Improvement of plant communities through revegetation with Kochia prostrata and Agropyron fragile on the desert zone of the Republic of Kalmykia

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Abstract. Restoring herbaceous cover of degraded ecosystems is an urgent issue for regions where livestock breeding is the main direction of the economy. The vegetation of the desert zone of the Republic of Kalmykia is used as a forage source almost all year round. Heavy grazing (exceeding stocking rates) in the region results in a reduction of valuable perennial forage species in the plant community and invasion of annual species that do not afford the sod. Grazing efficiency decreases, open areas of soil are subjected to wind erosion. Restoring vegetation in the areas that have lost the ability to self-regenerate is possible through revegetation, a method for improving degraded ecosystems by replanting the soil. The scientific literature on revegetation in arid conditions abounds with information available on ecological, biological and varietal characteristics, agricultural technology for revegetative species, and the yield of certain species on revegetated sites. The authors monitored plant communities enhanced through revegetation in the southern part of the Caspian lowland within the Republic of Kalmykia. The vegetation dynamics was studied through direct observation and indirect extrapolation of spatial series into time series. The paper presents data on the improvement of natural plant communities through revegetation, including adaptation of revegetative species in buffer zones, tops accumulation depending on the type and age of revegetative species, the effect of fires, etc.

1. Introduction
According to the botanical and geographical zoning [4], the southern part of the Caspian lowland within the Republic of Kalmykia belongs to the desert zone. Kalmykia is the driest region in the European part of Russia. The temperature in summer can reach in some years +45 °C, whereas the dry period lasts from May to October [5]. The amount of precipitation in the target area during the warm period is 130–165 mm. The sum of active temperatures above 10 °C ranges from 3400 to 3600 °C. Summer is hot and dry, the average July temperature being 24.5–25.5 °C. Winter is moderately cold, the average monthly temperature in January being –7 °C, the average absolute minimum being –25 °C. The frost-free period lasts 165–180 days. A limiting factor for the growth and development of vegetation is moisture. Zonal soils are brown semi-deserts of predominantly light particle size distribution [6].

2. Material and methods
The dynamics of plant communities enhanced through revegetation was observed and accounted throughout 2011–2013 on the sites located in the desert zone of Kalmykia. The sites were restored in
different years. Forage kochia (*Kochia prostrata* (L.) Schrad. (fam. Chenopodiaceae), a perennial half-shrub, and *Agropyron fragile* (Roth) Candargy (fam. Poaceae), a perennial grass were utilized as the main revegetative species. The area surveyed during 2011–2013 amounted to 7.758 ha to feature 9 sites improved by establishing *Kochia prostrata* and 11 630 ha to feature 6 sites improved by establishing *Agropyron fragile*.

The paper provides the names of the soils in accordance with the classification and diagnostics of soils of the USSR [7]. Latin names of the plants follow S.K. Cherepanov [8]. Monitoring and observation were carried out in line with generally accepted geobotanical surveys. The efficiency of plant communities was accounted with the cut-sample method on the target sites corresponding to the average indices typical of the described plant community in composition, status, height and total projective cover of pasture grass stand. To assess the productivity, the grass stand was cut at the soil level on the sites of 1 x 2.5 m in 4-fold repeatedness. The productivity is given in dt ha of hay. The dynamics of vegetation was studies based on direct observations and indirect extrapolation of spatial series into time series [9]. Microsoft Office Excel 2007 was applied to process the material.

*Kochia prostrata* and *Agropyron fragile* were seeded on the target sites, in treated strips 10 m wide. The width of untreated strips (areas of native vegetation – buffer zones) was also 10 m. The seeds of *Kochia prostrata* (sand ecotype) and *Agropyron fragile* collected on the eve of sowing in natural habitats were utilized.

3. Results and discussion

3.1. Vegetation on sites improved by *Kochia prostrata*

Plant communities dominated by *Kochia prostrata* are the best rangelands in the desert zone of Kalmykia. However, heavy grazing use in the second half of the 20th century resulted in a significant reduction of *Kochia prostrata* in the natural forage grasslands [10]. Geobotanical survey materials [11] showed that vegetation communities on the sites before revegetation efforts were mainly made up of annual grass species (*Alyssum desertorum* Stapf, *Anisantha tectorum* (L.) Nevski) and *Poa bulbosa* L., an ephemeroid. Forb production on the sites was 1.4 dt ha in spring and autumn months.

*Kochia prostrata* was established on the degraded pasture sites in 2001, 2004, 2007, 2010 and 2011. This enabled to observe plant communities improved with *Kochia prostrata* from the 1st to the 12th summer.

*Kochia prostrata* dominated the vegetation cover throughout the observation period, i.e., from the first to the twelfth summer. *Anisantha tectorum*, *Alyssum desertorum*, *Ceratocarpus arenarius* L. and the ephemeroids *Poa bulbosa* and *Carex stenophylla* Wahlenb were the subdominants in the plant communities from the first to the fourth summers after sowing *Kochia prostrata* in the restored strips. Establishing *Kochia prostrata* was followed by a succession of subdominants in the fifth summer, i.e. annual species and ephemeroids were replaced by perennial grass species *Stipa sareptana* Becker, *S. capillata* L. and a semi-shrub *Artemisia lerchiana* Web.

Establishing *Kochia prostrata* in the buffer zone was clearly noticeable over the 4th year following the revegtation, but over the 6th year the vegetation in the restored strips was still noticeably different from that of the buffer areas. The herbage levelling in the restored and buffer strips occurred by the 9th year following the establishment of *Kochia prostrata* with a dominance in buffer areas by this time.

3.2. Vegetation on sites improved by *Agropyron fragile*

*Agropyron fragile* forms monodominant plant communities in the plant cover of the desert zone of Kalmykia, with *Artemisia lerchiana* and *Stipa sareptana* being as subdominants.

*Agropyron fragile* entries were seeded in strips in 2001, 2003, 2006, 2012 and 2013 in degraded grass-dominated rangelands, including *Poa bulbosa*, *Alyssum desertorum*, *Anisantha tectorum*, with a yield of 1.4 dt ha in spring and autumn months [11]. From the 1st to the 3rd summer after sowing, *Agropyron fragile* became a dominant component of the vegetation on the restored sites. From the 4th year after sowing, *Stipa sareptana* and *S. capillata* were reported as subdominant components in the plant communities, with *Agropyron fragile* being a dominant plant species in all plant communities. In wet years, in the intervals between swards, *Poa bulbosa* increased in abundance.
Stipa species became prevalent in the buffer grass stands from the 4th to the 8th year following Agropyron fragile establishment in the restored strips. Revegetative species being a subdominant of plant communities in the buffer strips were present since the 4th year after sowing in the restored strips.

3.3. Efficiency and age of revegetative species

The following features characterize perennial revegetative species in monoculture, namely: severe plant destruction (especially in the summer) during the first summer, subsequent slowdown of mortality and stabilization of population density by the end of the third growing season [12]. There is virtually no difference in biomass yield during the growing season subject to the moisture conditions. The maximum yield in grass communities enhanced by Kochia prostrata in the years with different moisture conditions occurs in the flowering-ripening stage of Kochia prostrata. Aboveground mass yields in Kochia prostrata communities occur throughout the growing season, with no summer-related dormancy. The maximum production in plant communities enhanced by Agropyron fragile occurs in the heading-flowering stage. The table shows the values of biomass production in grasslands enhanced with Kochia prostrata and Agropyron fragile, starting from the 4th year after planting.

| Age of vegetative species, years | Kochia prostrata-dominated plant communities | Agropyron fragile-dominated plant communities |
|--------------------------------|---------------------------------------------|---------------------------------------------|
|                                | Restored strip | Buffer strip | Restored strip | Buffer strip |
| 4                              | 9.8 ± 1.1     | 6.2 ± 0.5    | –              | –            |
| 5                              | 8.4 ± 0.9     | 4.8 ± 0.6    | 10.8 ± 1.3     | 6.5 ± 0.7    |
| 6                              | 8.8 ± 0.7     | 3.9 ± 0.6    | 6.1 ± 0.5      | 4.5 ± 0.5    |
| 7                              | 9.2 ± 0.9     | 5.1 ± 0.7    | 7.2 ± 0.6      | 5.8 ± 0.8    |
| 8                              | 7.8 ± 0.8     | 4.6 ± 0.5    | 9.4 ± 0.9      | 6.9 ± 0.5    |
| 9                              | 8.6 ± 1.1     | 6.1 ± 0.8    | 5.6 ± 0.7      | 4.7 ± 0.4    |
| 10                             | 12.8 ± 1.2    | 6.6 ± 0.4    | 5.7 ± 0.7      | 6.0 ± 0.7    |
| 11                             | 9.6 ± 0.8     | 5.7 ± 0.7    | 5.9 ± 0.8      | 5.0 ± 0.6    |
| 12                             | 10.3 ± 0.9    | 5.9 ± 0.8    | 6.3 ± 0.8      | 5.6 ± 0.6    |

Biomass production in the plant communities enhanced by Kochia prostrata being 4 to 12 years old ranges from 7.8–12.8 dt ha of dry matter. No direct dependence of the grass production rate on the age of plant communities was found. Grass production values are determined mainly not by the age of plant communities, but by the hydrothermal conditions of a particular year. Grass production in the restored strips over the 8th year after sowing Kochia prostrata did not exceed 8.0 dt ha, and over the 10th year it was 12.8 dt ha. According to V.N. Nidyulina [3] the production of Kochia prostrata sown in 10.5 m² plots on brown loamy semi-desert soils was in the range of 10.3–16.7 dt ha. The somewhat lower grass production values in Kochia prostrata communities established on brown semi-desert sandy loam soils can be due to the fact that V.N. Nidyulina [3] provides production records for the non-grazed revegetative sites. In addition, the humus content in the surface layer of brown semi-desert sandy loam soils is 0.5–1.4 %, which is 1.6–1.8 times lower compared to brown semi-desert loamy soils – 0.8–2.5 % [6].

The observation outputs show that grass production on the sites improved by Agropyron fragile is slightly lower compared to those improved by Kochia prostrata; its values from 5 to 12 years range from 5.6±0.7–10.8±1.3 dt ha of dry matter. In the work of O.A. Lachko [13] the average production of plant communities created by sowing Agropyron fragile on brown semi-desert soils was 9.5±0.2 dt ha.

Based on the data, biomass production on Agropyron fragile sites, depending on their age, tends to decrease from the 9th year of planting grass entries.

3.4. Effect of fires

The main human-induced factors to have a significant impact on the state of native and restored plant communities of the desert zone of the Republic of Kalmykia include livestock grazing and fires. There
is a negative relationship between grazing intensity and fire rates \([10, 14, 15]\). *Kochia prostrata* is valued as a revegetative species not just for its high nutritional qualities, high yield, etc. but also for its resistance to fire. Less combustibility compared to other species because *Kochia prostrata* vegetates in the summer as well. The effect of fire on plant communities improved by *Kochia prostrata* was estimated in the area strip-seeded with *Kochia* entries in 2001. From 2008 to 2010, fires annually affected part of the site, whereas in 2011–2013 there were no fires recorded. Over the first year following the fires, the plant cover of creeping stem species *Carex stenophylla* increased from 0.5–1 to 3–4 \% and *Artemisia austriaca* from a single indicator to 1–2 \%. *Artemisia lerchiana* almost disappeared from the grass stand \([16]\). The *Kochia prostrata*-dominated plant cover decreased by 3–5 \%. The coenotic value of *Stipa sareptana* and *S. capillata* increased. These species became dominant and subdominant components. The production of plant communities over the first year following the fire decreased by almost half compared with that in an intact part of the site. In the second year following the fire, grass yield increased by 20 \%, in the third – by 1.5 times vs. the production recorded in the first year.

4. Conclusion
Monitoring the status of grasslands in the desert zone improved through revegetation with *Kochia prostrata* and *Agropyron fragile* showed that both species are actively established from restored strips into buffer ones. *Kochia prostrata* tended to become a subdominant in plant communities of buffer strips in the 4th year after sowing, while *Agropyron fragile* – in the 5th year.

With aging, the production of plant communities improved by *Kochia prostrata* remains the same, while *Agropyron fragile* yield decreases from the 9th year after sowing.

Biomass production improved by *Kochia prostrata* is restored over the 3rd year after the fire, with *Stipa sareptana* and *S. capillata* playing a significant role as a forage source.

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