

Ecological and biological characteristics and productivity of *Kochia prostrata* in the conditions of the Caspian semi-desert

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Abstract. *Kochia prostrata* (L.) Shrad. - a perennial plant with a height of 35-75 cm, according to its life form - a shrub, according to ecology - an euhaloxerophyte, according to an adaptive strategy - violent, an extremely drought-resistant and salt-tolerant, valuable forage plant in desert pastures. It grows on solonetz soils, stony soils, chalk outcrops, in saline and sandy steppes, plain desert sands, on gray soils. In the *growing season*, *Kochia prostrata* hay contains up to 16.5 % protein, 15.4 % ash substances, 2.7 % fat, 34.5 % nitrogen-free extractives and 29.6 % fiber. Fodder productivity reaches 2.2-2.5 t/ha of dry fodder mass, seed productivity - on average 100-150 kg/ha. High drought resistance and salt tolerance, good forage qualities make *Kochia prostrata* a promising forage plant for introduction into cultivation in arid regions of the Caspian semi-desert in order to restore the lost biodiversity and forage productivity of degraded pastures.

1 Introduction

The current state of natural areas in the arid regions of the Russian Caspian Sea region is characterized by a disturbed structure of pasture vegetation, loss of natural biodiversity, fodder productivity and need to be restored. Our study and research by other scientists show that *Kochia prostrata* (L.) Shrad is a promising forage plant for restoring feed productivity. [12].

Kochia prostrata (L.) Shrad. - semi-shrub 35-75 cm high. A valuable forage plant readily eaten by sheep in all seasons of the year [1, 2, 3]. In the growing season, *Kochia prostrata* hay contains 16.5 % protein, 15.4 % ash, 2.7 % fat, 34.5 % nitrogen-free extractives and 29.6 % fiber.

The range of the species includes the following areas: Upper and Middle Dnieper, Volga-Don, Nizhne-Volzhsy, Ciscaucasian, Verkhne-Tobolsk, Irtysh, Altai, Angara-Sayan, Daursky, Aral-Caspian, Balkhash, Gorno-Turkmeny, Dzhungarsko-Tibolsky and the Pamir-Alai [4], as well as Central Europe, Middle-earth, the Balkan Peninsula, Asia Minor, Iran, North-West and North-East China, Tibet and Mongolia [5].

It grows on solonetz soils, stony soils, chalk outcrops, in saline and sandy steppes, plain desert sands, on gray soils.

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M.I. Ilyin [4], who described *Kochia prostrata* in Flora of the USSR, notes the unusual polymorphism of this species. He distinguishes three geographical races, often associated with certain soil varieties: var. *villosissima* with white-haired pubescence - to the sands and sandy habitats of the semi-desert zone, var. *virescens* with almost bare green leaves - to solonchic habitats, var. *canescens* with compressed, dense pubescence - to mountain habitats, as well as to sandy loam soils.

This species was first described by Linnaeus in 1753 under the name *Salsola prostrata*. Later, in 1809, Schroeder gave this plant the name *Kochia prostrata* (L.) Schrad. Of the 30 representatives of the genus *Cochia*, eight species are found in the territory of the former USSR [4]. Among them, *Kochia prostrata* is the only perennial species within the genus with the life form of a semi-shrub. *Kochia prostrata* is a polymorphic species consisting of many polymorphic ecotypes. In our paper, we adhere to the intraspecific taxonomy given in the Flora of the USSR [4] by M.I. Ilyin, since the name of the kochia (sandy, solonchic - clayey, stony) in combination with some morphological characters well reflects the nature of the habitat of plants, which makes it possible to correctly navigate in the work with this species in justifying the direction of introduction and breeding work with *Kochia prostrata*, using as source material corresponding climatic, edaphic, or pasture ecotypes. *Kochia prostrata* grows on meadow-steppe solonchics, light chestnut and chestnut soils, light, typical gray soils of various textures and sands [6].

Formation of ecotypes is one of the main pathways of intraspecific evolution. Ecotypes are the genotypic adaptive response of a species to changing conditions of existence and appear as a result of the directed action of natural selection. All ecotypes are strictly hereditary categories, representing a link in a single hereditary evolution of the species system [7]. Currently, an ecotype is defined as a set of several natural populations of the same species that are homogeneous or closely related in origin, adapted to a certain type of environmental conditions and capable of self-reproduction with a relatively constant complex of environmental factors [6, 7].

According to E.N. Sinskoy [9], an ecotype is a more complex unity than a simple sum of its populations. The unity of an ecotype is expressed in the presence of common features of all the populations included in it, by which it differs from other ecotypes of the same species. These signs, developed in the process of adaptation to a certain complex of living conditions, are usually called ecotypic.

One of the main features of an ecotype is its reality, that is, each ecotype occupies its own area and in one place there cannot be two or more ecotypes of the same species [7].

In terms of the number of incoming ecotypes, polymorphic species can differ very significantly. As a rule, the wider the range of a species, the more diverse the set of its ecotypes.

V.N. Sukachev [10] and E.N. Sinskaya [9] noted that, being an ecological category, an ecotype is formed under the influence of the whole complex of ecological factors, however, in each specific case, one factor or another may have a predominant influence; in this regard, it is offered to name the ecotypes of the species by the name of the factors that had a decisive influence on their formation.

The aim of this paper is to study the ecological and biological characteristics and forage performance of *Kochia prostrata* in the xerothermal conditions of the Caspian semi-desert.

2 Methods

The Solenozaimischensky hospital is located in the northern part of the Astrakhan region. This territory is part of the soil and climatic region known as the Lower Volga region. The study area belongs to the semi-desert zone with complexes of zonal light chestnut and brown soils with solonchics (Fig. 1).

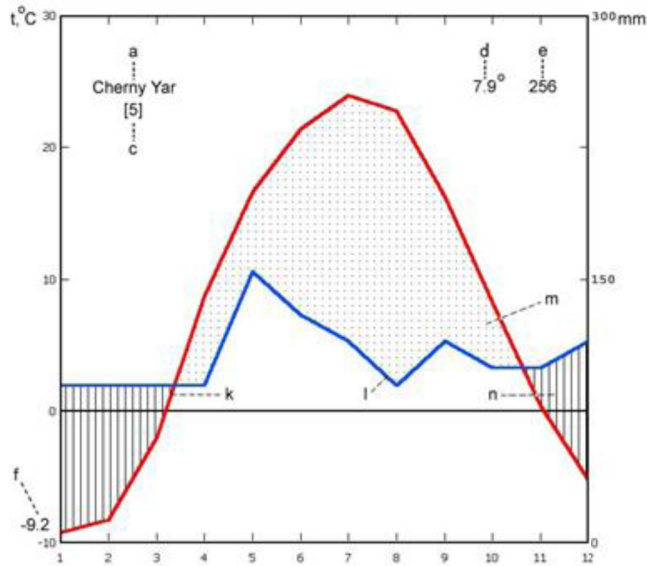


Fig.1. Climatic diagram for the region of studies (data of Cherny Yar meteorological station): a – station; b – altitude over the sea level; c – number of years of observations over temperature and precipitations; d – average annual temperature; e – average annual precipitations; i – absolute maximum; q – absolute minimum; k – temperature curve; l – precipitation curve; m – dry period; n – wet period of a year (applying Walter Lieth method [11]).

The climate is sharply continental and dry. In summer, it is formed mainly by the removal of extremely dry and warmed air from the Central Asian deserts. The sum of active temperatures is 3300-3600 °C. The average temperature in summer months is 24.5-25.5 °C. The maximum can reach 41-44 °C. Winters are moderately cold, with average monthly temperatures from -8.5 to -10 °C. Annual minimum temperatures -25-30 °C. The snow cover is usually unstable, its height does not exceed 10 cm. There is a small amount of precipitation, on average 250-260 mm. In some years, this figure may drop below 200 mm. Moisture coefficient - 0.25-0.27.

The predominant structure of the soil cover is light chestnut solonchak, solonchak and deep solonchak soils in combination with medium solonetz and meadow chestnut soils of depressions. According to the granulometric composition of the soil, mainly light and medium loamy, in some cases - sandy loam.

The ecological and biological features of the growth and development of prostrate *Kochia* and the formation of the root system, fodder and seed productivity of *Kochia prostrata* under culture were carried out according to the methodological instructions [12].

3 Results

3.1 Phenology

Observations that were carried out on the phenology of *Kochia prostrata* ecotypes of the first and third years of vegetation in the Caspian semi-desert showed that single seedlings appeared in crops in the second half of March, and massive ones - in April.

The growth and development of young plants proceeded normally. When side runners appeared, a certain difference in the onset of phenophases was observed in different

ecotypes of *Kochia prostrata*. In plants obtained from sowing seeds of the solonetz ecotype *Kochia prostrata* from Achikulak and sandy one from the Volgograd region, the phases of shoot formation, budding, and flowering began somewhat earlier than in other ecotypes. The beginning of flowering of ecotypes of the first growing season was noted in *Kochia prostrata* of the sandy ecotype from Volgograd and the solonetz one from Achikulak in early June, massive - in late June, in other ecotypes - in July. It was especially positive in the stony and clayey ecotypes of *Kochia prostrata* from Kyrgyzstan. Individual plants bloomed in mid to late September. In these ecotypes, the phases of fruit formation and seed maturation began later. In *Kochia prostrata* of the sandy ecotype, no noticeable differences in the passage of phenological phases were observed.

The vegetation period for *Kochia prostrata* sandy in the first year was 180 days, in the second year - 226, for *Kochia prostrata* stony and clayey from Kyrgyzstan - 195 and 230-283 days, respectively.

3.2 Laboratory and Field Germination of Seeds

The data obtained indicate that the laboratory germination of seeds of various ecotypes of *Kochia prostrata* varies within significant limits - from 5-10 to 80-90 %, field germination of seeds in the Caspian semi-desert conditions - within 0.05-17.0 %.

3.3 Dynamics of the Number and Survival of Plants

Observations carried out in the Caspian semi-desert by the end of the first year of life showed that the survival rate of seedlings was high. In the second year, the number of individuals in all populations of *Kochia prostrata* ecotypes stabilized somewhat, but decreased in the next year. The survival rate of individuals in populations of various ecotypes of *Kochia prostrata* by the end of the third year of life was in the range of 43.5–84.5 % (Table 1).

Table 1. Dynamics of standing density and survival of *Kochia prostrata* ecotypes in the Caspian semi-desert.

<i>Kochia prostrata</i> ecotype	1st year		2nd year	3rd year
	26.V	20.X		
Stony (Kyrgyzstan)	$\frac{5740 \pm 750}{100}$	$\frac{4900 \pm 620}{85.3}$	$\frac{4800 \pm 580}{83.6}$	$\frac{4850 \pm 530}{84.5}$
Clay (Kyrgyzstan)	$\frac{12040 \pm 666}{100}$	$\frac{9600 \pm 320}{79.7}$	$\frac{9250 \pm 360}{76.8}$	$\frac{8700 \pm 128}{72.2}$
Sandy (Southwest Kyzyl Kum)	$\frac{19400 \pm 470}{100}$	$\frac{13340 \pm 940}{68.7}$	$\frac{12900 \pm 1020}{66.4}$	$\frac{8450 \pm 542}{43.5}$
Sandy (Muyunkum)	$\frac{7240 \pm 1140}{100}$	$\frac{5400 \pm 2600}{74.5}$	$\frac{5200 \pm 680}{71.8}$	$\frac{4500 \pm 834}{62.1}$
Sandy (Volgograd)	$\frac{9100 \pm 2080}{100}$	$\frac{8200 \pm 884}{90.1}$	$\frac{6450 \pm 1080}{76.3}$	$\frac{5100 \pm 634}{56.0}$
Solontsovy (Achikulak)	$\frac{17940 \pm 4340}{100}$	$\frac{11940 \pm 1940}{66.5}$	$\frac{11000 \pm 1760}{61.3}$	$\frac{8650 \pm 1420}{48.2}$

Note. The number of plants per 1 ha: in the numerator - absolute numbers, in the denominator - %. The same in Table. 2.

In the experiment to find out the seeding rates of seeds in crops, where the plant density according to the variants of the experiment ranged from 2.9-15.2 thousand seedlings, the survival rate in the first year of life was quite high (78.9-100 %). In subsequent years, there was a tendency towards a decrease in the number according to the variants of the

experiment as the seeding rates increased. At the same time, in variants with a low seeding rate (1 and 2 kg/ha of seeds), starting from the second year, the number of plants not only did not decrease, but also slightly increased. Subsequently, the number of individuals stabilized (Table 2).

Table 2. Dynamics of the abundance and survival rate of *Kochia prostrata* of the stony ecotype in connection with different seeding rates in the Caspian semi-desert conditions.

Seeding rate, kg/ha	1st year		2nd year	3rd year
	spring	autumn		
1	$\frac{2940 \pm 390}{96.3}$	$\frac{3100 \pm 624}{101.0}$	$\frac{3000 \pm 360}{98.3}$	$\frac{3300 \pm 780}{108.0}$
2	$\frac{4940 \pm 550}{100}$	$\frac{4940 \pm 650}{100}$	$\frac{4850 \pm 580}{98.1}$	$\frac{5240 \pm 460}{106.0}$
4	$\frac{7800 \pm 440}{100}$	$\frac{7740 \pm 820}{99.2}$	$\frac{7700 \pm 240}{98.7}$	$\frac{7940 \pm 700}{101.7}$
5	$\frac{12046 \pm 3480}{100}$	$\frac{1020 \pm 1840}{84.7}$	$\frac{10200 \pm 916}{84.7}$	$\frac{10440 \pm 1920}{86.7}$
6	$\frac{15200 \pm 1340}{100}$	$\frac{12000 \pm 1050}{78.9}$	$\frac{12000 \pm 1024}{78.9}$	$\frac{10840 \pm 1160}{71.3}$

3.4 Plant Growth Dynamics

All *Kochia prostrata* ecotypes tested under the experimental conditions grow rather quickly and by the end of the first year of the growing season acquire quite normal forms of a semi-shrub. The *Kochia prostrata* ecotypes tested in culture under the conditions of the Caspian semi-desert were characterized by rapid growth (Tables 3, 4). All ecotypes in 2018 by the end of the year of life reached from 55.0 to 95.9 cm in height. By the fourth year of life, the height of *Kochia prostrata* plants in 2018 sowing reached 40.2-77.0 cm, in 2019 sowing - by the end of 3 years of vegetation - 47.7-76.6 cm. The highest growth rates among the tested ecotypes are characterized by *Kochia prostrata* stony and clay ecotypes from Kyrgyzstan, and the lowest - by *Kochia prostrata* clay from Stavropol and *Kochia prostrata* sandy ecotypes from Volgograd.

Table 3. Growth rates of *Kochia prostrata* ecotypes in culture in the Caspian semi-desert (2018 sowing).

<i>Kochia prostrata</i> ecotype	Average plant height, cm (M ± m)			
	1st year	2nd year	3rd year	4th year
Stony (Kyrgyzstan)	95.9	89.3±2.17	53.2±2.9	77.0±3.07
Clay (Kyrgyzstan)	73.8	79.4±1.23	45.7±2.1	71.4±3.20
Sandy (Kyzylkum)	60.7	63.8±3.04	39.7±3.5	66.0±2.70
Sandy (Muyunkum)	56.3	75.3±2.68	35.5±3.3	58.1±2.40
Sandy (Volgograd)	55.0	78.6±12.9	31.5±2.5	40.2±0.83
Solontsovy (Achikulak)	67.3	62.4±2.38	35.1±6.4	52.9±5.11

Table 4. Growth rates of *Kochia prostrata* ecotypes in culture in the conditions of the Caspian semi-desert (2019 sowing).

<i>Kochia prostrata</i> ecotype	Average plant height, cm (M ± m)		
	1st year	2nd year	3rd year
Stony (Kyrgyzstan)	88.0±1.63	61.4±6.42	76.6±5.5
Clay (Kyrgyzstan)	95.5±5.75	56.4±1.75	75.7±2.7
Clay (Malguzars)	80.0±4.14	42.0±2.06	59.0±5.65
Clay (Stavropol)	48.5±1.71	33.0±1.99	48.6±4.5

Sandy (Kyzylkum)	63.2±3.58	38.3±1.07	52.4±2.4
Sandy (Muyunkum)	57.3±6.5	37.5±2.91	47.7±4.15
Sandy (Volgograd)	56.5±1.82	38.0±3.43	52.2±5.7
Solontsovy (Achikulak)	61.8±3.83	35.4±1.19	49.6±3.0

3.5 Root System Development

The penetration depth of the root system of *Kochia prostrata* in the first year of life is 257 cm, at the age of three it deepens to 550 cm (Fig. 2). In the process of ontogenetic development, the main root divides into six lateral roots that penetrate vertically into the soil. In the course of the growth of the root system, two tiers can be traced. The first tier is limited by the zone of atmospheric humidification. Many thin lateral roots and roots are formed here. The second tier is marked by roots penetrating vertically into the soil, covering a larger volume of soil horizons. Therefore, the root system of *Kochia prostrata* under the conditions of the Caspian semi-desert can be characterized as powerful, deeply penetrating, capable of using water and mineral resources of a large volume of soil.

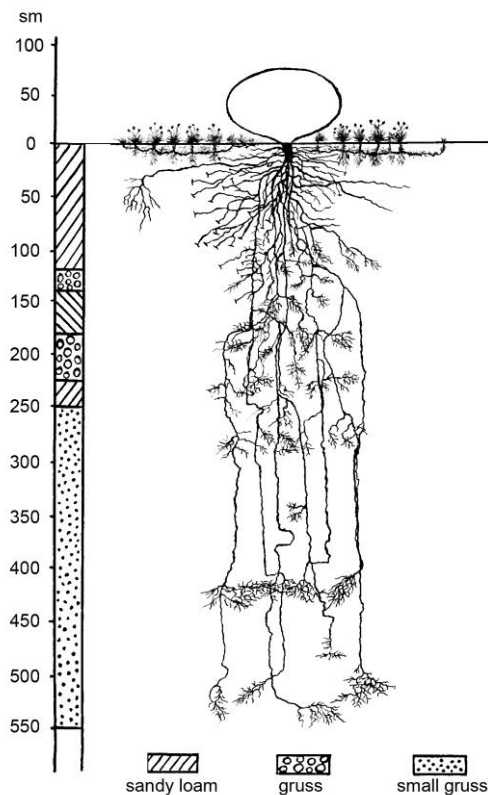


Fig. 2. Root system *Kochia prostrata* at the age of three years in the Caspian semi-desert.

3.6 Feed Productivity

Data on the forage productivity of *Kochia prostrata* ecotypes in the Caspian semi-desert conditions are given in Table 5. As can be seen, the *Kochia prostrata* stony and clay ecotypes from Kyrgyzstan were distinguished by the highest forage productivity among the

tested ecotypes. In these experiments, by the end of the growing season of the plant, on average over 3 years, the yield of *Kochia prostrata* of the stony ecotype was 1.22 t/ha, and of the clayey - 1.34 t/ha.

Among the sandy ecotypes, *Kochia prostrata*, obtained from the Southwestern Kyzyl Kum, was distinguished by the highest productivity, giving an average of 1.06 t/ha over 3 years. Samples of *Kochia prostrata* from the Muyunkum and Volgograd sandy ecotypes yielded 1.5–2 times less yield than the Kyzyl Kum ecotype. The clay ecotype from Stavropol and the solonetz one from Achikulak were characterized by relatively low forage productivity.

Table 5. Forage productivity (t/ha) of *Kochia prostrata* ecotypes in culture in the conditions of the Caspian semi-desert.

<i>Kochia prostrata</i> ecotype	1st year	2nd year	3rd year
Stony (Kyrgyzstan)	1.17	1.3±0.1	1.18±0.13
Clay (Kyrgyzstan)	1.14	1.58±0.1	1.31±0.17
Sandy (Southwest Kyzyl Kum)	1.18	1.28±0.078	0.73±0.03
Sandy (Muyunkum)	0.49	0.9±0.056	0.2±0.03
Sandy (Volgograd)	0.36	0.61±0.068	0.26±0.11
Solontsovy (Achikulak)	0.98	1.32±0.13	0.5±0.12

Therefore, this dwarf shrub, due to vigorous growth in the first year of life, is distinguished by a high productivity of forage mass. In subsequent years, as shown by the results of experimental crops, the productivity of *Kochia prostrata*, especially of the ecotypes of Central Asian origin, increases significantly.

3.7 Seed Productivity

According to the results of accounting for the seed productivity of the *Kochia prostrata* ecotypes, the average weight of seeds per plant on average over 3 years was the highest in *Kochia prostrata* of the stony ecotype (32.7 g), *Kochia prostrata* clay from Kyrgyzstan (18.0 g) and *Kochia prostrata* of the Kyzylkum sandy ecotype (9.7 g).

The average weight of seeds in other ecotypes obtained from the more northern regions of the range of this species is low - from 5.29 to 8.32 g per plant. Seed productivity of *Kochia prostrata* in relation to long-term average data fluctuates in some years from 2 to 8 times, and in relation to the best year - from 6 to 14 times. The value of seed productivity is less susceptible to fluctuations from year to year in the *Kochia prostrata* ecotypes of Central Asian origin, while in ecotypes of somewhat northern origin it fluctuates within wider limits.

The data characterizing the mass of 1000 seeds (Table 5) are of particular interest. The largest weight is observed in the *Kochia prostrata* of stony (1.92 g) and clay ecotypes from Kyrgyzstan (1.73 g), the smallest - in the sandy ecotype from Volgograd (0.88 g). The other three ecotypes are intermediate.

Table 5. Weight of 1000 seeds of *Kochia prostrata* ecotypes in culture in the Caspian semi-desert.

<i>Kochia prostrata</i> ecotype	Weight of 1000 seeds, g.			
	1st year	2nd year	3rd year	3-year average
Stony (Kyrgyzstan)	2.41	2.10	1.45	1.99
Clay (Kyrgyzstan)	1.95	2.13	1.63	1.90
Sandy (Kyzylkum)	1.31	1.19	1.26	1.25
Sandy (Muyunkum)	1.37	0.99	1.72	1.36

Sandy (Volgograd)	0.99	0.72	0.84	0.85
Solontsovy (Achikulak)	1.12	0.94	0.99	1.02

Kochia prostrata Kazakh and Volgograd sandy ecotype and Achikulak solonetz ecotype, i.e. ecotypes from more northern areas of the range of this species gave 2-3 times less yield. In the conditions of the Caspian semi-desert, as can be seen from the data in Table 6, the highest seed yield was noted for samples of ecotypes of Central Asian origin. In addition, the seed productivity of *Kochia prostrata* is subject to significant fluctuations, especially strong on crops of *Kochia prostrata* of the Muyunkum sandy ecotype (7.8 times), *Kochia prostrata* from Volgograd (7.4 times), *Kochia prostrata* of the solonetz ecotype (14.0 times). At the same time, in the *Kochia prostrata* ecotypes (stony, clayey, and sandy) of Central Asian origin, seed productivity fluctuates to a much lesser extent (3.3-5.0 times).

Table 6. Seed productivity of various ecotypes of *Kochia prostrata* in culture in the Caspian semi-desert.

<i>Kochia prostrata</i> ecotype	Seed yield, kg/ha			
	1st year	2nd year	3rd year	3-year average
Stony (Kyrgyzstan)	205.3	67.0	145.2	139.17
Clay (Kyrgyzstan)	137.0	52.0	167.1	118.70
Sandy (Kyzylkum)	144.6	21.2	66.2	77.33
Sandy (Muyunkum)	64.3	8.2	12.9	28.47
Sandy (Volgograd)	55.2	7.5	26.3	29.67
Solontsovy (Achikulak)	163.8	11.7	47.7	74.40

Under the conditions of the Caspian semi-desert, the highest seed yield on average for 3 years was obtained on crops of the South Kyrgyz stony ecotype in the amount of 139.17 kg/ha, the South Kyrgyz clay ecotype - 118.7 kg/ha, and the Kyzylkum sandy ecotype - 77.3 kg/ha of seeds.

4 Discussion

Kochia prostrata belongs to the type of adaptive strategy to violet plants. The strategic type of plants with violet properties according to L.G. Ramensky [13] or competitors (C-types) by J. Grime [14] are highly competitive plants, capable of capturing and holding the territory for a long time due to their rapid growth, suppressing the rival with the energy of vital activity and the full use of environmental resources. The ability to economically use moisture for transpiration plays a significant role in the formation of the violet properties of *Kochia prostrata* under the xerothermal conditions of the Caspian semi-desert.

In the course of evolution and natural selection under xerothermal conditions, plants have developed the most important ecological properties - resistance to moisture deficiency and a high degree of tolerance to salt stress, thanks to which *Kochia prostrata* conquered vast land areas. This is evidenced by the huge range of this plant.

The range of the species includes the following areas: Upper and Middle Dnieper, Volga-Don, Nizhne-Volzhsy, Ciscaucasian, Verkhne-Tobolsk, Irtysh, Altai, Angara-Sayan, Daursky, Aral-Caspian, Balkhash, Gorno-Turkmeny, Dzhungarsko-Tibolsky and the Pamir-Alai [3], as well as Central Europe, Middle-earth, the Balkan Peninsula, Asia Minor, Iran, North-West and North-East China, Tibet and Mongolia [4].

An important ecological-cenotic property of *Kochia prostrata* is the ability to form highly productive multi-species pasture communities in desert and semi-desert zones.

5 Conclusion

Kochia prostrata (L.) Shrad. - a perennial plant with a height of 35-75 cm, according to its life form - a shrub, according to ecology - an euhaloxerophyte, according to an adaptive strategy - violent, an extremely drought-resistant and salt-tolerant, valuable forage plant in desert pastures. It grows on solonetz soils, stony soils, chalk outcrops, in saline and sandy steppes, plain desert sands, on gray soils. It is characterized as a highly nutritious forage plant, eaten by all types of herbivorous animals. In the above-ground sphere, *Kochia prostrata* reaches an average height of 35-65 cm. One plant has up to 30 generative and 55 vegetative shoots. The length of generative shoots on average reaches 50-70 cm, vegetative ones - 10-15 cm. In the underground sphere, according to our data, the root system deepens up to 7 m, in the horizontal direction - up to 150-170 cm.

Fodder productivity reaches 2.2-2.5 t/ha of dry fodder mass, seed productivity - on average 100-150 kg/ha. High drought resistance and salt tolerance, good forage qualities make *Kochia prostrata* a promising forage plant for introduction into cultivation in arid regions of the Caspian semi-desert in order to restore the lost biodiversity and forage productivity of degraded pastures.

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