. Forest reclamation of unproductive lands in the arid zone. – pp. 213-233, Moscow, Russia (1991).
35. A. Manaenkov, Modern problems of afforestation of sands of the arid zone with pine, in Sat. conference Centuries-old experience of the formation of forest ecosystems in agro landscapes of the arid zone, Kamyshin, September 16-19, 2003. pp. 162-172 (2003).
36. V. Kravchenko, A. Melnikov, Guidelines for planting pine crops on the hilly sands of the Middle Don. 9 p. (1974).
37. N. Zyuz, M. Lobacheva, Yu. Zhdanov, Planting pine crops on sand without the use of manual labor, in collection. tr. VNIALMI Reclamation and economic development of sands in arid regions. pp. 82-91 (1981).
38. A. Manaenkov, N. Zyuz, B. Zhunisov, Lesn. Household. Forest conditions and forest cultural development of the Urdinsky sandy massif. No. 5. pp. 35-38. (1995).
39. A. Manaenkov [et al.], Recommendations on the technology of creating reclamation, recreational and other forest plantations on the sands of the south-east of the European part of the CIS. 43 p. (1993).
40. E. Robonen [et al.], Izv. universities Forest magazine Morphometric criteria for assessing the quality of container seedlings of coniferous species. No. 5. pp. 42–57. (2023).https://doi.org/10.37482/0536-1036-2023-5-42-57

41. V. Sakhnov [et al.], Lesn. messenger, FORESTRY BULLETIN. Growth and development of Scots pine forest crops created by planting material with a closed and open root system in various conditions of the Republic of Tatarstan. **Vol**. **27**. No.2. 38-48 (2023).
42. A. Ilyintsev [et al.], Lesn. messenger, FORESTRY BULLETIN. Experience in creating forest crops on microelevations during excavation tillage. **Vol**. **28**. No. 2. P. 5–16 (2024). DOI: 10.18698/2542-1468-2024-2-5-16
43. V. Mironov, V. Karlin, The structure of pine crops on the Middle Don and thinning in them, in collection. works Donskoy NILOS, 1970. **Vol.3**. P. 39-49 (1970).
44. A. Orlov, Y. Abaturov, A. Matveeva, Forestry. The state of pine after the drought of 1972 in the southeast of the Moscow region. No. 6. pp. 35-46 (1974).
45. V. Rubtsov, Pine cultures in the forest-steppe. 285 pp. (1969).
46. P. Komarovsky, Lesn. household On the reasons for the drying out of crops in the Buzuluk forest. No. 5. pp. 32-33 (1951).
47. P. Komarovsky, Lesn. household Fundamentals of the sustainability of pine crops on the dune hills of the Buzuluksky forest. No. 1. pp. 25-29 (1953).
48. V. Zherebtsov, Lesn. household Planting density and timing of closure of forest crops in the steppe. No. 1. pp. 27-29 (1957).
49. V. Rubtsov, Lesn. household On the question of the initial density of forest crops. No. 1. p. 25-27 (1957).
50. Forest household On the issue of planting density of forest crops (final article). No. 11. p. 30-36 (1958).
51. T. Govorova, I. Shinkarenko, The influence of the density of pine crops on their productivity in the northern part of the steppe forests of Ukraine, in collection. Forestry and agroforestry. **Vol. 55**, pp. 60-64 (1979).
52. A. Gursky, Abstract. diss. Doctor of Agricultural Sciences nuk. Principles for improving the assessment of forest resources, management and forest management in Kazakhstan. 36 p. (1997).
53. I. Sukhov, Patterns of growth and productivity of experimental pine crops of different densities in the Voronezh region, in collection. Pine forests of Russia in the system of multi-purpose forest management, Voronezh September 29 – October 1, 1993 Section 2-3. pp. 40-41 (1993).
54. A. Ivanov, M. Dryuchenko, Integrated development of sands. 302 p. (1969).
55. A. Manaenkov, Results and experience of pine afforestation in southern European arenas in Russia, in collection. tr. VNIALMI Protective afforestation: history, achievements, prospects. Issue 1 (108). pp. 48-56 (1998).
56. A. Manaenkov, Lesn. household The basis for the stability of pine crops under unstable moisture conditions. No. 4. pp. 35-38 (2002).
57. A. Manaenkov, Lesn. household. Urgent problems of forestry in southern Russia. No. 3. pp. 8-9 (2012).
58. I. Shinkarenko, T. Govorova, P. Kravtsova, The influence of the density of pine crops on their productivity in the conditions of steppe forests of Ukraine, in collection. Forestry and agroforestry. **Vol. 45**. pp. 12-19 (1976).
59. N. Zyuz, Lesn. household Increasing the drought resistance of young pine trees. No. 3. P. 38-40 (1978).
60. A. Manaenkov, Methodological recommendations for the design of thinnings in artificial young pine forests. 34 pp. (2004).
61. V. Vinogradov, Lesn. household. Ways to increase the biological sustainability of forest crops in the steppe. No. 7. pp. 40-45 (1971).
62. I. Matyuk, Sustainability of forest plantations. 133 p. (1983).

63. A. Manaenkov, A. Ponomarev, Izv. Universities. Forest magazine. Forest suitability of ecotopes of the Volga-Akhtuba floodplain for pine crops. **Vol. 4**. pp. 127-145 (2022). Doi:10.37482/0536-1036-2022-4-127-145.
64. Guidelines for research and design of measures for the integrated development of sands in the south and southeast of the European part of the USSR under the general direction of V.N. Vinogradova. 78 p. (1985).
65. N. Zyuz, N. Prozorov, Radical amelioration of plant conditions on the sands of arid regions, in collection. VNIALMI Comprehensive economic assessment of protective forest plantations. **Vol. 3 (98).** pp. 120-130 (1989).
66. I. Sudnitsyn, Movement of soil moisture and water consumption. 254 p. (1979).
67. I. Sudnitsyn, E. Shein, A. Gael, Forestry. The influence of pine root concentration on soil moisture absorption. No. 4. 9-17 (1976).
68. N. Muromtsev, Reclamation hydrology of soils. 272 p. (1991).
69. N. Prozorov, Radial growth of Scots pine as one of the indicators of variability in the ecological conditions of its growth on the sands of the steppe zone, in collection. tr. VNIALMI Forest reclamation and landscape. **Vol. 1 (105).** pp. 145-157 (1993).
70. A. Manaenkov, A. Kulik,Forestry information. Water-mineral characteristics of the substrate and drought resistance of pine trees.No. 2. pp. 46-56 (2017).
71. I. Matyuk, V. Mironov, Consolidation and afforestation of sands in the European part of the USSR. 104 p. (1951).
72. R. Slatuer, Plant-water relationships. – 336 p., London. Academic Press (1967).
73. E. Newman, The Plant Root and Its Environment, ed. Carson EW – Charlottesville: University Press of Virginia. Root and soil-water relations. – P. 363-440 (1974).
74. A. Gael, A. Yakshina, L. Brysova, Sands of the Volga-Ural interfluve and the Urda delta as an object for afforestation, in collection. tr. VNIALMI Increasing the productivity of agricultural land in the Caspian region using forest reclamation methods. **Vol. 3 (89).** pp. 12-26 (1986).
75. A. Molchanov, Hydrological role of pine forests on sandy soils. 487 p. (1952).
76. A. Gael, R. Voronkov, Botanical Journal. Root system of pine (Pinus sylvestris L.) on sandy soils of Kazakhstan and the Don. No. 4. pp. 503-517 (1965).
77. V. Rutkovsky, Buzuluksky pine forest. **Vol. 4**. 144 p. (1950).
78. P. Yazan, Terek-Kuma sands, their consolidation and use in agriculture and forestry. 78 p. (1955).
79. V. Petrov [et al.] Recommendations for the formation of forest-pastures in the arid zone. 42 p. (2000).
80. D. Ricosky, Pattern of water uptake and root distribution of soybeans (Glycine max) in the presence of a water table-Agron. J. 64. – P. 292-297. (1972).
81. N. Smirnov, A. Polyakova, Results of the introduction of tree and shrub species on the Terek Sands, in collection. tr. on the development of the Terek-Kuma sands. **Vol. 1**. pp. 123-134 (1963).
82. A. Orlov, S. Koshelkov, Soil ecology of pine. 323 p. (1971).
83. N. Bondarenko, Lesn. household. Thinning in pine crops in the steppe, No. 8. P. 30-31 (1972).
84. L. Yashcheritsina, Bulletin of the Volgograd CSTI. Timely thinning of transpiration mass reserves as a way to increase the drought resistance of pine. 4 s. (1985).
85. A. Yurkovsky, Abstract. diss. to-ta agricultural Sci. The influence of thinning on the water regime and phytomass of steppe pine plantations. 18 p. (1978).
86. N. Zyuz, A. Manaenkov, Forestry information. Problems of protecting pine forests in the south of European Russia. No. 8. 33 (1996).

87. E. Artsybashev, V. Gusev, A. Manaenkov, Fire protection of forest crops in the steppe zone (Practical recommendations). 55 p. (2003).
88. A. Manaenkov, V. Yurchenko, Prevention of forest fires in pine forests of the Volgograd region (Practical recommendations). 52 p. (2006).
89. A. Menaenkov, Forest-ecological and pyrogenic role of the edges of pine plantations, in materials of the international. scientific-practical conference Ecological and reclamation aspects of rational environmental management, Volgograd, January 31 – February 3. **Vol. 4**. pp. 445-450 (2017).
90. Yu. Kiryukov, News of Universities. Forest magazine. The growth of hollow-gross plantings created by P. A. Lukyanov in the Salsky forestry. No. 3. pp. 8-11 (1961).
91. S. Kraevoy, Protective afforestation in semi-desert. 120 s. (1968).
92. E. Godnev, Lesn. household On the possibility of creating oak forests in the dry steppe. No. 8. pp. 38-39 (1983).
93. A. Manaenkov, M. Kostin, V. Shkurinsky, Bulletin of PSTU. Ser. "Forest. Ecology, Nature Management". Current state and possibility of growing oak forests of industrial importance on complex soils of dry steppe and semi-desert. **Vol. 2 (16).** pp. 12-19 (2012).
94. A. Manaenkov [etc.],Methodological guidelines for increasing the durability of wide-area protective forest plantations in the south of the European territory of Russia. 56 p. (2013).
95. A. Manaenkov, V. Shkurinsky, M. Kostin,Bulletin of PSTU. Ser. "Forest. Ecology, Nature Management". Peculiarities of growth and durability of “oak forests of industrial importance” plantings on zonal soils of the dry-steppe Don region. **Vol. 2 (18).** pp. 5-17 (2013).
96. A. Manaenkov, Vestn. Moscow un-ta. Ser. 5. Geogr. Growing conditions and cultivation of oak forests on the plains and slopes of the Volga and Ergeninskaya uplands and the plains of the Salo-Manych interfluve. **Vol. 79**. No. 3. pp. 53–63 (2024). DOI: 10.55959/MSU0579-9414.5.79.3.5
97. A. Manaenkov, S. Andreev, M. Ulyanov, Features of growth and cultivation plantings of Quercus robur L. on the sands of the North-Eastern Ciscaucasia (to be published).
98. A. Kuznetsov,Soil erosion, protective afforestation and harvest (practical recommendations). Reclamation of ravine-beam lands. pp. 57-64 (1979).
99. I. Zykov, V. Ivonin, V. Dukhnov, Protection of slopes from erosion. 64 p. (1985).
100. V. Anopin, Geographical basis for forest reclamation of degraded urban landscapes of the Lower Volga region. 170 pp. (2005).
101. A. Manaenkov, P. Podgaetskaya, M. Podgaetsky,Vestn. Moscow un-ta. Ser. 5. Geogr. Peculiarities of growth of small-row forest belts on chestnut soils. No. 3. – pp. 134–142 (2022).
102. A. Manaenkov, P. Podgaetskaya, V. Popov, Vestn. Moscow un-ta. Ser. 5. Geogr. The influence of shelterbelt forest belts on the development of spring wheat in the edge zone of crops. **Vol**. **78.** No. 4. pp. 97–106 (2023).DOI: 10.55959/MSU0579-9414.5.78.4.9
103. A. Manaenkov, L. Abakumova, P. Podgaetskaya, NEWS OF Nizhnevolzhsky Agro-University Complex: science and higher professional education. Increasing the durability of shelterbelts in the south of Western Siberia. **Vol. 2 (34).** pp. 41-47 (2014).
104. A. Manaenkov, P. Podgaetskaya, Izv. Universities. Forest magazine. On the water regime of forest belts in the dry steppe of the Altai Territory (to be published).