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Dynamics of soil cover state and degradation processes intensity in natural soil zones of the Altai Region

Gennady Morkovkin [a,*], Yekaterina Litvinenko [a], Nina Maksimova [b]

[a] Altai State Agricultural University, Department of Soil Science and Agro-Chemistry, Barnaul, Russia
[b] Altai State Agricultural University, Department of Natural Resources Management and Geo-Ecology, Barnaul, Russia

Abstract

It is shown that the agricultural landscapes of the natural soil zones of the Altai Region are subjected to intense anthropogenic impact, and they are in an unstable state. Agricultural use has caused an extensive development of degradation processes, and the resulting indicator of those is the increase of eroded soils areas, dehumification, and the decrease of humus soil horizon thickness.

More active wind erosion is revealed in the chestnut soil zone of the dry steppe and in the subzone of southern chernozems of arid steppe; a combined action of wind and water erosion is observed in the subzones of arid, temperate-arid and forest-outlier steppe, and water erosion develops in the zones of central forest-steppe and meadow steppe.

The highest intensity of dehumification is observed in arid and temperate-arid steppe, and a greater change rate of soils areas in terms of humus horizon thickness decrease is observed in the chestnut soil zone of dry steppe and in the subzone of southern chernozems of arid steppe.

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Introduction

Soil cover is a central element of biogeocenosis and a landscape component, but at the same time it is an extremely vulnerable formation that covers the land surface with the thinnest coat, and, ultimately, the life on the Earth depends on its normal functioning. At present, almost all countries of the world experience accelerating soil degradation. The rate of fertile soils losses over the recent 50 years has increased 30 times compared to the historical average, and amounts to 8-15 million ha annually (Dobrovolskiy and Kust, 1996).

The causes of soil degradation include a growing world population, increasing arable lands by marginal lands, erosion, depletion, salinization, acidification, pollution, and the deterioration of physical soil properties. And the soil cover of the Altai Region is not the exception among the areas where the degradation processes are intensively revealed.

The soil cover of the Region is much varied, the most valuable being chernozemic soils which occupy 5.62 million ha (Burlakova et al., 1988), or 33.5% of the total land area of the Region. The chernozems, naturally formed in the environmental conditions of the Altai Region as highly fertile soils, have lost much of their fertility by now. They are subjected to the maximum anthropogenic impact which results in their accelerated degradation. Among the degradation processes rendering an intense effect the state of chernozems erosion a special place is taken by erosion processes.

* Corresponding author.
Altai State Agricultural University, Department of Soil Science and Agro-Chemistry, Barnaul, 656049, Russia
Tel.: +7 3852 628389 Fax: +7 3852 628358 E-mail address: ggmork@mail.ru
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The purpose of this research is to identify the intensity of degradation processes' occurrence in various natural soil zones of the Altai Region in temporal and spatial aspects to evaluate the resistance of agricultural landscapes to anthropogenic impact. To achieve this purpose, the land use patterns change was analyzed, and the intensity of wind and water erosion processes and the dynamics of soil humus state in various natural and soil zones of the Altai Region were defined.

Material and Methods

The research objects were the agricultural landscapes of various natural soil zones of the Altai Region. The subject of the research was the evaluation of the resistance of the agricultural landscapes of the natural soil zones to degradation processes under an intense anthropogenic impact.

Soil cover is used in this work as an indication sign of agricultural landscapes' functioning stability, for soil cover reflects not only the peculiarities of climate, hydrological regimes, and the properties of rocks and relief (Isachenko, 1991), but also the response of the landscape to anthropogenic impact.

To satisfy the research objectives, a comparative analysis of the results of two soil survey rounds (1960-70s and the 1980-90s) was conducted; the archive data was granted for the research by OAO AltaiNIIGiprozem (Altai Research, Design and Surveying Institute of Land Management). The dynamics of agricultural land areas, the degree of wind and water erosion occurrence, the indices of humus content in the soil and the state of soil humus horizon thickness were studied. This work presents the results of analytical studies conducted at reference sites (three typical farms of each natural soil zone) for the conditions of the following five natural soil zones and subzones of the Altai Region: chestnut soils of dry steppe, southern chernozems of arid steppe, ordinary chernozems of temperate-arid and forest-outlier steppe, leached chernozems and gray forest soils of central forest-steppe, and typical and leached chernozems of meadow steppe.

Results and Discussion

The conditions of the studied natural soil zones vary considerably. The climate varies from arid warm in the dry steppe to humid temperately warm in the meadow steppe. In general, the average annual temperature in the zones is positive or close to 0°C. The average temperature of the coldest month (January) ranges from -16°C to -18°C, and that of the warmest month (July) ranges from +18°C to +21°C. The precipitation amount for the period with temperatures above +10°C increases west-to-east, and ranges from 155 mm in the zone of the dry steppes up to 250-300 mm in the zone of meadow steppe. The average snow cover makes 40-60 cm, it reduces to 20-30 cm in the western areas. The climate is characterized by warm and short summers and cold winters with little snow (Agroclimatic Resources, 1971).

The relief of the studied areas is classified as plain; however, it reveals significant variations in the natural soil zones. The chestnut soil zone of the dry steppes is located in the Kulundinskaya nizmennost (the Kulunda Lowland) with the altitudes of 80-160 m with poorly broken relief. The zone of the arid and moderately arid steppes occupies the Priobskoye plateau (the Ob River Plateau) with rolling plain relief and the altitudes of 150-220 m in the south-west part, and elevated ridged relief in the north-east with the altitudes of 200-320 m. The zone of leached chernozems and gray forest soils of the central forest-steppe is located in the Biysko-Chumyshskaya vozvyshennost (Biysk-Chumysh River Upland), an elevated dissected plain with hilly ridged relief and the altitudes of 300-350 m. The zone of the meadow steppes of piedmont plains is heavily dissected with the altitudes up to 400 m (Burlakova, 1984).

The natural principle that ensures a sustainable functioning of the landscapes in each of those areas is disturbed in agricultural landscapes. Anthropogenic activities result in the creation of a system with fewer components compared to a natural system; the created system is characterized by artificial selection of plants and animals and subsequent removal of phytomass (Urazayev, 2000). Accordingly, due to the anthropogenic impact on a landscape there occurs the simplification of agricultural landscapes, that is, the reduction of their complex structure and ecological (specific) diversity (Bunina, 2004).

The anthropogenic impact reveals common features in all zones (Mukha, Kartamyshev, Kochetov, et al., 1994): the destruction of the natural vegetation cover, a systematic mixing of the top soil layer, and the changes of physical, chemical and biological soil properties. Zonal variations are revealed by the specific indices that characterize the soils and the intensity of their changes.

Landscape transformation trends of the studied areas may be judged on by the land use patterns in the reference sites of each examined zone.

In all investigated zones between the two survey rounds the portion of arable lands decreased, such trend is illustrative of the whole Region, and is has been continued from the early 1990s. These processes are also revealed in the dynamics of the areas under crop; in 1990 there were 6380.0 thousand ha of sown areas in the Region, while in 1999 and in 2010 there were 5457.4 thousand ha and 5149.3 thousand ha respectively. Such developments are caused by transfer of lands to long-term fallows, or using unprofitable arable lands as perennial grasslands (http://ak.gks.ru; Smelyanskiy, 2003). The greatest decrease of arable land areas is observed in the central forest-steppe and is mainly caused by the land transfer from the "arable land" category to the category of "other lands." In the dry steppe the decrease of the arable land portion is caused by the increase of pasture-lands area, and in the temperately arid and forest-outlier steppes this transformation is due to the increase the area of other lands and the lands under forest.

The area under shrub and forest vegetation has increased in the zone of temperately arid and forest-outlier steppes; the increasing percentage of forest in the total farm land holdings may prove the fact of abandoned lands' overgrowing with wild plants, that is, we may judge on the restoration of the plant communities natural for this landscape (Morkovkin and Litvinenko, 2011).

In all zones, except the meadow steppes of piedmont plains, despite the decrease of arable land portion, the largest percentage of land area belongs to a field type of agricultural landscapes, in which soil cover is subjected to the maximum anthropogenic impact. A field type of agricultural landscape is characterized by a repeated plowing of soil, the application of fertilizers, weed control, and annual removal of most of the phytomass (Volnov, 2006). The arable layer bears the entire impact and changes most actively in accordance with the new conditions of the landscape, reflecting the features of the current soil formation (Mukha, 1994).

When exposed to an intense anthropogenic factor, the structure of a landscape is increasingly simplified, losing its natural stability (Urazayev, 2000). However, it functions according to the natural laws of the area (Chernikov, 2000). Accordingly, each zone reveals its proportion of transformed and natural, natural and anthropogenic landscapes that ensure a sustainable functioning of natural systems. According to Reimers (1990), an estimated portion of transformed landscape may reach 60-75% for forest-steppe, 40-60% for steppe, whereas for piedmont areas, non-transformed landscapes should make at least 80-98% of the total area.

By the proportion of agricultural lands in the studied zones it may be concluded that none of the zones is not in the state of sustainable functioning. And since in an agricultural landscape a regulation and stabilization function is performed not by the system itself, but by man, one of the major challenges to ensure landscapes' sustainability is the protection and reproduction of soil fertility and the prevention of degradation processes (Urazayev, 2000; Chernikov, 2000). In the Altai Region the consequence of the unstable state of agricultural landscapes' functioning has been a wide-spread occurrence of wind and water erosion which greatly reduce soil fertility and render a negative effect on the environment (Table 1). As seen, active wind erosion is revealed in the dry steppe zone; a combined action of wind and water erosion is observed in the subzones of arid, temperate-arid and forest-outlier steppe, and water erosion develops in the zones of central forest-steppe and meadow steppe.

Table 1. State of soil cover in terms of erosion degree at reference sites, in percentage of the total area (2nd soil survey round)

State of soils in terms of erosion degree	Dry steppe	Arid steppe	Temperate arid steppe	Central steppe	Meadow steppe
Non-eroded	28.2	11.4	22.4	69.1	88.2
Slightly washed-off	0.0	3.7	6.5	26.4	10.0
Moderately washed-off	0.0	0.1	0.9	4.4	1.4
Severely washed-off	0.0	0.0	0.2	0.1	0.4
Slightly wind-eroded	62.2	82.4	66.0	0.0	0.0
Moderately wind-eroded	9.0	2.4	4.0	0.0	0.0
Severely wind-eroded	0.6	0.0	0.0	0.0	0.0

In all studied zones the increase of eroded soils areas is observed (Table 2). The intensity of erosion processes occurrence in the zones varies. The greatest change of eroded lands area is monitored in the zone of southern chernozems of arid steppe making about 4.5% per year. Besides, the chernozems of the temperate-arid steppe and chestnut soils of dry steppe are subjected to intense erosion; the annual increase of eroded soils area during the monitoring period made 3.72% and 3.42% respectively. To a lesser degree

the change of eroded soils area was observed in the meadow steppe (0.19% per year) due to the prevailing pastureland use in that region.

Chestnut soils of the dry steppe are exposed to wind erosion. The area of slightly wind-eroded soils increases by almost 3% annually, fostered by the arid climate with strong winds. In the area of the temperate-arid and arid steppes both water and wind erosion is revealed. In both sub-zones wind erosion is a prevailing erosion type. However, when in the arid steppe the correlation of water erosion to wind erosion intensity makes 1:22.4, in the temperate-arid and forest-outlier steppe that makes 1:14.5; that is, with increased humidity of the climate the percentage of the areas exposed to water erosion increases, but is not equal to wind erosion in this zone.

Table 2. Intensity of eroded soils area change, percent per annum

State of soils in terms of erosion degree	Dry steppe	Arid steppe	Temperate arid steppe	Central steppe	Meadow steppe
Non-eroded	-3.42	-4.45	-3.72	-1.11	-0.19
Slightly washed-off	0.00	0.19	0.20	1.01	0.32
Moderately washed-off	0.00	0.00	0.03	0.10	-0.11
Severely washed-off	0.00	0.00	0.01	0.00	-0.01
Slightly wind-eroded	2.99	4.12	3.27	0.00	0.00
Moderately wind-eroded	0.43	0.13	0.21	0.00	0.00
Severely wind-eroded	0.03	0.00	0.00	0.00	0.00

An intensive agricultural use has resulted in the decrease of humus content in the soil and the reduction of humus horizon thickness (Table 3, 4).

Table 3. Intensity of soil types' areas change in terms of humus content, percent per annum

Soil types in terms of humus content	Dry steppe	Arid steppe	Temperate arid steppe	Central steppe	Meadow steppe
Slightly-humic	+0.08	+2.73	+1.09	+0.37	-
Low-humic	+0.55	-2.46	-1.05	-0.14	+0.14
Moderately-humic	-0.63	-0.27	-0.04	-0.23	-0.14

All natural soil zones involved in the study reveal a decreasing portion of soil type areas with relatively high humus content and a corresponding increasing portion of soil type areas with low humus content. Most intensively these processes occur in the arid and temperate arid steppes.

Table 4. Intensity of soil types' areas change in terms of humus horizon thickness, percent per annum

Soil types in terms of humus horizon thickness	Dry steppe	Arid steppe	Temperate arid steppe	Central steppe	Meadow steppe
Thin	2.30	2.09	1.34	1.64	0.35
Moderately-thick	-2.30	-2.09	-1.34	-1.64	0.97
Thick	0.00	0.00	0.00	0.00	-1.32

The decrease of soil humus horizon thickness is observed in the natural soil zones. In the period between the two soil survey rounds the area under thin soils has increased, and, accordingly, the area under moderately-thick soils has decreased. The highest intensity of soils area changes has been monitored in the chestnut soil zone of the dry steppe and in the southern chernozem zone of the arid steppe, and made 2.3% and 2.09% per annum respectively. In the meadow steppe zone the increase of thin and moderately-thick soils' area occurs due to the decrease of thick soils' portion by 1.32% per annum.

Conclusion

The agricultural landscapes of the natural soil zones of the Altai Region are exposed to intense anthropogenic impact, and they are in an unstable state. Agricultural use has caused an extensive development of degradation processes, and the resulting indicator of those is the increase of eroded soils areas, dehumification, and the decrease of humus soil horizon thickness.

More active wind erosion is revealed in the chestnut soil zone of the dry steppe and in the subzone of southern chernozems of the arid steppe; a combined action of wind and water erosion is observed in the

subzones of arid, temperate-arid and forest-outlier steppes, and water erosion develops in the zones of the central forest-steppe and meadow steppe.

The highest intensity of dehumification is observed in the arid and temperate-arid steppe, and a greater change rate of soils areas in terms of humus horizon thickness decrease is observed in the chestnut soil zone of the dry steppe and in the subzone of southern chernozems of the arid steppe.

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