

Agricultural populations of *Festuca pratensis* (Poaceae) on the coal mining spoils in the forest-steppe of the Kuznetsk Basin, Russia

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Abstract. The study of meadow fescue agropopulations was conducted in the agricultural phytocoenoses, established on the leveled coal mining spoils in the forest-steppe zone of the Kuznetsk Basin mining region in Russia. In agrophytocoenoses the fescue is not a dominant species, as in the natural meadows of herbs and fescue, which occupied the area prior to spoiling. However, the presence of the meadow fescue in the newly established plant communities resulted in increasing their biological diversity and improving the forage quality. The species was shown to sustain in agricultural communities on the coal mining spoils for more than 25 years, whereas when sown on the zonal soils it maintains its presence for 4-6 years. The ontogenetic groups of the plant in all communities were found to be dominated by virginile, young and mid-aged generative specimen. By the 25th year of agricultural phytocoenoses development the vitality of the agropopulations decreased on the coal mining spoils, composed of both Quaternary and Permian sediments. The study showed for the first time that meadow fescue is a species with good potential to restore vegetation cover in the areas disturbed by the open coal mining.

1 Introduction

Sustainable strategy of the fuel and energy industry in Russia is currently based on the coal priority. The major coal mining should be done in Siberian coal basins, primarily in the Kuznetsk Basin region. Increasing open coal mining results in increasing areas disturbed by such process. Moreover, the territories that experience negative consequences of land disturbance by open mining, such as disturbed hydrological regime, contamination of adjacent landscapes by technogenic toxic compounds, increased erosion were estimated as 10 times exceeding in size the areas of direct disturbance. Coal mining regions are becoming increasingly adverse for human population, stressed by deteriorating environment and social tensions. Consequently, all these increase the importance of technologies for the accelerated restoration of disturbed landscapes in the Kuznetsk region, including assessing plant species for their potential in restoring disturbed territories and introducing promising species into practice.

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The aim of the study was to follow meadow fescue performance in the artificial plant communities, established on the coal mining spoils in the Kuznetsk Basin. The meadow fescue *Festuca pratensis* Huds. s. l. is a perennial bunch grass 120–130 cm or more in height. Its root system is fibrous, spreading mainly in the ploughed layer down to 20–25 cm [1]. The plant is a typical meadow mesophyte, growing very well on organic matter rich and sufficiently moist soils.

The species is common in Eurasia: in Russia it grows in the Arctic, the Caucasus, the West and East Siberia and the Far East, and beyond Russia the meadow fescue grows in Europe (Scandinavia, Atlantics, and Central Europe), the Mediterranean and Asia Minor. The plant can be found in floodplains and dry watershed valleys, as well as forest edges and roadsides [2].

In the forest-steppe and sub-taiga conditions the meadow fescue is often the dominant member of plant communities, forming fescue meadows [3]. The species is of high economic significance as a forage crop of the highest palatability. Some studies showed the importance of detailed research into the development of *F. pratensis* populations during the restoration of anthropogenically disturbed territories [4, 5]. However, practically little is known, both in Russia and abroad, about meadow fescue performance in the artificial communities on the coal mining spoils [6, 7]. So the aim of our study was to examine for the first time the species performance during plant cover restoration in the Kuznetsk Basin areas, disturbed by the open coal mining.

2 Methods and conditions of the study

The study was conducted on the spoils produced by the “Listvyansky” coal mining pit (53.403, 86.570), situated in the forest-steppe in the south of the Kuznetsk Basin 15 km to the south-west of Novokuznetsk town (Kemerovo region, Russia).

Prior to spoiling, leached and podzolized chernozems prevailed in the area. Presently, due to open mining, the area is covered with spoils. According to the relative age of the subsoil and undelaying sediment deposits, the excavated substrates can be categorized in two groups. If coal deposits are shallow, the overlaying substrate is composed of the Quaternary sediments, represented by potentially fertile loess loams. If the coal deposits are located at a greater depth, overlaying substrates are comprised of the Permian sediments of argillites, aleurolites and sandstone. The mechanical composition of the substrates impedes biological recultivation [8]. Some mechanical and chemical properties of the substrates, as well as chemical properties of their water extracts, were reported earlier by T. G. Lamanova and N. V. Sheremet [9]. Annual precipitation in the study area ranges 400–600 mm.

The fescue seeds were sown on the ‘Listvyansky’ coal mining spoils at the beginning of July 1989 and 1990 on the areas occupied by carefully leveled spoils. The meadow fescue was one of the components in the sown mixture of herbs and grasses; gradually the fescue began to invade the adjacent cultural and natural areas. The artificial plant communities at the ‘Listvyansky’ pit technological area were monitored since 1990 till 2014.

On each study site every year, starting with the second one, in July–early August the aboveground phytomass was cut in four replicates to estimate its stock and species composition. Additionally, in 1990–1993 and 2000, 2013 ten 1 m² subplots were chosen to determine plant projective cover, density, ontogenetic stage structure, the number of generative shoots of all the species, comprising the communities. The age status of an individual plant was established in compliance with the recommendations [1].

3 Results

Based on the duration of the entire ontogenesis, L. A. Zhukova [10] regards meadow fescue as a bunch grass with the average ontogenesis duration ranging from 5 to 15 years, sometimes more. The general ontogenesis duration of the species is 6–20 years and more [1].

When growing in artificial phytocoenoses on the zonal soils in the West Siberia, the meadow fescue holds on for 4–6 years, and longer, provided good management and fertilization [11]. On the leveled coal mining spoils in the forest-steppe zone of the Kuznetsk Basin *F. pratensis* was a notable agrophytocoenosis component for 25 years, gradually invading the adjacent phytocoenoses, which on the Quaternary sediments were initially composed of *Medicago sativa* and *Festuca arundinacea* and on the Permian sediments of *Trifolium pretense*, and of diverse community on the plot under natural self-revegetation.

Prior to spoil formation the area was occupied by fescue-herbs meadows, where *F. pratensis* was the major coenosis-forming species with its contribution in the total aboveground phytomass reaching 27 % [2, 11]. After open mining the coenotic importance of the meadow fescue in grasses and herbs mixtures, established on the ‘Listvyansky’ spoils, drastically decreased as the species was not found among the dominant species. The *F. pratensis* share in the aboveground phytomass ranged from 0.1 to 16.6 % in different years. Only once the meadow fescue was found to perform as a dominant, i.e. when its share in the green standing phytomass on the Quaternary sediments exceeded 10 % in 2002 (the 14th year of the agrophytocoenosis development).

The aboveground production of artificial phytocoenoses was significantly lower than production in natural (1.5–2.0 t/ha) and cultured (45–60 t/ha of hay) meadows [12]. Maximal values of the aboveground phytomass in the grass mixture on the Quaternary sediments were obtained in 2002 (0.49 t/ha), whereas the minimal ones (0.01 t/ha) were obtained for *Medicago sativa* in 1998 and under natural revegetation on Quaternary sediments in 1995. Despite its little role in the standing aboveground phytomass, the presence of the meadow fescue was shown to be beneficial for the increased biodiversity of plant communities growing on the coal mining spoils.

In the agrophytocoenoses on the Quaternary sediments, the dry aboveground phytomass estimates, as averaged over the study period, were higher as compared with the ones on the Permian sediments (0.16 ± 0.5 vs. 0.8 ± 0.2 t/ha). The average contribution of *F. pratensis* in the aboveground phytomass ranged 0.2–16.6 and 0.3–5.3 %, respectively [13].

The highest (over the study period) estimates of density, projective cover and the number of *F. pratensis* generative shoots on the ‘Listvyansky’ mining spoils were observed in the third year (1991) in the grass mixture on the Permian sediments with a density of 24.8 ± 18.2 ind./m², projective cover of 9.0 ± 4.0 % and the number of generative shoots of 24.8 ± 18.2 pcs./m² (table). In the monospecies phytocoenoses the maximal aboveground phytomass stock of the meadow fescue was obtained in the first and second years, in the first year already developing nearly the maximal density and sustaining such density during the following years [14]. In the 10th year of the community growth and development density and projective cover were found to be not high, and usually higher on the Quaternary sediments as compared with the Permian ones. The number of *F. pratensis* generative shoots in the 10th year of the community development was also higher on the Quaternary sediments as compared with the Permian ones, with the maximal numbers of 17.8 ± 10.4 pcs./m² found under natural revegetation on the Quaternary sediments and only 0.7 ± 0.5 pcs./m² on the Permian ones. Therefore the Quaternary sediments, composed of loess loams, were found to be more beneficial for the meadow fescue growth and development. Over the course of the 25 years of the study the vitality *F. pratensis* agropopulations were found to be decreasing both on the Quaternary and Permian sediments.

Table 1. Some properties of *Festuca pratensis* agropopulations in the agricultural phytocoenoses developing on the leveled coal mining spoils in the forest-steppe zone of the Kuznetsk Basin (mean \pm standard error of the mean)

Year of observation (year of plant ontogenesis)	Projective cover, %	Number of shoots, pcs./m ²	Number of generative shoots, pcs./m ²	Height of the generative shoots, cm
Quaternary deposits				
Grass mixture				
1998 (10 th)	6.2 \pm 0.2	2.8 \pm 0.7	3.1 \pm 1.0	59.0 \pm 13.9
<i>Medicago sativa</i>				
1998 (10 th)	0.9 \pm 0.4	4.8 \pm 0.9	6.7 \pm 1.7	55.0 \pm 2.5
<i>Festuca arundinacea</i>				
1998 (10 th)	0.3 \pm 0.1	1.6 \pm 0.8	3.2 \pm 1.6	62.0 \pm 0.2
2013 (25 th)	0.05 \pm 0.05	0.1 \pm 0.1	0.4 \pm 0.4	18
Natural revegetation				
1998 (10 th)	4.8 \pm 3.0	5.9 \pm 2.7	17.8 \pm 10.4	60.3 \pm 4.5
Permian sediments				
Grass mixture				
1991 (3 th)	9.0 \pm 4.0	15.4 \pm 12.2	24.8 \pm 18.2	96.4 \pm 2.6
1998 (10 th)	0.2 \pm 0.1	2.4 \pm 0.7	0.1 \pm 0.4	43.4 \pm 6.0
Grasses mixed with <i>Onobrychis arenarea</i>				
2000 (12 th)	0.2	0.7 \pm 0.4	2.1 \pm 1.4	38.6 \pm 1.3
2013 (25 th)	0.3 \pm 0.3	0.1 \pm 0.1	2.6 \pm 2.6	75.8 \pm 3.1
<i>Trifolium pratense</i>				
2013 (24 th)	0.05 \pm 0.05	0.5 \pm 0.5	0.5 \pm 0.5	65.6 \pm 1.5
Natural revegetation				
1998 (10 th)	0.1 \pm 0.1	0.3 \pm 0.2	0.7 \pm 0.5	44.0 \pm 18.2

The age spectra of the *F. pratensis* agropopulations on the ‘Listvyansky’ spoils were regular juvenile, definitive and lacking some age stages. Over all the study years sub-senile and senile plants were not found in the communities. The lack of certain age stages can be an element in the general strategy of the species survival in technogenic ecotopes.

The maximal diameter of the fescue bunches of the middle-aged mature specimen in the third year grass mixture on the Permian sediments was 12.8 \pm 1.3 cm, with the overall maximum of 16.5 cm. The highest number of the generative shoots was 24.8 \pm 18.2 pcs./m², the same shoots also being the tallest ones (96.4 \pm 2.6 cm, table). The height of the meadow fescue generative shoots in natural phytocoenoses in the floodplain meadows of the Oka, Northern Dvina and Malaya Kokshaga Rivers was reported as ranging 51.0–93.2 cm [10], with the highest values observed under favourable weather conditions of a year.

Therefore the highest viability of *F. pratensis* individual plants and agropopulations were observed in grass mixtures in the third year of growth on the Permian sediments, when *Bromopsis inermis* with its long rhizomes contributed 31% into the aboveground phytomass stock. In 1998 this species contributed as much as 74.6%, thus decreasing the vital status of the meadow fescue populations. By the 10th year of the agrophytocoenosis development the fescue decreased its vital status yet more to be substituted with the longer rooted Hungarian brome. This trend was also observed in the grass mixtures on the zonal soils in the northern forest-steppe in the Southern Urals, where the meadow fescue was actively substituted by the brome [15].

When grown on the zonal soils in the Southern Urals in a monospecies community, the number of *F. pratensis* generative shoots remained almost the same for nine years; when fertilizers were applied, the number increased 3-fold, but afterwards began to decrease drastically. In the grass mixture with fertilization the meadow clover suppressed the *F. pratensis* growth and development in the third year. Therefore fertilization was shown to increase strongly the meadow fescue vital status in the monoculture, but had no effect in its combined growth with other components in the grass mixture [16]. This finding suggests that the *F. pratensis* synecological optimum lies in poor soil environments, whereas its autecological optimum lies with rich soils.

In the study area, i.e. in the forest-steppe zone of the Kuznetsk Basin, prior to the open coal mining prevailing meadow communities were represented by fescue-and-herbs ones, where meadow fescue played the role of the violent. After mining the grass mixtures were sown on the leveled spoils, and meadow fescue shifted its ecocoenotic strategy to performing as an ecotopic patient under the abiotic stress due to the stony Technosol substrate and overall adverse soil environment, significantly deteriorated in comparison with the zonal leached and podzolized chernozems.

4 Conclusions

The long-term (1990–2014) study of the meadow fescue (*Festuca pratensis* Huds.) performance on the leveled coal mining spoils of the Kuznetsk Basin showed the following regularities.

Prior to land disturbance by mining the species was the main coenosis-forming one among other grass species, and after disturbance this coenotic importance of the meadow fescue sharply decreased. However, under novel environmental conditions the species was found to perform as a long-living one, with its life longevity on the spoils in the forest-steppe zone of the Kuznetsk Basin being about the same as in hayed meadows sown on the zonal soils. Different years may differentiate in the weather conditions, beneficial for the fescue growth on the spoils, composed of the Quaternary or Permian sediments. During the last years of the study the meadow fescue plants density decreased on soil substrates, differing in relative age.

Using the meadow fescue, a high quality forage plant, as a component in agricultural phytocoenoses established on substrates of different geological age results in increasing the biological diversity during the restoration of the lands, disturbed by the coal open mining.

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