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Restoration of Degraded Lands in the Arid Zone of the European Part of Russia by the Method of Phytomelioration

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Abstract: In arid areas, it is necessary to apply phytomelioration widely to create an organized, stable and ecologically well-maintained forest–agrarian landscape in which agricultural lands can provide diverse and stable products, and to provide optimum ecologyfor the existence of a natural and anthropogenic system. The aim of this work is to select shrub and herbaceous plant species for the restoration of degraded lands in the arid zone of the European part of Russia with the prospect of preserving and increasing the productivity of native biodiversity, and the structure and dynamics of pasture ecosystems. The object of this study is the desert and semi-desert zone in the south-east of the European part of Russia within the Caspian lowland. The productivity of vegetation in the studied zone is largely determined by soil conditions, seasonal weather phenomena and animal grazing. The lowest forage productivity is characterized by the winter period with very strongly beaten white-field-grain pastures on unsalted, weakly- and medium-salted light chestnut soils; very strongly beaten bulbous-bluegrass-white-field pastures on saline deep, medium and strongly saline light chestnut soils; or medium-beaten black-wormwood and bulbous-bluegrass-black-wormwood pastures on small and crusty salt flats. The highest productivity is observed in the spring-summer period on unbroken areas of unsalted, weakly and medium saline light chestnut soils occupied by white-field cereal phytocenoses. The intensity of transpiration of perennial forage grasses growing on sandy loam soils of the dry steppe zone was measured. The analysis of biomorphological features of native forage species resistant to climate change and pasture load, and promising for phytomeliorative reconstruction of degraded pastures include: ecotypes of the genus *Artemisia* (*A. pauciflora*, *A. Lercheana*) and the genus *Agropyron* (*A. cristatum*, *A. fragile*, *A. pectinatum*), growing on various soils in natural conditions in the south-east of the European part of Russia. It was revealed that the seed productivity of *Agropyron* varieties varies within 0.5–4.0 c/ha depending on the variety, the method of sowing and climatic conditions of the year. To increase seed productivity, wide-row sowing with row spacing widths of 45 and 70 cm is promising.

Keywords: desertification; degradation; vegetation cover; shrubs; pasture ecosystems; phytomelioration; transpiration

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1. Introduction

There are arid territories in more than 110 countries. For them, there is the threat of the global environmental problem of human impact resulting in desertification and drought. The main areas of the world's arid lands are located in North Africa (up to 60%), Eurasia and the Americas [1–6]. The share of degraded lands in the arid regions of Europe is 33.2%. In Russia, arid zones cover an area of about 150 million hectares, where extremely and highly arid territories (aridity coefficient of 0.11–0.30) amount to 8.7–13.1 million hectares and are confined to the Caspian province of the desert and semi-desert zones of Russia.

The general global vector is moving in the direction of expansion (by 12 million hectares on average annually on a global scale) and strengthening of anthropogenic desertification, especially local foci. The most susceptible areas to land degradation are near settlements, water points and areas with gentle slopes [7–9]. Large-scale and long-term global studies of these processes make it possible to support an effective and flexible policy of environmental restoration [10,11]. International organizations (FAO, UNEP, ICRAF) are paying great attention to measures to combat this dangerous phenomenon since about 30% of the world's population lives in desert territories, which occupy 22% of the land area [12–18]. The increasing pace of desertification processes increases the urgency to study its patterns in order to identify mechanisms for natural stabilization of ecosystems and restoration of potential vegetation on their basis. To bridge the gap between biophysical and ecosystem assessments of desertification, new integrated methods and techniques are needed, such as remote sensing [19], and others [20–23]. Predictive ecological models should have a practical focus on the restoration of degraded arid lands [24,25]. Modeling of changes in the area of reclaimed land and the return of cultivated land to forests or pastures under future climatic scenarios is of great practical importance for ensuring sustainable development and national food security [26]. Effectively combating desertification also involves identifying areas vulnerable to desertification [5].

The signs of desertification and ecological destabilization of natural landscapes are most clearly manifested as a result of anthropogenic impact in the territory of the steppe, semi-desert and dry steppe zone in the European part of Russia (EPR). Aridity and the anhydrous conditions of the territory, the salinity of soils and the low productivity of vegetation hinder the economic development of these vast lands. Extreme droughts form here once every few years and cover large areas [27]. The maximum frequency (five droughts in ten years) is observed in May and July near the northern and southern borders of the subhumid zone. For 100 years there has been an increase in aridization which has been more influenced by the increase in the frequency and intensity of summer droughts than spring droughts [22,23,28]. Droughts are accompanied by significant crop losses (especially grain) [29]. Presumably, this trend will continue. According to the UKMO global climate change scenario, wheat yields are projected to decrease to 22% in some regions [30].

Forecast estimates of the development of desertification processes against the background of general climate warming allow us to speak about serious physical, geographical and agroecological changes. The nature, trends and rates of desertification of the EPR lands indicate that it occurs as a result of irrational anthropogenic impact combined with adverse climatic phenomena, and modern conditions lead to a decrease in the area of farmland, an increase in environmental tension and a deterioration of the social situation. Currently, the natural feeding grounds of the Astrakhan and Volgograd regions, the Republic of Dagestan and Kalmykia, the eastern districts of the Rostov Region and the Stavropol Territory are in a crisis situation on the territory of the EPR. The share of degraded lands in this territory is 9–67%. In the Volgograd and Rostov regions, more than 60% are subject to degradation, and the share of improved land is only about 10% [31].

The increasing trends in the number and area of desertification foci cause serious concern about the preservation of existing landscapes, which are increasingly being transformed into deserts. Such landscapes are unstable, and under certain conditions. they are a reserve for the progression of desertification [32]. Often, several processes are going on simultaneously in the same territory, leading to degradation of the soil and vegetation cover (salinization, deflation, erosion) [33,34]. Especially severe desertification is characteristic of light soils of sandy and sandy loam granulometric composition [21]. Reduction of protective forest cover and reclamation efficiency of forest plantations contributes to the strengthening of degradation processes [35]. The most important factor of desertification is also a significant increase in the area of secondary saline soils. Over the past 10 years, their area has increased 2.6 times.

Against the background of the increased negative impact of natural and anthropogenic factors, the process of degradation and desertification is aggravated by the irrational organization of the land use territory [36,37]. Plowed soils annually lose tens of tons of fine-grained soil from each hectare, which reduces the natural fertility of the land and accelerates the overall degradation of steppe ecosystems. This happens especially during blocking processes when a powerful anticyclone is installed. In this case, the energy of the wind load on the soil surface increases significantly in relation to the climatic norm, and its destruction takes on the character of a catastrophe [36].

There is a close relationship between the spatial structure of vegetation and desertification associated with intensive pasture grazing [11]. Degradation proceeds intensively and reaches a high level on pastures that are used year-round. Unregulated cattle grazing and overgrazing are the main cause of pastoral vegetation digression, soil degradation and formation of mobile sand arrays [5,38]. Pastures are most at risk during the dry season. If a severe and prolonged drought occurs, then desertification can occur quickly. In a good year, relatively intact territories can use their "resilience" strategy, but degraded places are always more vulnerable. The consequences of anthropogenic impact can be assessed by the change of plant communities that perform the environmental function [39–41]. The change of communities can be reversible if the habitat is not disturbed. If the habitat is disturbed, the restoration of vegetation cover is delayed indefinitely [42].

The current negative transformation of pasture ecosystems has reached unprecedented proportions, and the increase in the rate of desertification has led to the need to eliminate the consequences of pasture digression and wind erosion, including through biological reclamation and phytomeliorative technologies [43,44]. Phytomelioration of semi-desert-steppe communities (consolidation of sands with grasses, semi-shrubs and woody plants, improvement of grasslands by sowing grasses, creation of protective forest plantations, etc.) is one of the techniques for restoring agro-resource potential and improving the functioning conditions of degraded lands with the help of herbaceous or woody vegetation [10,27,45]. In protected areas, the hydrothermal regime is significantly improved, surface runoff is reduced, soil formation processes are optimized, rivers and reservoirs become cleaner and fuller, flora and fauna are richer and more diverse [46,47]. The efficiency of phytomelioration increases with the formation of an interacting ecosystem using the energy resources of plant phytomass throughout the agro-landscape territory. The greatest positive effect is achieved when covering entire catchment basins or areas of deflation and desertification, regardless of the boundaries of administrative and economic formations [35].

When performing work in the foci of deflation, phytomelioration includes a sequence of local work, effective techniques for creating a stable vegetation cover, accelerating the natural overgrowth of desolate areas and reducing the salinity of the upper soil layer [48–51]. The advantage of phytomeliorated lands over natural ones is undoubted [52]. Semi-shrubs and grasses form a high proportion of the feed mass eaten from the second year of life. The growth of phytomass occurs within 4–8 years. Perennial cereal and legume agrocenoses form 65% of the crop before July with productive longevity of 4–6 years, semi-shrub communities reach the maximum yield during the summer-autumn period with productive longevity of 16 years or more. The agrophytocenoses created from introduced semi-shrubs and grasses accumulate the highest stock of feed mass eaten and exceed the yield of natural pastures by 3–5 times.

The aim of this work is to select shrubby and herbaceous plant species for the restoration of degraded lands of the arid zone in the EPR of Russia with the prospect of preserving and increasing the productivity of native biodiversity and the structure and dynamics of pasture ecosystems.

This research expands bioecological knowledge about the features of degradation and restoration of arid pastures with the help of native grass species.

2. Materials and Methods

2.1. Geographic Area of Research

The territory of the desert and semi-desert zone is located in the southeast of the European part of Russia within the Caspian lowland. According to administrative zoning, the arid zone occupies the Astrakhan Region, the Republic of Kalmykia, the southeastern part of the Volgograd Region and the north of the Republic of Dagestan.

The geographical location of the territory determines the main climatic features. They manifest themselves in the formation of a continental climate characteristic of large areas of land, as well as the periodic introduction of Atlantic air masses. By this, a climate is formed in the study area with a relatively cold and snow-free winter, and a long hot summer. Cyclones penetrating into the Caspian Sea, as a rule, are inactive and therefore give negligible amounts of precipitation. The average annual precipitation is 150–250 mm. The indicators of the average annual air temperature change in the direction from the northeast to the southwest. The hottest month is July. The average monthly temperature is +24.5–25.0 °C. The coldest month is January. An increase in temperatures and a decrease in precipitation from north to south increase the aridity of the climate in this direction. Annually, more than 800 mm evaporates from the surface of the northern part of the Caspian Sea, and the humidification coefficient is 0.3. The sum of active temperatures ranges from 2700° in the northern part of the region to 3300° in the south. Dry winds peculiar to the territory of the Caspian lowland further aggravate its aridity.

The soil cover of the arid zone of the EPR is mainly represented by chestnut soils of light mechanical composition with a predominance of sandy loam. In all soils of light mechanical composition, the predominance of the fine sand fraction, which makes up more than 50% of the sum of fractions, is clearly noticeable. The content of coarse-powdered and silty fractions decreases from light-loamy soils to sandy ones. With such a ratio of soil fractions, they have high water permeability, insignificant capillary rise, and are in a dry state. They are subject to fluttering (deflation). The upper horizons of chestnut soils of light mechanical composition are low-humus. The humus content ranges from 1.1–1.7% in light loamy soils, 0.6–0.95% in sandy loam and no more than 0.80% in sandy soils.

2.2. Data Collection

The work is based on modern methods of botanical–geographical and ecological–phytocenological research using scientific and practical methods of restoration and prolongation of productive longevity of pastures. The research was carried out taking into account expedition materials to assess the productivity of forage lands and identify ways to increase their feed capacity. Monitoring studies cover the territories of the Republic of Kalmykia, Volgograd and Astrakhan regions.

Biomorphological indicators and productivity of ecotypes of the genus *Artemisia* (*A. pauciflora*, *A. Lercheana*) and the genus *Agropyron* (*A. cristatum*, *A. fragile*, *A. pectinatum*) growing on various soils in natural conditions of the south-east of the European part of Russia were studied. Biomorphological indicators of species of the genus *Artemisia* and *Agropyron* allow us to assess their real state in places of natural growth, as well as to form the basis for the development of scientifically sound approaches to their rational use. The work uses generally accepted methods of biomorphology and geobotanical descriptions: Ramensky (1956), Gatsuk (1974), Serebryakov (1980), Mazurenko (1986) and Tsatsenkin (1974). The main methods of morphological research were: ontogenetic and structural–functional. The life form was determined by adult individuals who were in the middle-aged generative state. The results of the study expand the understanding of the features of growth, development and productivity of cenopopulations of forage species of pasture ecosystems, depending on their seasonal variability, livestock and soil conditions.

The study of the characteristics of the water regime formed under the influence of environmental conditions makes it possible to assess the physiological state of perennial forage plants, their development and productivity. Transpiration plays an important role in the regulation of plant water exchange. The main indicator of transpiration is its intensity—the amount of water evaporated by the plant (grams) per unit of time (hour) by the leaf surface (in dm^2). The intensity of transpiration of perennial forage grasses growing on sandy loam soils of the dry-steppe zone (Volgograd) was revealed by the method of rapid weighing by L.A. Ivanov: *Krascheninnikovia ceratoides* L. Gueldenst., *Chamaecytisus borysthenicus* (Gruner) Klask., as well as *Poaceae* species: *Festuca pratensis* Huds., *Bromusin ermis* L., *Agropyron cristatum* L. and *Elytrigia* elongata (Host) Nevski.

Research on the cultivation of perennial forage grasses was carried out on the vegetation sites of the lysimetric complex of the Federal Research Center of Agroecology of the Russian Academy of Sciences (Volgograd, 48°65′ s.sh., 44°16′ v.d.) in the period from 2011 to 2017. The influence of the sowing method (continuous and wide-row) on the seed productivity of *Agropyron* varieties of Stavropol selection was studied. These were the varieties: *A. fragile* "Innovator" and *A. cristatum* "Vikrav". Sandy loam soils were light chestnut. The cultivation technology corresponded to the zonal system. The area of the plots was 1.75 × 3.6 m. Sowing was carried out in early spring in compliance with the width of the aisles according to the experimental scheme. The depth of seed embedding was 1.5–2.0 cm. Seeding rate: for continuous crops:15–20 kg per 1 ha; for wide-row crops:10–12 kg per 1 ha; the repetition was three-fold. Climatic features during the observation period were analyzed using data from the weather station (WatchDog) 2000 Series, located on the territory of the Federal Research Center for Agroecology of the Russian Academy of Sciences (Volgograd).

2.3. Data Analysis

The current state, appearance and quality of pasture ecosystems is determined by the degree of degradation of vegetation cover, which must be determined before carrying out phytomeliorative work. Diagnostics of pastures according to the degree of degradation of vegetation cover was carried out according to the method of Doctor of Agricultural Sciences V.P. Voronina [53], Table 1.

Table 1. Indicators for the diagnosis of pasture degradation [53].

The Degree of Downed Pasture	Projective Coverage, %	Loss of Biomass from Protected Conditions, %	Age Structure of the Cenosis	Composition of Phytomass, %	Composition of Life Forms, %
Weakly beaten	>75	0–5	The presence of individuals of all age structures in optimal quantities	Dominants + subdominants—50–70, motley grass—30–50	Semi-shrubs—55, Annuals—40, Other types—5
Average Beaten	75–51	45–50	Generative individuals dominate, there are also few juvenile and senile plants	Dominants + subdominants—70–80, motley grass—20–30	Semi-shrubs—45, Annuals—50, Other types—5
Badly beaten	50–25	60–70	Senile groups of shrubs and semi-shrubs, generative ephemera and ephemeroids, there are almost no juvenile plants	Dominants + subdominants—80–90, motley grass—10–20	Semi-shrubs—5, Annuals—90, Other types—5
Very badly beaten	<25	75–90	Senile groups of all botanical groups dominate, there are no juvenile plants	Dominants + subdominants—95–100, motley grass—5–10	Semi-shrubs—0–1, Annuals—90, Other types—10

The intensity of transpiration of perennial forage grasses was determined by the method of rapid weighing of the selected leaf by L.A. Ivanov. The measurements were carried out in three-fold repetition over a period of 3 h on the leaves of the lower and upper tiers. According to the difference between the first weighing immediately after cutting and after 3–5 min, the amount of evaporated water was determined. Comparison of the intensity of transpiration in the same and different species under different microclimatic conditions allowed us to identify their biological features. The processing of the received data was carried out using the Microsoft Excel 2020 program.

The assessment of the power of species of the genus *Artemisia*, which is an indicator of the vital state of individuals and the population as a whole, was carried out on a 5-point scale in different ecological and phytocenotic conditions. A decrease in the degree of development (power) of individuals or shoots indicates a deterioration of the population. To assess the power, indicators such as the height of shoots, the number of shoots, the diameter of the trunk, the number, length and width of leaves, the number of inflorescences and their length, the number of flowers, fruits and seeds, etc. were used. Plants characterized by scores of 1 and 2 were considered not powerful, with scores of 3—medium-sized, 4–5—powerful.

A comparative characteristic of the resistance to lodging and reproductive ability of species of the genus *Agropyron* (*A. cristatum*, *A. fragile*, *A. pectinatum*) growing on various soils in natural conditions in the south-east of the European part of Russia and selectively acquired species of the genus *Agropyron* (*A. fragile* "Innovator" and *A. cristatum* "Vikrav".) is given.

To assess the reproductive ability, a scale was used that reflected: 1—mature plants do not bloom; 2—plants do not bloom, do not bear fruit, or seeds are not suitable; 3—plants bloom moderately, but there are few seeds or they are low in germination, they can reproduce vegetatively, 4—plants bloom and bear fruit well, sometimes abundantly, seeds with high germination, but do not self-seed in rain-fed conditions, 5—plants bear fruit abundantly and regularly, self-seeding in areas without watering. Plants characterized by scores 1 and 2 are considered not fully adapted to local conditions, with scores 3–5—adapted.

The resistance of the ecotypes of the genus *Agropyron* to lodging was determined by the force applied to pull plants out of the soil using a dynamometer. The lodging resistance score (*Б*) was calculated by the formula:

$$Б = 1 + \left(\frac{4 \cdot C}{в}\right) \quad (1)$$

where

$в$—plant height (cm),

C—a layer of decayed stems (cm).

Resistance to lodging was assessed on a scale: 5—no lodging, 4—weak lodging, stems slightly inclined, 3—average lodging, stems slope to the soil surface at an angle of 45, 2—strong lodging, 1—very strong lodging.

3. Results and Discussion

3.1. Assessment of the State and Productivity of Pasture Ecosystems during Vegetation Degradation

The vegetation productivity of the studied zone is largely determined by soil conditions, seasonal weather phenomena and grazing (overgrazing) of farm animals, Table 2, Figure 1.

The lowest forage productivity is distinguished by the winter period with very strongly beaten white-field-grain pastures on unsalted, weakly or medium-salted light chestnut soils (0.03 t/ha); very strongly beaten bulbous-bluegrass-white-field pastures on deep, medium and strongly saline light chestnut soils (0.03 t/ha); medium-beaten black-wormwood and bulbous-bluegrass-black-wormwood pastures on small and crusty salt flats (0.04 t/ha). The highest productivity of spring–summer pastures is observed in unbroken areas of unsalted, weakly and medium-saline light chestnut soils occupied by white-field cereal phytocenoses (0.32–0.38 t/ha). In wormwood-cereal phytocenoses, productivity is also quite high and reaches 0.33–040 t/ha on meadow-chestnut saline soils and meadow saline soils, 0.38–0.40 t/ha on unsalted and slightly saline soils of dry estuaries and depressions.

With severe degradation of vegetation cover, 15–20% of shrubs and semi-shrubs, 20–30% of cereals, 10–15% of legumes and about 5% of various grasses should be introduced (of the potential yield). With an average degree of degradation, 5–10% of shrubs, 10–20% of cereals, 10–15% of legumes and 5% of herbs are introduced. With a weak degree of degradation, 10% of cereals, 10% of legumes and 3–5% of herbs are introduced.

Table 2. Seasonal productivity of pastures (fodder units, t/ha) in the south-east of the European part of Russia, depending on soil conditions and the degree of downing.

Phytocenoses	Spring	Summer	Autumn	Winter
White-wormwood-cereals on unsalted, weakly and medium-saline light chestnut soils on the plain or micro-elevations				
unbeaten	0.32	0.38	0.24	0.13
average beaten	0.16	0.14	0.20	0.09
badly beaten	0.15	0.17	0.20	0.08
very badly beaten	0.06	0.05	0.09	0.03
Bulbous-bluegrass-white wormwood on solonetzes of deep, medium and highly solonetzic light chestnut soils				
unbeaten	0.10	0.13	0.23	0.10
average beaten	0.15	0.15	0.17	0.10
very badly beaten	0.03	0.05	0.05	0.03
Black wormwood and bulbous-bluegrass-black wormwood on small and crusty solonetzes				
unbeaten	0.07	0.09	0.20	0.08
average beaten	0.15	0.14	0.14	0.04
Wormwood-cereals on unsalted and slightly saline soils of dry estuaries and depressions				
unbeaten	0.33	0.40	0.31	0.20
badly beaten	0.05	0.12	0.18	0.06
Wormwood-cereals on meadow-chestnut saline soils and meadow salt flat				
unbeaten	0.38	0.40	0.31	0.14
badly beaten	0.09	0.25	0.20	0.07

It is possible to exclude degradation processes resulting from excessive livestock loading by a system of rational use of pastures, including the introduction of rational pasture rotations, the preparation of a feed balance with the determination of sources of covering the shortage in feed in different years and seasons, as well as schemes of pasture rotations for different types of forage lands.

If the proportion of non-eaten shrubs and semi-shrubs is large, then it is advisable to carry out their step-by-step replacement with eaten species (5–8%). The species composition should be focused on the dominant animals grazed on the pasture. Medicinal plants that improve the sanitary and hygienic condition of the pasture, as well as those that directly affect the animal (anthelmintic, antiseptic, etc.) can make up the main share of various grasses.

The objects of phytomelioration are hotbeds of desertification with an area of more than 100 hectares, which pose a serious threat to the surrounding area, as they can become larger and more complex for phytomelioration. The theory and basic techniques for restoring degraded pasture ecosystems of arid areas have already been developed [14–18,23]. They have received experimental confirmation in large-scale works and measures to suspend the processes of desertification and restore degraded lands. In recent decades, these studies have received a new development. The need to improve established reclamation schemes and technologies is associated with the further development of feed production and changed socio-economic conditions. This requires significant technological and organizational changes. Studies on the optimization of the cenotic structure and species composition of phytocenoses were carried out with an emphasis on this situation in order to stabilize productivity and increase the productive longevity of pasture ecosystems.

The share of forest–agrarian landscapes belongs to the anthropogenically transformed system and is about 50% of the land. Unlike natural landscapes, which have evolutionary mechanisms of self-regulation and stabilization, transformed landscapes require constant energy subsidies, which can lead to loss of soil fertility and biological productivity, and regional changes in the energy balance.

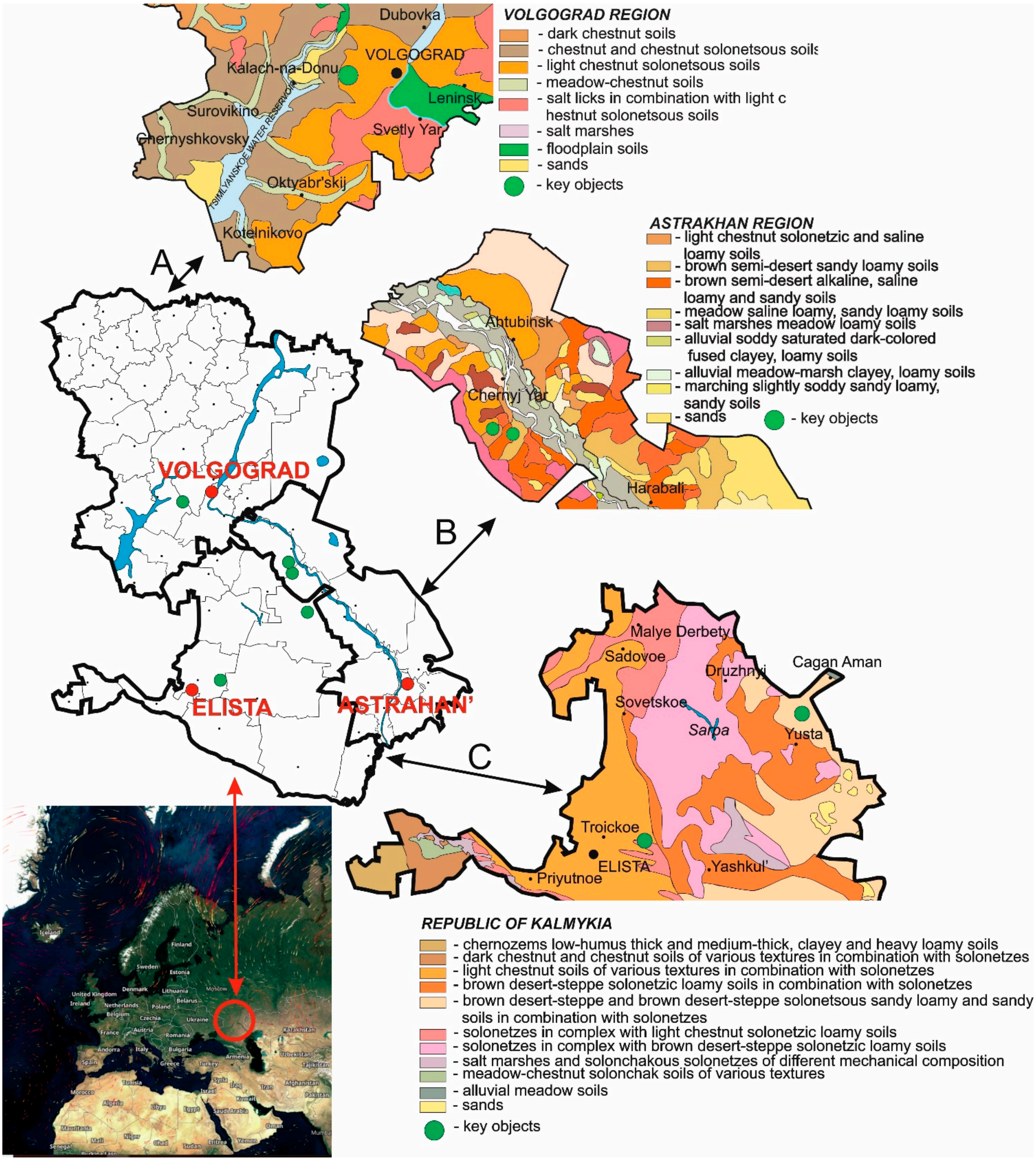
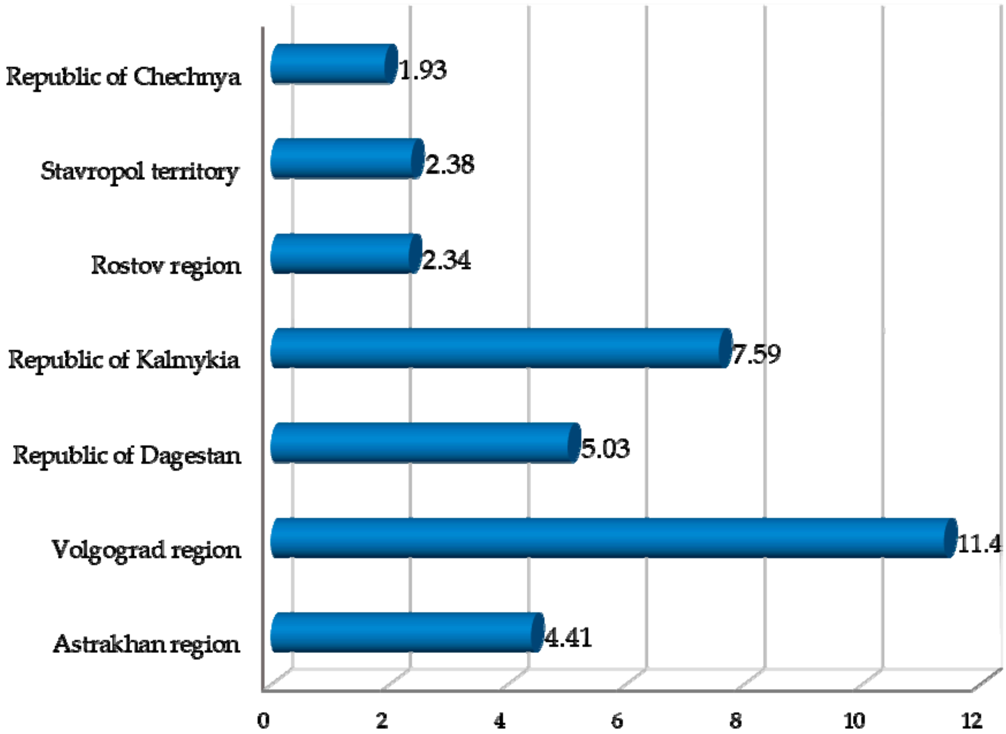


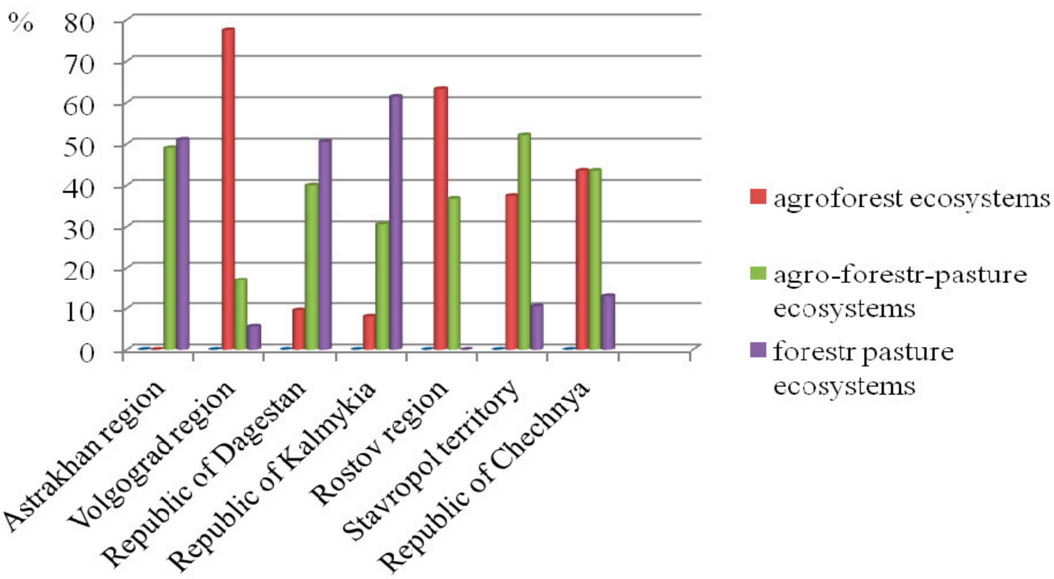
Figure 1. Soils of the study area of the Volgograd region (**A**), Astrakhan region (**B**) and the Republic of Kalmykia (**C**).

Forest plantations can stabilize biotic and abiotic indicators (climate, soil, etc.), transform energy flows within the system and contribute to the effective assimilation of anthropogenic energy. Their role in stabilizing the ecological situation is a priority, especially in areas of ecological disaster and adjacent territories. At the moment, this is the most effective, low-cost and time-prolonged means and is a safe technology for increasing the potential productivity of agroecosystems.

In the Russian Federation, the most frequently encountered and used types of forest–agrarian ecosystems in anthropogenic landscapes are: agroforestry (agricultural crops + woody vegetation); agroforestry (agricultural crops + pastures + woody vegetation + animals); forest pasture (pastures + animals + woody plants). Their occurrence and distribution areas in the southeast of the European part of Russia are determined by natural and climatic conditions, and historical and economic factors, Figure 2.



(**a**)



(**b**)

Figure 2. Areas (**a**) and the share of different types (**b**) of forest ecosystems in the south-east of the European part of the Russian Federation.

Agroforestry landscapes dominate in the semiarid and arid zones. Territories with unproductive, degraded lands in such landscapes are occupied by pastures. Recommended afforestation for such landscapes is 8–10% [14,15].

Pasture landscapes are most common in the arid zone, especially in areas with moderate to severe degradation of land and vegetation cover. Pasture plants should have salt and drought resistance, tolerance to erosion and climatic factors. The recommended optimal afforestation is 5–8%. The range of pasture lands should be 55–70% [15].

Forest pasture ecosystems can be of natural or anthropogenic origin. Agroforestry ecosystems of mixed type are most often found when phytomeliorative works are carried out and one or more missing elements are introduced (protective forest stands, tree umbrellas, reclamation and fodder plantations) in order to increase the stability and yield of forage lands. Agroforestry ecosystems are confined to pasture and hay lands, arable lands are transferred to another category of land use. They are created on degraded pastures with low feed capacity, poor species composition, as well as on lands with high deflationary mobility of soil, salt marshes and salt marshes and other inconvenient lands. Priority of phytomeliorative development is given to territories near settlements and with a high concentration of livestock.

Depending on the economic interest and the potential capacity of the ecological environment on pasture lands, it is possible to form specialized agroecosystems that have one or more specialized areas, significantly improve the fodder capacity of the pasture and improve microclimatic conditions that allow reclamation and fodder plantations. The most popular plantings are in the form of wings with a width of 50–100 m with interstage spaces of the same width. If trees are used instead of shrubs, then reclamation and forage plantations of the "savanna" type are formed, for which pasture territories with natural or artificially created micro-depressions are suitable.

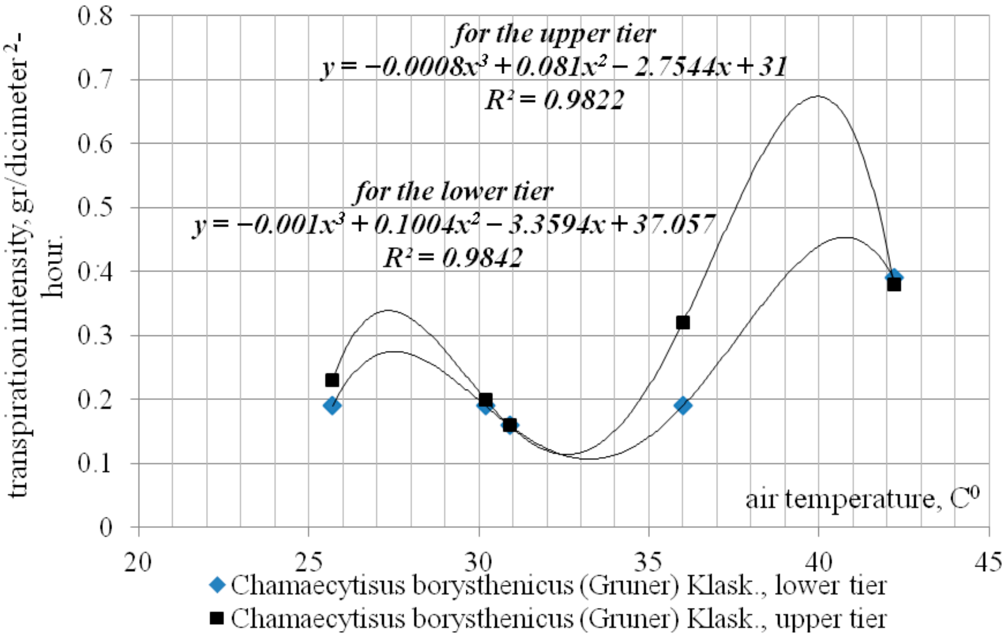
Reclamation and forage plantations occupy 10% or more of the total area of the reclaimed territory. It is best to create plantings from long-growing forage shrubs and semi-shrubs, which are readily eaten by animals in the autumn–winter and early spring period, which allows you to extend the duration of the exploited area and make up for the shortage of feed during this period. The greatest anthropogenic impact (trampling, eating) is on the intercellular space. The degree of its phytomeliorative arrangement depends on the species composition, the state of pastures and the degree of degradation of vegetation cover. Phytocenosis is considered to be stable, where there are optimal proportions: ephemera and ephemeroids, annual and perennial cereals, long-growing shrubs and semi-shrubs, perennial legume species, various grasses.

3.2. Analysis of the Correlation of the Intensity of Transpiration of Phytomeliorants Depending on Temperature and Humidity

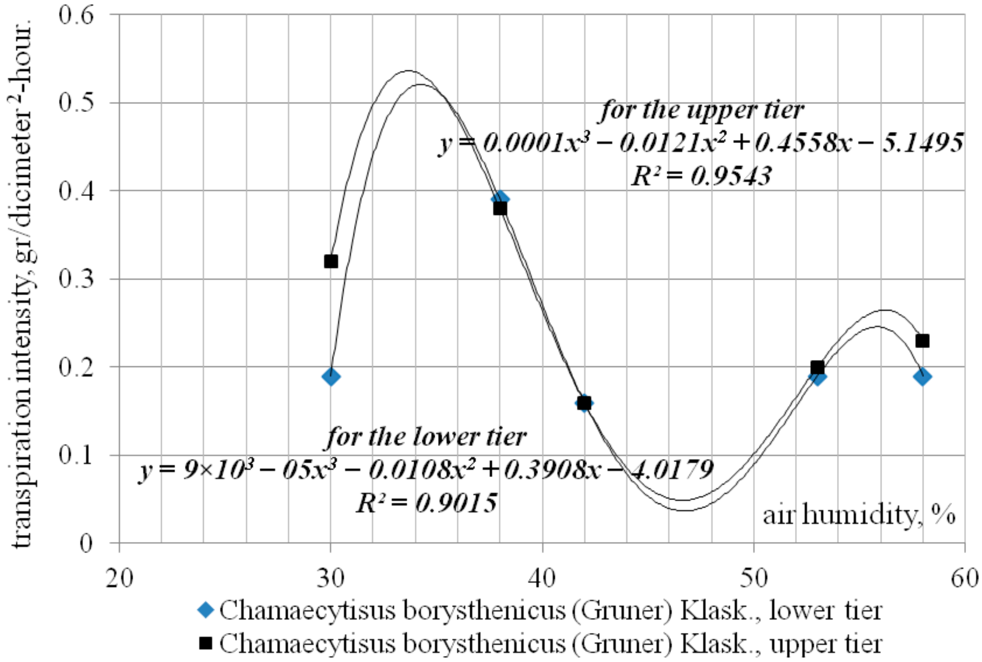
Natural flora is one of the main sources of raw material for breeding. About eight thousand species of higher plants grow in the desert, semi-desert and steppe regions of Russia and the Central Asian region. Of this amount, over 300 species of forage plants of 29 botanical families were tested, including *Poaceae*—75, *Chenopodiaceae*—40, *Fabaceae*—29, *Brassicaceae*—25, *Asteraceae*—17, *Polygonaceae*—14 and *Apiaceae*—10 species. The remaining 22 families include only 50 species. The overwhelming number of species refers to grasses (perennials, biennials, annuals); trees, shrubs and semi-shrubs account for about 10%. Trees, shrubs, semi-shrubs are more productive and resistant to harmful environmental conditions.

Shrubs and semi-shrubs in culture in degraded arid territories contribute to the development and use of new ecological niches of the air and soil environment. They can serve as a radical and promising technique for improving pasture lands, as they are characterized by rapid growth and development, early entry into the reproductive phase and abundant fruiting. Thanks to the deeply penetrating root system, they use not only the moisture of atmospheric precipitation but also condensation, capillary soil moisture and groundwater. Their high productivity in arid conditions is also explained by the fact that they economically consume soil moisture reserves for transpiration. Indicators of transpiration intensity differ significantly in different species and depend on humidity and air temperature. These differences are especially noticeable during the most favorable hydrothermal regime, i.e., at the beginning of the growing season (mid-April–end of May).

The obtained coupling equations show the regularities of transpiration in the studied plant species depending on microclimatic factors (humidity and air temperature), and the determination coefficients (R^2) indicate a close relationship of the signs with the result, Figures 3–5.

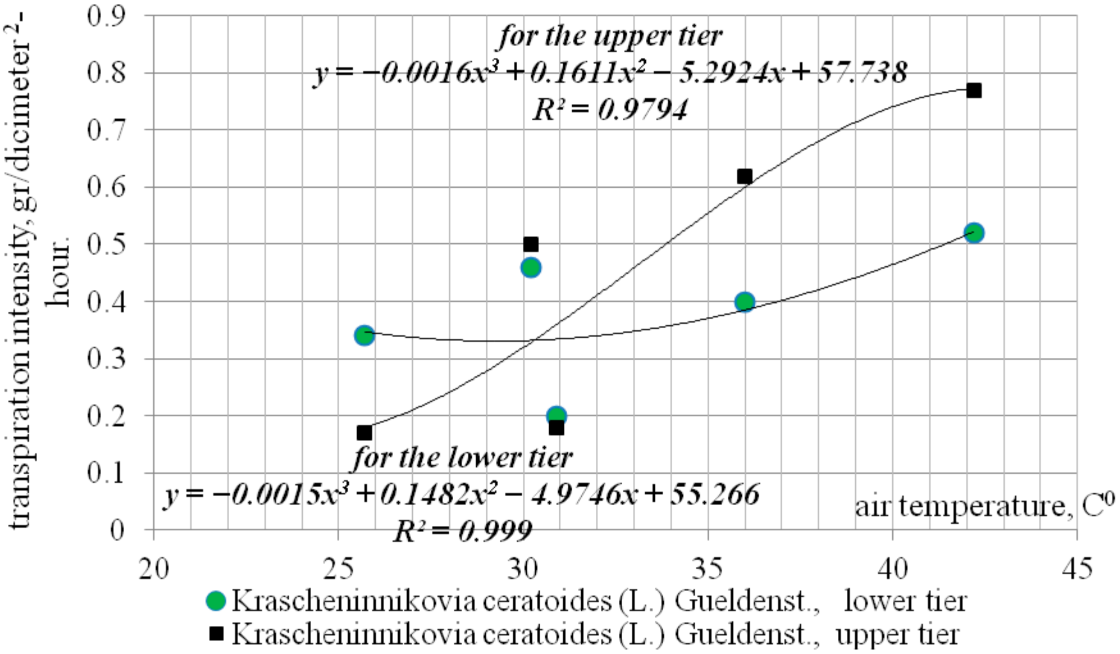


(**a**)

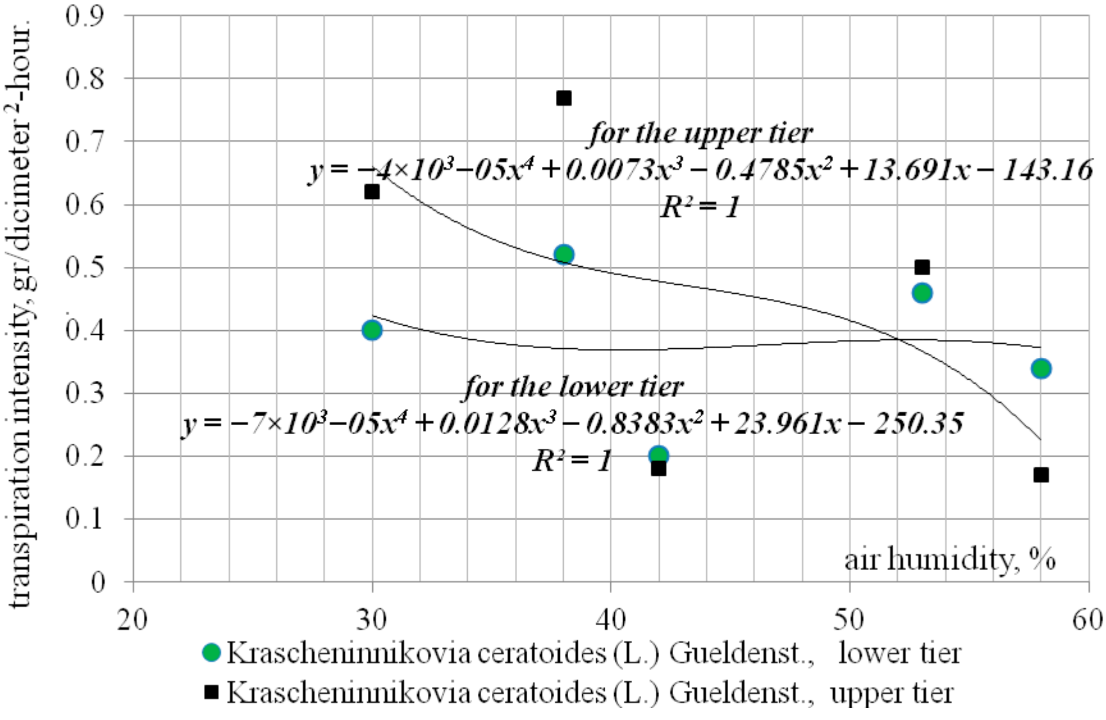


(**b**)

Figure 3. Change in transpiration intensity of *Chamaecytisus borysthenicus* (Gruner) Klask. depending on changes in temperature (**a**) and humidity (**b**) of the air in the conditions of the dry steppe zone of Russia in sandy soils.

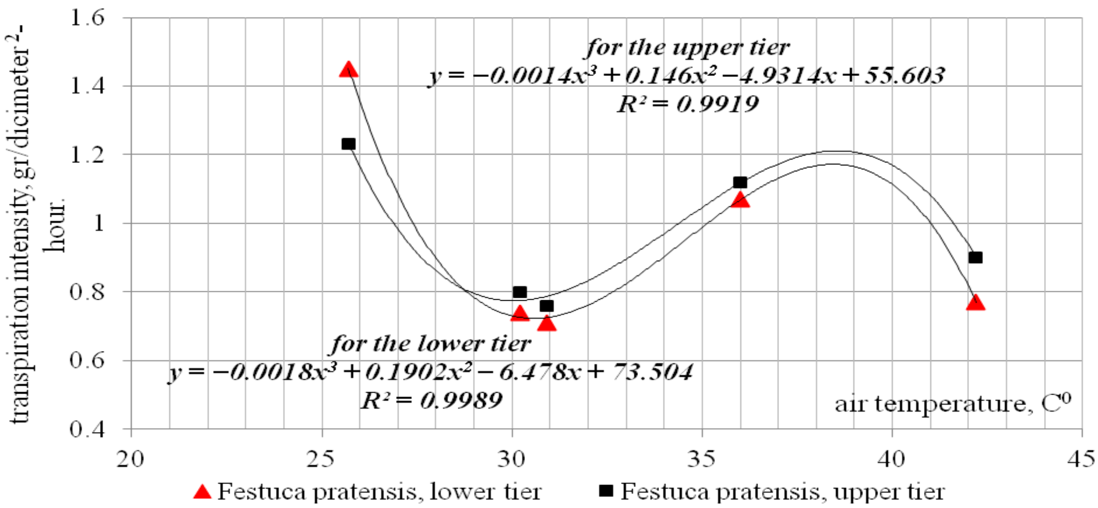


(**a**)

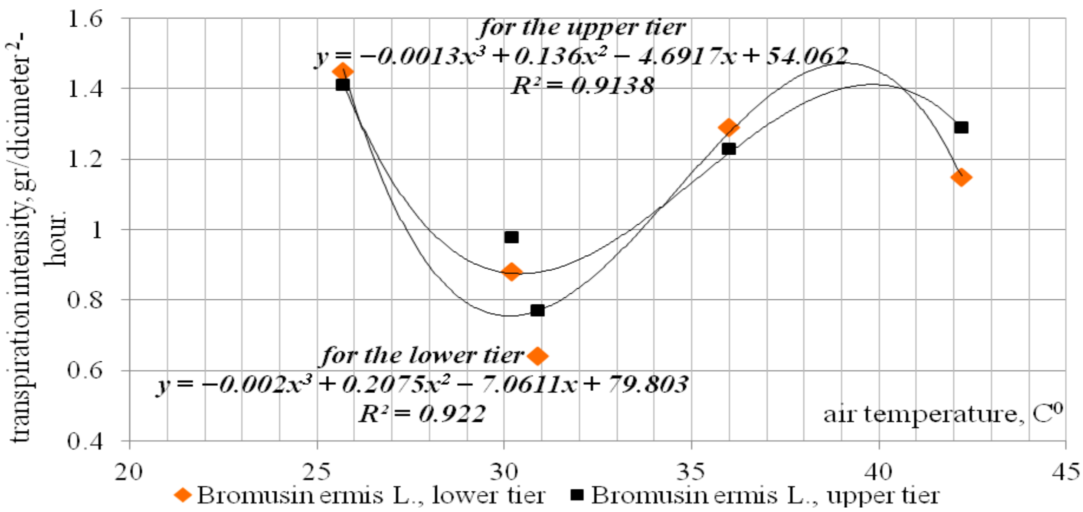


(**b**)

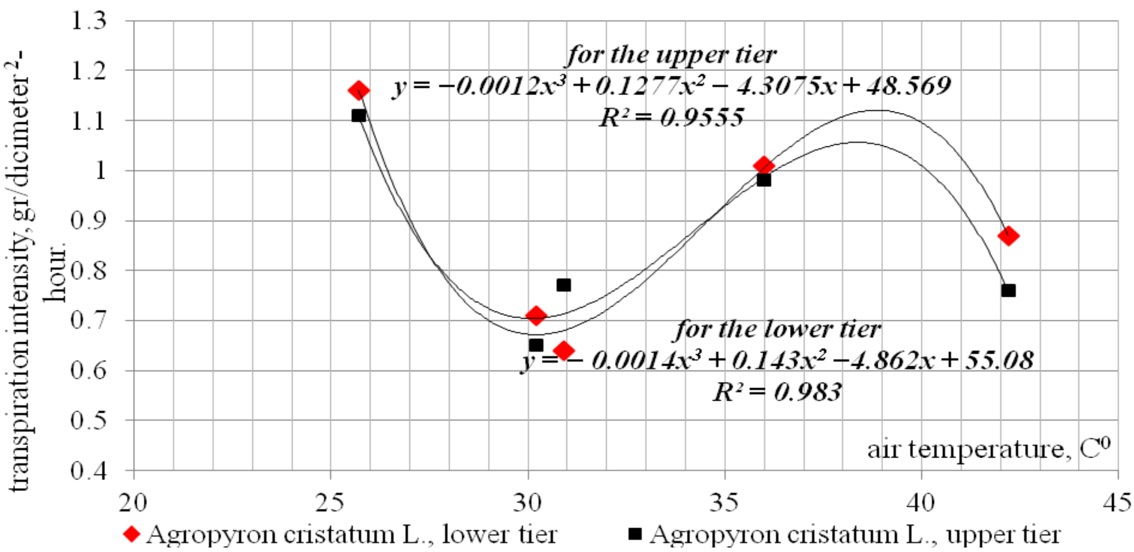
Figure 4. Change in transpiration intensity of *Krascheninnikovia ceratoides* (L.) Gueldenst. depending on changes in temperature (**a**) and humidity (**b**) of the air in the conditions of the dry steppe zone of Russia in sandy soils.



(**a**)



(**b**)



(**c**)

Figure 5. Changes in the intensity of transpiration of *Poaceae* family (*Festuca pratensis*—(**a**), *Bromusin Ermis* L.—(**b**), *Agropyron cristatum* L.—(**c**)) species depending on changes in air temperature in the conditions of the dry steppe zone of Russia in sandy soils.

In the conditions of a dry steppe with sandy soils (Volgograd), it was found that fluctuations in the transpiration intensity index during the day are observed in all the studied species, but they differ in value and in the number of peaks. The highest rates of transpiration intensity were found in species of the *Poaceae* family (up to 1.45 g/dm^2-h), while the transpiration intensity in *Chamaecytisus borysthenicus* reached 0.4 g/dm^2-h, and in *Krascheninnikovia ceratoides*—0.77 g/dm^2-h, Figures 3–5.

A higher transpiration activity in perennial cereal species compared to shrubs indicates a greater consumption of water by cereals. And since the indicator of drought resistance in conditions of iodine deficiency is the economical use of water by vegetation, this means that, compared with cereal species, shrubs and semi-shrubs are more adapted to dry conditions. In drought-resistant species, economical use of water and reduction of transport processes provides greater stability, preservation of hydration of tissues and the possibility of recovery after stress relief.

3.3. Analysis of Biomorphological Features of Native Species of Forage Plants Promising for Phytomeliorative Reconstruction of Degraded Pastures

In order to develop technologies to improve degraded arid pastures, the biomorphological features of some species of the genus *Artemisia* growing on natural pastures were studied. *Artemisia* L. is a good foot food for sheep all year round, especially in the autumn–winter period. Up to 500 species of the genus *Artemisia* are known on the globe. In the Russian Federation, there are more than 15 species of the genus *Artemisia* from various ecological and geographical areas. The yield of *Artemisia* varies depending on the species in the range of 0.2–0.6 t/ha of dry weight and within insignificant limits by year, Table 3.

Table 3. Yield of dry fodder mass (t/ha) of ecotypes of the genus *Artemisia* growing in various soil conditions of the south-east of the European part of Russia.

Soils (Region) of Growth, Type	2nd Year of Life	3rd Year of Life	4th Year of Life	5th Year of Life	Plant Power Rating *, Point
Brown sandy loam saline soils (Astrakhan region), *Artemisia pauciflora*	0.21	0.32	0.41	0.52	4
Light chestnut loamy saline soils (Astrakhan region), *Artemisia pauciflora*	0.26	0.35	0.45	0.55	4
Light chestnut solonetsous soils of the wormwood-fescue-feather grass steppe (Volgograd region), *Artemisia pauciflora*	0.18	0.28	0.38	0.49	4
Brown desert-steppe and brown desert-steppe alkaline sandy loamy and sandy soils in combination with solonetzes (Republic of Kalmykia), *Artemisia pauciflora*	0.19	0.29	0.38	0.48	5
Salt licks in combination with light chestnut solonetzic loamy soils (Republic of Kalmykia), *Artemisia lercheana*	0.27	0.39	0.48	0.58	5

* on a 5-point scale.

The highest yield of *Artemisia* is observed at the age of 2–12 years. The period of productive longevity depends on the species and exceeds 20 years. In natural conditions, in the first year of vegetation, plants remain in the rosette phase with a well-developed root system. In the second and third years, their ground part reaches 36–47 cm in height, Table 4. In the fifth year of life, the bushes acquire a spherical or sprawling shape and reach a height of 40–51 cm. In the conditions of culture, various *Artemisia* species usually form higher yields of fodder mass in comparison with natural pastures.

Table 4. Growth dynamics (cm) of ecotypes of the genus *Artemisia* growing in various soil conditions of the south-east of the European part of Russia.

Soils (Region) of Growth, Type	1st Year of Life	2nd Year of Life	3rd Year of Life	4th Year of Life	5th Year of Life
Brown sandy loam saline soils (Astrakhan region), *Artemisia pauciflora*	20.2	30.2	36.9	40.7	41.2
Light chestnut loamy saline soils (Astrakhan region), *Artemisia pauciflora*	27.1	36.1	46.8	49.6	51.4
Light chestnut solonetsous soils of the wormwood-fescue-feather grass steppe (Volgograd region), *Artemisia pauciflora*	18.6	29.8	35.8	38.0	39.7
Brown desert-steppe and brown desert-steppe alkaline sandy loamy and sandy soils in combination with solonetzes (Republic of Kalmykia), *Artemisia pauciflora*	19.9	30.0	36.1	38.2	39.8
Salt licks in combination with light chestnut solonetzic loamy soils (Republic of Kalmykia), *Artemisia lercheana*	26.3	34.6	44.2	47.9	49.7

The maturation period of *Artemisia* seeds begins at the end of October and ends at the beginning of the first week of November. The seed yield of the studied species of the genus *Artemisia* varies from 3.2 to 4.9 kg/ha, the maximum is in *Artemisia pauciflora* growing on light chestnut saline soils of the sagebrush-tipchak-kovyl steppe (Volgograd region) Table 5.

The maximum protein content in all studied species of the genus *Artemisia* was noted during the vegetation phase and sharply decreases during the budding phase. The fat content, on the contrary, increases 2–3 times by the fruiting phase. Changes in the content of fiber and NES (nitrogen-free extractive substances) with the age of plants are insignificant. The number of ash decreases as plants age in all *Artemisia* species. The maximum amount of protein (19.4%) was contained in *Artemisia lerchiana*, which lives on salt flats in a complex with light chestnut saline loamy soils (Republic of Kalmykia). The maximum amount of fat was contained in *Artemisia pauciflora* growing on brown sandy loam saline soils (Astrakhan region) (13.2%) Table 6. The protein of all types of studied wormwood contains essential amino acids. Their content decreases with age.

Long-term observations of the growth and development of forage species of the Poaceae family in arid conditions also indicate their high practical advantages for phytomelioration. One of the important indicators of the stability and adaptability of plants to extreme environmental conditions in arid zones is their survival. Valuable pasture plants are *Agropyron* species. In natural conditions, they are mainly found in Russia and in the Central Asian region, they are of little use to soil conditions. The studied morphological criteria of *Agropyron* ecotypes growing in various conditions in the south-east of the European part of Russia showed that they grow rapidly and form individuals giving seeds by the end of the first year of life, Table 7.

According to their ecological and biological features, plants successfully combine the signs of xerophytes and halophytes. *Agropyron* ecotypes from the northern regions are characterized by a high ability to regrow after mowing. High resistance to extreme conditions is primarily due to the development and structure of a powerful root system and depends on the age of plants, the mechanical composition of the soil and cultivation techniques. *Agropyron* can withstand significant periodic drainage and compaction of the root layer of the soil and excess water-soluble salts during wet periods. The drought resistance of *Agropyron* is largely explained by the anatomical and morphological features of the structure of the leaves, which have a xeromorphic structure. *Agropyron* is characterized by high winter hardiness and frost resistance because it tolerates harsh winters in semi-desert conditions with unstable snow cover.

The most important indicator for the introduction of a particular type of plant is the yield of feed mass and the value of seed productivity, Tables 7 and 8. The dynamics of the yield of the granary pasture in arid conditions show that the yield of *Agropyron* increases with age. Already in the first year of vegetation, the granary increases a large feed mass. These facts indicate the high stability of this plant even on humus-poor and saline soils.

Table 5. Distinctive features of seeds of various ecotypes of the genus *Artemisia* growing in various soil conditions in the south-east of the European part of Russia.

Soils (Region) of Growth, Type	Seed Yield, kg/ha	Seed Size, mm	Weight of 1000 Seeds, mg	Seed Shape
Brown sandy loam saline soils (Astrakhan region), *Artemisia pauciflora*	4.6	1.0–1.4	280–310	oblong-ovate
Light chestnut loamy saline soils (Astrakhan region), *Artemisia pauciflora*	4.4	1.1–1.5	300–320	oblong-ovate
Light chestnut solonetsous soils of the wormwood-fescue-feather grass steppe (Volgograd region), *Artemisia pauciflora*	4.9	0.9–1.2	290–320	oblong-ovate
Brown desert-steppe and brown desert-steppe alkaline sandy loamy and sandy soils in combination with solonetzes (Republic of Kalmykia), *Artemisia pauciflora*	3.9	0.7–0.9	250–290	oblong-ovate, slightly flat
Salt licks in combination with light chestnut solonetzic loamy soils (Republic of Kalmykia), *Artemisia lercheana*	3.2	0.6–0.9	280–300	oblong-ovate, furrowed

In addition to positive biological features, *Agropyron* has good feed advantages. In spring, the grass contains a large amount of protein. As a result of this it is readily eaten by animals. In the full tillering phase, when spring bleaching is usually carried out, *Agropyron* contained, depending on the species and growing areas, 4.6–6.6% protein, 1.1–2.2% fat and only 11.0–19.5% fiber. During the full tillering and earing phase, *Agropyron* contained a significant amount of calcium (3.9–5.4 g per kilogram of feed) and phosphorus (1.2–2.1 g per kilogram of feed). The amount of carotene varied from 8.0 to 16 mg/kg.

Studies on the cultivation of perennial forage grasses on vegetation sites of the lysimetric complex of the Federal Research Center of Agroecology of the Russian Academy of Sciences have shown that the seed productivity of *Agropyron* varieties varies within 0.5–4.0 c/ha depending on the variety, the method of sowing and climatic conditions of the year, Tables 9 and 10.

It was found that the seed productivity of the *A. fragile* "Innovator" variety with a wide-row sowing method with a row spacing width of 45 cm was higher than with continuous sowing by 0.2–2.2 c/ha. An even better result was shown by a wide-row sowing method with a row spacing of 70 cm, in which seed productivity increased by 0.4–2.5 c/ha. For *A. cristatum* "Vikrav", the wide-row sowing method also turned out to be more promising: with a row spacing of 45 cm, seed productivity was higher compared to continuous sowing by 0.1–1.8 kg/ha; with a row spacing width of 70 cm, seed productivity was higher compared to continuous sowing by 0.4–1.9 kg/ha. This can be explained by the fact that with wide-row sowing, the placement of plants per unit area is optimal, which affects the growth rate and development of plants. Thus, by optimizing the sowing method, it is possible to adjust the amount of seed productivity of *Agropyron*.

Table 6. Nutrient content of ecotypes of the genus *Artemisia* growing in various soil conditions inf the south-east of the European part of Russia.

The Phenological Phase	Chemical Composition, % by Absolutely Dry Weight				
	Protein	Fat	Fiber	Nitrogen-Free Extractive Substances (NES)	Ash
Brown sandy loam saline soils (Astrakhan region), *Artemisia pauciflora*					
Vegetation	18.0	4.6	24.0	43.3	10.1
Budding	9.2	10.1	23.2	49.8	7.7
Fruiting	7.6	13.2	27.6	45.0	6.6
Light chestnut loamy saline soils (Astrakhan region), *Artemisia pauciflora*					
Vegetation	18.6	5.7	19.3	46.1	10.3
Budding	11.6	10.9	19.8	48.9	8.8
Fruiting	7.1	11.5	24.5	50.2	6.3
Light chestnut solonetsous soils of the wormwood-fescue-feather grass steppe (Volgograd region), *Artemisia pauciflora*					
Vegetation	16.9	4.1	24.3	44.5	10.2
Budding	9.6	9.7	23.0	49.6	8.1
Fruiting	6.8	11.9	29.8	45.3	6.2
Brown desert-steppe and brown desert-steppe alkaline sandy loamy and sandy soils in combination with solonetzes (Republic of Kalmykia), *Artemisia pauciflora*					
Vegetation	17.1	4.5	23.5	45.0	9.9
Budding	8.9	10.3	24.3	48.7	7.8
Fruiting	7.0	12.5	28.6	45.9	6.0
Salt licks in combination with light chestnut solonetzic loamy soils (Republic of Kalmykia), *Artemisia lercheana*					
Vegetation	19.4	5.1	17.8	46.9	10.8
Budding	12.1	11.1	20.5	48.2	8.1
Fruiting	7.2	12.3	25.4	49.1	6.0

Comparative point characteristics of species of the genus *Agropyron* (*A. cristatum*, *A. fragile*, *A. pectinatum*) growing on various soils in natural conditions in the south-east of the European part of Russia, and selectively improved (*A. fragile* "Innovator" and *A. cristatum* "Vikrav") showed that the latter are somewhat more resistant to lodging and a have better reproductive ability.

Table 7. Morphological features affecting crop formation, ecotypes of the genus *Agropyron* growing in various soil conditions in the south-east of the European part of Russia.

Soils (Region) of Growth, Type	Weight of One Plant, Grams	Plant Height, cm	Number of Generative Shoots, pcs.	Spike Length, cm	Spike Width, cm	Leaf Blade, cm		Evaluation of Reproductive Ability *, Score
						Length	Width	
Brown sandy loam saline soils (Astrakhan region), *Agropyron cristatum*	245.0	60–75	71.2	9.8	1.04	24.5	0.62	4
Light chestnut loamy saline soils (Astrakhan region), *Agropyron fragile*	235.6	64–85	44.4	8.0	0.60	17.2	0.41	3
Sandy and sandy loamy soils of the fescue-feather grass steppe (Volgograd region), *Agropyron pectinatum*	195.4	53–75	67.2	10.3	1.32	23.2	0.62	4

Table 7. *Cont.*

Soils (Region) of Growth, Type	Weight of One Plant, Grams	Plant Height, cm	Number of Generative Shoots, pcs.	Spike Length, cm	Spike Width, cm	Leaf Blade, cm		Evaluation of Reproductive Ability *, Score
						Length	Width	
Brown sandy loam saline soils (Astrakhan region), *Agropyron cristatum*	245.0	60–75	71.2	9.8	1.04	24.5	0.62	4
Light chestnut loamy saline soils (Astrakhan region), *Agropyron fragile*	235.6	64–85	44.4	8.0	0.60	17.2	0.41	3
Sandy and sandy loamy soils of the fescue-feather grass steppe (Volgograd region), *Agropyron pectinatum*	195.4	53–75	67.2	10.3	1.32	23.2	0.62	4
Dark chestnut soils of the fescue-feather grass steppe (Volgograd region), *Agropyron cristatum*	220.1	61–78	67.6	7.2	1.20	23.1	0.79	3

* on a 5-point scale.

Table 8. Yield of dry fodder mass (t/ha) of ecotypes of the genus *Agropyron* growing in various conditions of the south-east of the European part of Russia.

Soils (Region) of Growth, Type	1st Year of Life	3rd Year of Life	5th Year of Life	7th Year of Life	Plant Resistance to Lodging *, Point
Brown sandy loam saline soils (Astrakhan region), *Agropyron cristatum*	0.59	1.20	1.37	1.51	4
Light chestnut loamy solonetsous soils (Astrakhan region), *Agropyron fragile*	0.68	1.26	1.51	1.80	5
Sandy and sandy loamy soils of the fescue-feather grass steppe (Volgograd region), *Agropyron pectinatum*	0.71	1.41	1.49	1.52	3
Dark chestnut soils of the fescue-feather grass steppe (Volgograd region), *Agropyron cristatum*	0.75	1.33	1.53	1.85	5
Light chestnut solonetsous soils of wormwood-fescue-feather grass steppe (Volgograd region), *Agropyron cristatum*	0.69	1.37	1.46	1.76	4
Common and southern forb-fescue-feather grass steppe chernozems (Volgograd region), *Agropyron fragile*	0.61	1.18	1.40	1.68	4

Table 8. *Cont.*

Soils (Region) of Growth, Type	1st Year of Life	3rd Year of Life	5th Year of Life	7th Year of Life	Plant Resistance to Lodging *, Point
Brown desert-steppe and brown desert-steppe alkaline sandy loamy and sandy soils in combination with solonetzes (Republic of Kalmykia), *Agropyron pectinatum*	0.62	1.39	1.41	1.61	4
Solonetzes in combination with light chestnut solonetzic loamy soils (Republic of Kalmykia), *Agropyron pectinatum*	0.77	1.42	1.54	1.70	5

* on a 5-point scale.

Table 9. Dynamics of seed productivity (c/ha) of *Agropyron* varieties of Stavropol selection in the period from 2011 to 2017 at the vegetation sites of the lysimetric complex of the Federal Research Center of Agroecology of the Russian Academy of Sciences, Volgograd.

Variety	Seeding Method	Year of Observations							Assessment of Reproductive Ability *, Point	Plant Resistance to Lodging *, Point
		2011	2012	2013	2014	2015	2016	2017		
A. fragile «Innovator»	solid	3.2	2.8	1.0	1.0	0.5	0.5	0.5	5	4
	width 45 cm	3.6	3.0	3.2	1.6	0.8	0.7	0.9	5	5
	width 70 cm	4.0	3.4	3.5	2.0	1.0	0.9	1.2	5	5
A. cristatum «Vikrav»	solid	3.2	6.3	2.5	2.8	1.8	1.0	1.4	5	4
	width 45 cm	3.8	6.5	4.3	3.0	2.3	1.1	1.8	5	5
	width 70 cm	5.1	6.8	4.5	3.8	2.4	1.5	1.8	5	5

* on a 5-point scale.

Table 10. Climate indicators for 2011–2018 research, Volgograd.

Meteorological Elements	Year	March	April	May	June	July	August	September
Temperature (°C)	2011	−3.4	8.6	3.0	6.2	0.9	2.0	15.7
	2012	−4.1	4.0	12.0	15.0	24.0	2.1	17.3
	2013	0.2	41.0	25.0	113.0	28.0	2.0	13.8
	2014	0.8	8.3	19.9	27.4	24.4	26.0	15.7
	2015	1.3	9.2	16.5	24.0	24.1	22.9	20.1
	2016	3.4	11.3	16.3	21.5	24.5	26.0	14.6
	2017	3.2	9.5	15.2	20.2	24.4	26.1	17.8
	2018	−4.6	10.2	20.6	23.5	26.1	23.8	18.2
	X ± Sx	−1.0 ± 1.1	14.2 ± 6.7	15.3 ± 3.7	37.1 ± 19.3	20.3 ± 4.9	11.0 ± 5.5	16.5 ± 1.0
Precipitation (mm)	2011	8.6	8.1	17.7	22.4	28.2	23.4	39.0
	2012	4.0	14.7	20.0	24.6	25.1	24.3	1.3
	2013	41.0	10.3	20.7	22.2	23.0	22.7	118.0
	2014	15.0	46.4	18.1	46.9	26.6	29.0	12.0
	2015	5.5	31.8	7.0	25.8	17.8	0	11.7
	2016	49.1	32.3	77.2	73.9	37.1	17.4	60.8
	2017	30.9	24.6	23.9	27.6	4.3	0	23.8
	2018	70.4	8.0	0	1.0	127.3	0.8	19.2

Note: X ± Sx is the mean ± standard deviation.

4. Conclusions

In this study, it was found that in arid areas, it is necessary to apply phytomelioration widely to create an organized, stable and ecologically well-maintained forest–agrarian landscape in which agricultural lands provide diverse and stable products, and provide a optimum ecology for the existence of a natural and anthropogenic system. Forest reclamation measures also prevent desertification.

To increase the productivity of degraded pastures, it is desirable to introduce long-term vegetating shrubs and semi-shrubs in culture in order to create long-term highly productive artificial phytocenoses. Their high productivity is explained by ecological and biological properties: they grow and develop rapidly, bear fruit abundantly, quickly form the aboveground part, quickly enter the generative phase and economically consume soil moisture reserves, which largely determines the possibility of introducing them into culture in harsh agro-climatic conditions.

The intensity of transpiration of perennial forage grasses growing on sandy loam soils of the dry steppe zone: *Krascheninnikovia ceratoides* L. Gueldenst., *Chamaecytisus borysthenicus* (Gruner) Klask., as well as species of the *Poaceae* family: *Festuca pratensis* Huds., *Bromusin ermis* L., *Agropyron cristatum* L. and *Elytrigia elongata* (Host) Nevski have been experimentally established. The obtained coupling equations show the regularities of transpiration in the studied plant species depending on microclimatic factors (humidity and air temperature), and the coefficients of determination (R^2) indicate their close relationship.

Artemisia L. is a good foot food for sheep, especially in the autumn–winter period. The yield of Artemisia varies depending on the species in the range of 0.2–0.6 t/ha of dry weight. The highest yield of Artemisia is observed at the age of 2–12 years. The period of productive longevity depends on the species and exceeds 20 years.

Long-term observations of the growth and development of forage species of the Poaceae family in arid conditions also indicate their strong practical advantages for phytomelioration. *Agropyron* plants successfully combine the signs of xerophytes and halophytes, can withstand significant periodic desiccation and compaction of the root layer of the soil and excess of water-soluble salts in wet periods and they tolerate well harsh winters in semi-desert conditions with unstable snow cover. With phytomeliorative reconstruction of pasture lands by *Agropyron* species, the use of wide-row sowing (45 and 70 cm) is promising, in which, regardless of the climatic conditions of the year, an increase in seed productivity is observed compared to continuous sowing by 0.2–2.5 c/ha.

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