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The influence of soil composition on the productivity of phytocenoses

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Abstract. Soil factors play a decisive role in the formation of the species composition of plant communities in the steppe zone. The purposeof the research work was: a comprehensive assessment of the productivity of natural lands and agrocenoses. Field research was carried out in the Orenburg Urals region. It was established that the productivity of above-ground phytomass decreases from steppe areas - 2.38 t/ha to agrocenoses - 0.38 t/ha. In the steppe area, 89 plant species from 27 families were noted; in the forest belt - 59 species from 22 families; fallows - 28 species from 10 families, the agrocenosis is represented by 5 species from 4 families. When assessing soil fertility, the quantitative content of humus and basic plant nutrients: nitrate nitrogen, mobile phosphorus and exchangeable potassium, were important. The amount of humus in the soils of the steppe area at a depth of (0 -10 cm) is 0.77% and (30-40 cm) is 1.4%. The smallest amount of humus in the soils of the agrocenosis is at a depth of (0-10 cm) - 0.32% and (30-40 cm) - 0.36%. The heterogeneity of the content of mobile phosphorus was revealed, high values were noted in the soils of the agrocenosis at a depth (0-10 cm) - 51 mg/kg and the lowest values in the soils of the steppe area at a depth (30-40 cm) - 17.16 mg/kg. A significant content of mobile forms of potassium was noted in the forest belt at a soil depth (0-10 cm) - 761.1 mg/kg, the minimum parameters of the steppe area at a soil depth (30-40 cm) - 106.4 mg/kg. Microclimate, the amount of nutrients in the soil, and anthropogenic impact are the main indicators of the productivity formation of the phytocenosis of a particular tract.

1 Introduction

Among the regions of the Russian Federation, the Orenburg region ranks second in terms of the volume of developed land [1]. A significant part of the steppes of the Orenburg region was plowed from 1954 to 1961, and the remaining part was used as natural feeding grounds, therefore, to preserve the biodiversity of ecosystems, it is important to study the productivity and species composition of phytocenoses [2]. The founder of this concept of biocenosis productivity is V.I. Vernadsky [3]. Plant productivity, the beginning of the material and energy cycle on Earth, plays a critical role in global vegetation growth under a

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changing climate [4-5]. Spatial heterogeneity of plant communities is controlled by several factors, both biotic and abiotic, including topography and soil nutrients [6-7]. Among edaphic factors, soil factors play a decisive role in the formation of the species composition of plant communities. Thus, soil nutrients are necessary for the formation of primary vegetation production, this includes available forms of phosphorus, nitrogen and nitrates; with sufficient soil moisture, these parameters increase the yield of agricultural crops and the productivity of pastures [7-8]. In addition, physical soil properties, such as soil texture and soil grain size fractions, are key factors in the productivity of phytocenoses. These factors also influence the spatiotemporal distribution of vegetation [8-9].

Purpose of the work: comprehensive assessment of the productivity of natural lands and agrophytocenoses.

2 Materials and methods

Field research was carried out in the Orenburg Urals. In the study area, the possibility of restoring soil fertility using the potential of natural ecosystems is being studied. The work used the results of field studies of soils of 4 reference plots located in the vicinity of the village. Nezhinka of the Orenburg district of the Orenburg region on plowed soil (more than 70 years) southern chernozems, medium-thick, medium-humus. Research has been carried out on previously plowed areas for more than 70 years [2] and currently represents anthropogenically modified areas, but some tracts are being restored and represent steppe areas, that is, restoration processes are taking place due to the potential of natural ecosystems. The study areas are located on the right bank of the river. Ural is 9 km east of Orenburg and 6 km southwest of Orenburg International Airport. To take into account the primary productive phytomass, untouched steppes and anthropogenically modified types of landscapes (fallow lands, protective forest belts, agrocenoses) were studied. In addition to taking into account the productive phytomass, phenological studies of plants in local areas were carried out. The coordinates of the study area are 51°72'27" N; 54°17'30.4" E. Based on their landscape location, the reference areas can be attributed to eluvial facies, on upland watershed surfaces with a slight slope of 1–2°, which form a single genetic system [10].

Reference area No. 1 is located in agrocenoses of durum wheat.

Reference plot No. 2 – fallow land for 1-2 years, located 150 m from the studied agrocenoses.

Reference area No. 3 – protective forest belt of agrocenoses in the vicinity of the village. Nezhinka, Orenburg district, Orenburg region.

Reference area No. 4 is a steppe area, located parallel to the studied agrocenoses.

The selected study areas were located on a homogeneous area, but belonged to different tracts. The study of the productivity of agrocenoses was carried out in accordance with GOST 9353-2016 [11]. The experiment was repeated 4 times. The dimensions of the plots are 14.4 m 60 m. To establish field experiments (agrocenoses), MTZ-1221, T-25 tractors, KPS-4 cultivator, and BZSS-1.0 harrow were used. The sowing of the experimental plots was carried out using SN-16 and SZ-3.6 seeders, and harvesting with a "Terrion - 2010" combine. The agricultural technology in the experiments met the requirements for cultivating crops in the experimental zone. The description of plant communities was accompanied by their location on the ground according to their position in the relief. When describing herbaceous communities, the general projection cover was noted and the full floristic composition was revealed [10]. Herbarium collection was carried out at the study sites. Plant identification was carried out using the "Identification of Vascular Plants of the Orenburg Region" [12]. To work on identifying plants, binocular magnifying glasses and a Mikmed-5 microscope (binocular) were used. The soils of the Orenburg district of the Orenburg region are characterized by a non-percolative regime, most of the chernozems are alkaline, often with high carbonate content. Soil samples were taken from a horizon of 0-10 cm, 30-40 cm. The humus content in the soil was determined by the Tyurin method [13], nitrate nitrogen - using an ion-selective electrode [14], mobile phosphorus, exchangeable potassium - according to Chirikov [15]. Analyzes were performed on the basis of the Shared Use Center of the Federal State Budgetary Scientific Institution Federal Scientific Center BST RAS (https://ckp-rf.ru/catalog/ckp/77384/). The studies used generally accepted methods: field, stationary, local and landscape observations, office methods [11-12, 15]. The map of the study area was produced in the Arc GIS 10.5 program.

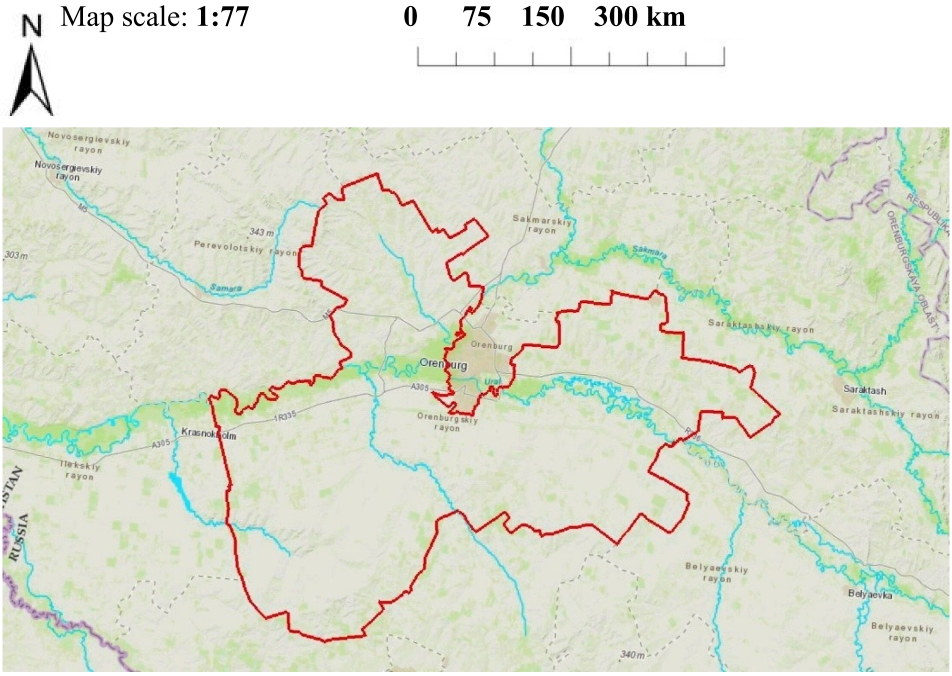

Fig. 1. Map – diagram of the study area in the vicinity of the village. Nezhinka, Orenburg district, Orenburg region.

Statistical processing of material. The results obtained were subjected to statistical processing with the determination of the arithmetic mean value (M), the average error (m). Graphs and figures were created using the Statiatica 10.1 program.

3 Results and Discussion

Insignificant anthropogenic impacts lead to significant changes in natural cycles [3]. The amount of primary biological productivity of a local area depends on the amount of incoming solar energy (heat) and moisture [3]. Analysis of reference area No. 1 (agrophytocenosis) in the vicinity of the village of Nezhinka, Orenburg district, Orenburg region, is characterized by the dominance of the cultural species Triticum durum L. At the same time, weeds belonging to 5 species from 4 families were found (1 monocotyledonous, 4 dicotyledonous). The threshold of weed harmfulness does not exceed critical values. The share of weeds from the total primary biomass is 10.48%, while the productivity of the above-ground phytomass agrocenosis is 0.38 t/t. Types of harmful weed plants in arable lands:*Panicum miliaceum* L., *Amaranthus retroflexus* L., *Conyza canadensis* (L.) Cronquist they are found in wastelands, on roadsides and in natural steppe areas. Ruderal plant species *Artemisia absinthium* L*, Achillea millefolium* L*, Convolvulus arvensis* L.*, Polygonum aviculare* L.*,*They also grow on arable land. There is a close relationship between plants growing in natural conditions and on arable land. Reference area No. 2 is a deposit, located 150 m from the studied agrophytocenoses, therefore they form a single geosystem of eluvial facies with a slope of 1. Fallow land (1-2 years) is characterized by the presence of weeds. Young deposits are polydominant. The herbaceous flora is dominated by:*Cirsium arvense* (L.) Scop, *Conyza canadensis* (L.) Crong., *Xanthium strumarium* L, *Anthemis cotula* L. Among the cultivated plants there are *Panicum miliaceum* L., *Heliánthus annuus* L. 28 plant species were recorded in the study area. The productivity of vegetative parts of land plants was 1.23 t/ha. Reference area No. 3 – forest belt. The forest stand is dominated by Fraxinus americana L. cop2, the height of the tree stand is 2.6 − 3.5 m, the trunk diameter is from 10 − 25 cm. It is found in the undergrowth *Sorbus aucuparia L.* Dominant species *Fraxinus americana L.* has a crown density of 0.5; as a result of shading, the lower herbaceous layer has a total projection cover of 15-20%. The grass stand consists of bluegrass-forb formation (*Poa trivialis* L.+B*romus mollis* L.*).*The species composition of the grass stand consists of the following species:*Agrimoniaeupatoria L., Melilotus officinalis* (L.)Pall*, Plantago media* L., *Achillea millefolium* L.*, Artemisia absinthium* L.*, Taraxacum officinale* Wigg and other types. There are 59 plant species from 22 families on the site. The productivity of land plants was 1.21 t/ha. Reference area No. 4 − The steppe area of the Orenburg district of the Orenburg region is characterized by wheatgrass-grass formation (*Agropyron cristatum*L.+ *Stīpa zalēsskii* Wilensky*).* The total projection coverage is 50−60%. The basis of the grass stand is formed *Agropyron cristatum* (L.) Gaertn.– cop2, *Stīpa zalēsskii* Wilensky– cop1, *Poatrivialis* L.*– sp*. Other types of herbs are found*Euphórbia virgata* Waldst. &Kit., *Artemísia absínthium*L., *Gypsophilapaniculata* L.*, Tragopogon dubius* Scop., *Salvia stepposa* Shost. The total number of plant species in the natural phytocenosis study area is 89 out of 27 families. The most numerous is the family Asteraceae Dumort– 16 видов, сем. Poaceae Barnhart– 13, other families are represented by fewer species. The productivity of land plants was 2.38 t/ha. Lavrenko E.M. [16] noted that the dominant synusia in steppe communities, which forms the maximum of primary biological production, is represented by turf grasses, where the phytocenoses include tall turf grasses and less tall small turf grasses. As a result of the floristic study of phytocenoses, the usual pattern of decrease in species diversity and productivity of natural lands from steppe areas to plowed agrocenoses was revealed [17-18]. Thus, from Figure 2 it is clear that the human impact on phytocenoses is colossal. The steppe areas contain about 89 species from 27 families, the forest belt contains up to 59 species from 22 families, and the fallow lands contain 28 species from 10 families.

What is common to anthropogenically modified areas is a visible change in plant communities with a depletion of phytodiversity and the predominance of weeds (1–2 year fallow land, agrophytocenosis), that is, natural cenoses are being replaced by weeds [15-16]. During the growing season in the study area surrounding the village. Nezhinka, Orenburg district, Orenburg region, productivity of plant communities: agrocenosis - 0.38 t/ta; fallow (1-2 years) - 1.23 t/ha; forest belt - 1.21 t/ha; steppe area - 2.38 t/ha (Table1).

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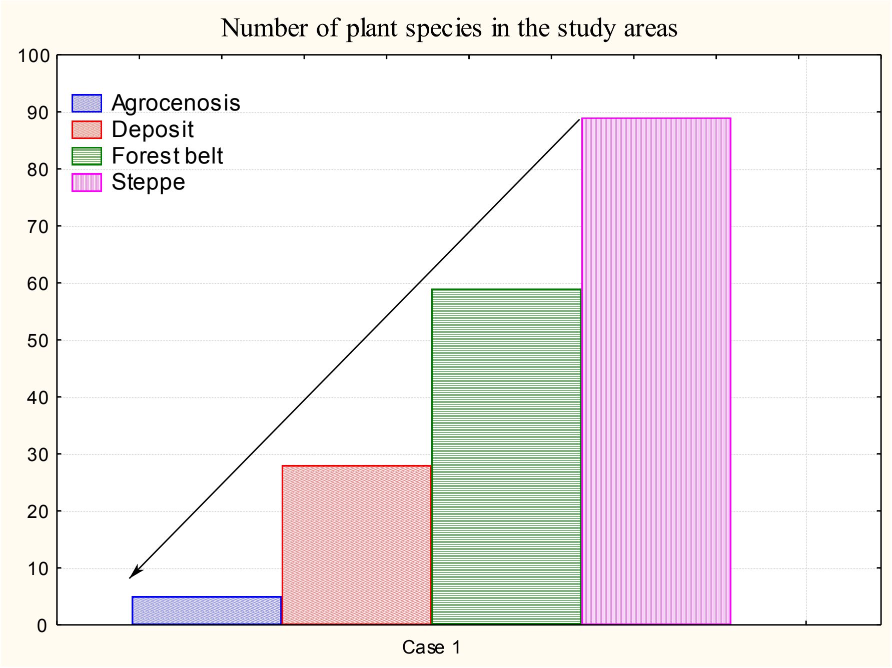

Fig. 2. The number of plant species in the studied tracts in the vicinity of the village. Nizhina, Orenburg district, Orenburg region.

Table 1. Productivity of above-ground phytomass in air-dry weight.

No. plot	Productivityofabove-groundphytomass, t/ha (M±m)	QuantityofLitter, t/ha (M±m)
1	0.38±0.001	0.26±0.002
2	1.23±0.005	0.96±0.003
3	1.21±0.002	6.5±0.02
4	2.38±0.003	4.73±0.003

The basis of the phytocenosis is the Poaceae family; perennials play a large part in the herbage. One of the factors for good productivity of phytocenoses is the presence of moisture and other organic active components of the soil. The litter of phytocenoses constitutes the energy potential of the biogeocenosis, since the bulk consists of the current year's litter, microorganisms and humifying plant residues. The smallest amount of mulch was on site No. 1 (agrocenosis) - 0.26 t/ha, on site No. 2 (fallow land) plant residues were - 0.96 t/ha, on site No. 3 (forest belt) - 6.5 t/ha ha, on site No. 4 (steppe) - 4.73 t/ha. From Table 2, it is clear that the mulch of agrophytocenoses is 18 times inferior to steppe felt and 25 times inferior to forest felt. In agrocenoses, organic matter is removed annually, while in other study areas there is a litter of plant residues, thus, the quantitative content of humus depends on the supply of plant matter. The main indicators of soil fertility include: humus content, pH, exchangeable bases K+, P_2O_5 $-NO_3$. Organic matter is one of the most important elements of soil fertility. Humus affects the thermal, water, air properties of the soil, and its biological activity [17]. The overwhelming majority of the studied soils of agrocenoses and anthropogenically modified areas are characterized by an acidic and neutral reaction of the environment (Table 2). Analysis of the results of studies of the quantitative content of humus in soils (0-10 cm) in the plots showed: in plot No. 2 (fallow land) the humus content is 2 times higher than in plot No. 1 (agrocenosis); the amount of organic matter in the soils of plot No. 3 is 2.25 times greater than in plot No. 1 (agrocenosis) and the humus content of the soils of plot No. 4 is 2.4 times higher than the reserve of organic matter in the soils of plot No. 1. An assessment of the reserves of organic matter in the soils of the experimental plots at a depth (30-40 cm) demonstrated: in plot No. 2, the humus content in the soils is 1.4 times higher than in the soils in plot No. 1; at reference site No. 3, the humus content in the soils is 2.13 times higher than in the soils of site No. 1; at site No. 3, the humus content in the soils is 3.8 times higher than in the soils at site No. 1. The amount of humus in the soils of the steppe area at a depth of (0-10 cm) is 0.77% and (30-40 cm) is 1.4%. The smallest amount of humus was noted in the soils of the agrocenosis at a depth of (0-10 cm) - 0.32% and (30-40 cm) - 0.36%. Consequently, the highest content of soil organic matter is at depths (0-10 cm) and (30-40 cm) in site No. 4 (steppe). The smallest amount of organic matter in soils is at a depth of (0-10 cm) and (30-40 cm) of plot No. 1 (agrocenosis). At the same time, in reference area No. 4, the processes of humus formation and humus accumulation predominate. Steppe areas have the greatest potential for soil restoration as a result of anthropogenic impact. Thus, the work of Chinese scientists Xiaohang Bai et al. [19] showed that carbon stocks in the soil have a positive correlation with plant diversity at the early stage of pasture restoration and a significant positive correlation with species diversity at the late stage of pasture restoration. Research by Wu L., Liu H, et al. [20] built a model of the processes of restoration of the degraded steppe in Mongolia. It takes longer to restore a typical steppe than a meadow steppe. Our studies have demonstrated that the quantitative content of macroelements in soils depends on the location of the studied tracts (Table 2).

Table 2. Content of averaged macroelements in soils of the study area during the growing season.

No.	Soil research depth, cm	pH	Humus, %	$N\text{-}NO_3$, (mg/kg) (M±m)	P_2O_5, (mg/kg) (M±m)	K_2O, (mg/kg) (M±m)
1	0-10	5.78	0.32	1.3±0.02	51±0.57	513.95±1.38
	30-40	5.81	0.36	2.0±0.05	50±0.28	326.65±2.43
2	0-10	6.98	0.64	1.0±0.02	42±0.52	491.8±1.07
	30-40	6.9	0.52	1.4±0.005	44.1±0.1	393.56±0.72
3	0-10	6.56	0.72	3.31±0.10	148.1±0.61	761.1±0.57
	30-40	6.75	0.77	3.84±0.073	88.1±2.57	357.1±0.59
4	0-10	6.8	0.77	4.40±0.08	24.3±0.98	243.7±0.58
	30-40	7	1.4	6.85±0.97	17.16±0.13	106.4±1.01

To determine the supply of soils with available forms of macroelements, their actual content was compared with a standard scale. As a result of comparison with the standard scale, we obtained a very low content of nitrate nitrogen in all areas, except for steppe area No. 4 in a layer of 30-40 cm (Table 3). We noted a low level of nitrate nitrogen content in agrocenose soils of 1.3 mg/kg. The low supply of soils with nitrate nitrogen content at all study sites, varying in anthropogenic load, shows the need to apply nitrogen fertilizers to the soils of site No. 1 (agrocenosis). Nitrogen fertilizers are most effective compared to phosphorus and potassium fertilizers.The deficiency of the ammonium form of nitrogen to a very low level of soil supply is associated with its redistribution along the soil profile, and also serves as the main source of plant nutrition. A high content of available phosphorus was noted in the following areas: agrocenosis No. 1, forest belt No. 3. At deposit No. 2, an increased content of macroelements was noted. At steppe site № 4, an average level of soil phosphorus supply was noted. We revealed heterogeneity in the content of mobile phosphorus, high values were noted in the soils of the agrocenosis at a depth (0-10 cm) - 51 mg/kg and the lowest values in the soils of the steppe area at a depth (30-40 cm) - 17.16 mg/kg, this indicates about the easy solubility and availability of the macroelement to plants; phosphorus is also an important component for the development of a whole complex of soil organisms. A significant content of mobile forms of potassium at the soil depth (0-10 cm) of the forest belt is 761.1 mg/kg, the minimum parameters at the soil depth (30-40 cm) in the steppe area are 106.4 mg/kg. Average values of mobile potassium in soils (0-10 cm) were recorded in plot No. 4 (steppe); in the soil layer (30-40 cm) there was a low content of mobile potassium. Most of the mobile forms of potassium are contained in the surface layers (0-10 cm) of soils in all experimental areas. Thus, the low provision of soils with nitrate nitrogen content at all study sites, varying in anthropogenic load, shows the need to apply nitrogen fertilizers to the soils of site No. 1 (agrocenosis). Heterogeneity in the content of available phosphorus was noted in the experimental plots, from very high values in plots No. 1-3 to average values in plot No. 4. Most of the mobile forms of potassium are contained in the surface layers (0-10 cm) of soils in all experimental areas. The content of available nutrients in the soil is mosaic in nature, depends on the degree of anthropogenic impact on the studied tracts and affects the productivity of plant communities. The productivity of the herbaceous layer is an important informative indicator that makes it possible to assess the conditions for the formation of a plant community. In research works [21] of the steppe landscape of the Aituar steppe of the Southern Urals, using the NDVI index, it was determined that each tract has a significant difference in the types of intraseasonal dynamics of the production of ground plant phytomass.

According to V.P. Voronina et al. [22] on the plains in the tussock-grass steppes in the upland hydrographic network of the Middle Don, loose-bush grass-forb phytocenoses with a productivity of above-ground phytomass of 0.21-9.28 t/ha were formed.

TThus, at site No. 4 there is a gradual steppeification of the tract, that is, a wheatgrass-grass formation occurs (*Agropyron cristatum* L.+ *Stīpa zalēsskii* Wilensky*)*. The basis of the grass stand is formed *Agropyron cristatum* (L.) Gaertn.– cop2, *Stīpa zalēsskii* Wilensky-cop1, *Poa trivialis* L.- *sp.* The productivity of the aboveground phytomass of the steppe tract fluctuates within 2.38 t/ha, which brings the plant community closer in this parameter to the meadow and dry steppe.

As a result of research in individual areas, the productivity of phytocenoses changes and depends on the tract, soil-forming layer, climatic factors, and the time of human impact. Steppe areas stand out among the studied areas based on their ability to restore the fertility of arable soils. Such observations will make it possible to predict the dynamics of restoration of anthropogenically modified areas to steppe ones due to the potential of natural ecosystems.

4 Conclusion

- In the steppe area, 89 plant species from 27 families were recorded; in the forest belt - 59 species from 22 families; fallows - 28 species from 10 families, the agrocenosis is represented by 5 species from 4 families. The most numerous is the familyAsteraceaeDumort (астровые) – 16 species, family. PoaceaeBarnhart (bluegrass) – 13, other families of vascular plants are represented by fewer species. The litter of phytocenoses constitutes the energy potential of the biogeocenosis, the smallest amount of mulch in the agrocenosis is 0.26 t/ha, the largest amount of litter in the forest belt is 6.5 t/ha.
- The amount of humus in the soils of the steppe area at a depth of (30-40 cm) is 1.4% and (0-10 cm) is 0.77%. The smallest amount of humus in the soils of the agrocenosis is

at a depth of (0-10 cm) - 0.32% and (30-40 cm) - 0.36%. We noted a low level of nitrate nitrogen content in agrocenose soils of 1.3 mg/kg. The heterogeneity of the content of mobile phosphorus was revealed, high values were noted in the soils of the agrocenosis at a depth (0-10 cm) - 51 mg/kg and the lowest values in the soils of the steppe area at a depth (30-40 cm) - 17.16 mg/kg. A significant content of mobile forms of potassium at the soil depth (0-10 cm) of the forest belt is 761.1 mg/kg, the minimum parameters at the soil depth (30-40 cm) in the steppe area are 106.4 mg/kg.

- Productivity of above-ground phytomass on southern chernozems: agrocenosis - 0.38 t/t; fallow (1-2 years) - 1.23 t/ha; forest belt - 1.21 t/ha; steppe area - 2.38 t/ha. There is a gradual but obvious steppeification of the tract, since the basis of the grass stand is the wheatgrass-grass formation (*Agropyron cristatum* L.+ *Stīpa zalēsskii* Wilensky*).*
- Steppe areas stand out among the studied areas based on their ability to restore the fertility of arable soils.

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