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Temporal change of soil chemical properties in the southern forest-steppe of the Ufa region of the Republic of Bashkortostan, Russia

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Abstract

Modern technologies make it possible to obtain a lot of diverse information about the soil properties using satellite images, but field studies are also required to create or refine digital soil maps. To create a digital soil map scaled 1:25 000 in 2016, a classical field study was conducted with the laying of soil sections in places with the same coordinates as in the mapping of 1982. It allowed to carry out retrospective monitoring of transformation of morphogenetic and agrochemical properties of soils of the southern forest-steppe of the Republic of Bashkortostan (Russia) for the 34-year period of farm use. Thus, the correction and digitization of the soil map allowed to establish that arable land occupies 69.792 ha (67.9%) in the structure of agricultural land (102 811 ha). The monitoring showed deterioration of the main characteristics of arable soil fertility: the diminishing of humus-accumulative horizons, significant decrease of humus content ($p \leq 0.05$), a small but reliable acidification of the medium reaction and reducing labile phosphorus. Losses of organic matter occurred mainly in the most fertile soils; their proportion decreased from 55.9% of the total area of agricultural land to 12.4%.

Key words: *agrochemical properties, forest-steppe, monitoring, soil fertility, soil maps*

INTRODUCTION

Modern technologies make it possible to obtain a lot of diverse information about the soil properties using satellite images, but field studies are also required to create or refine digital soil maps [COLLARD *et al.* 2014; DEBELLA-GILO, ETZELMULLER 2009; MENDES *et al.* 2019]. Corrected and digitized large-scale soil maps are the basis for the formation of explications of soil varieties and land plots for agricultural purposes [ASKARI *et al.* 2015; HENGL *et al.* 2017; MINASNY, MCBRATNEY 2016]. In Russia such work is carried out on the basis of maps drawn up in the 20th century. Restudies make it possible to directly assess the current trends in the development of soils and geosystems as a whole. Detailed studies conducted several decades ago were used as a basis for retrospective monitoring [ASYLBAEV *et al.* 2016; DELLA CHIESA *et al.* 2019; GABBASOVA *et al.* 2016; KHITROV 2008; MILLER *et al.* 2019]. The obtained data on the quantitative and qualitative changes in the fertility elements are necessary to assess the degree of soil degradation and develop a scientifically based forecast for their further farm. Different indicators systems are used. They characterize physical, chemical and other soil properties such as water physical properties, particle distribution according to the size, soil density, electrical conductivity, pH, organic carbon and nutrients content, biological soil activity [GHAEMI *et al.* 2014; LIMA *et al.* 2013; RAHMANIPOUR *et al.* 2014]. Monitoring studies are also im-

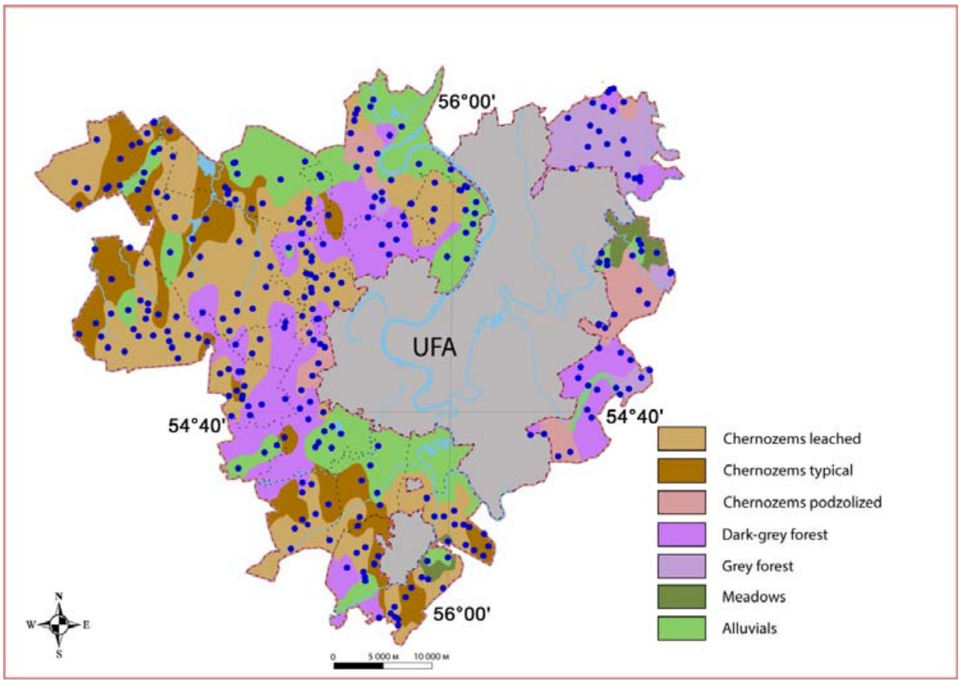

Fig. 1. A soil map and places of laying soil cross sections; source: own elaboration

portant for studying the ecological functions of soils and the biogeochemical carbon cycle in the context of global climate change [ASYLBAEV *et al*. 2018; CHEN *et al*. 2019].

The purpose of this paper is a retrospective analysis of the transformation of morphogenetic and agrochemical soil properties of the southern forest-steppe of the Republic of Bashkortostan (Russia) for the 34-year period of farm use.

MATERIALS AND METHODS

The objects of research were the soils of cultivated lands in the southern forest-steppe within the Ufa region of the Republic of Bashkortostan. The southern forest-steppe extends from the western foothills of the southern Urals (53°28' N; 56°30' E) to the mouth of the Belaya River (55°26' N; 54°19' E). It is characterized by a complex geomorphological structure of land use and a variety of natural and environmental factors. The general relief is represented by a hillside and undulating plain with elevation points of 120–200 m. The degree of dissection is 0.5–15 km·km^{-2}, the depth of local erosion bases is 25–152 m. Parent rock materials are represented by deluvial and eluvial-deluvial deposits. The climate of the region is characterized by the following indicators: the average annual air temperature is +2.3°C; the annual amount of precipitation is 525 mm; the effective heat sum (T > 10°C) is 2200; the average daily temperature of the warmest month (July) is +19.1°C; the average daily temperature of the coldest month (January) is –14.8°C; the duration of the frost-free period is 110–130 days.

Field correction soil map of soil survey materials scaled 1:25 000 and made in 1982 was studied and soil sections were laid. The author's copy of the soil map of state and collective farms of the Ufa region of the Bashkir Autonomous Soviet Socialist Republic was transformed into bmp- format (halftone image), and then was brought into coincidence with the rural village councils boundaries issued and computerized in the form of orthophotos in 2007 in bmp format.

After having gathered all initial cartographic records, plotting on a planimetric base of the rural areas borders, settlements, soil contours and relief has been started. Points of soil samples selection were plotted on the received graphic material in GPS-coordinates according to earlier surveys conducted in 1982. Aerial photography materials and comparison of the obtained graphic material gave an objective idea of the soil distribution laws (Fig. 1). Having analyzed the received papers and taking into account orthophotos, there have been revealed territories where changes in the soil cover (soil improvement or deterioration) are associated with human economic activity.

Soil samples were selected by genetic horizons, and analytical studies were carried out using the same methods as in 1982 [Nauka 1975]. Archival materials of the soil survey of 1982 were used for retrospective analysis of soil properties.

The data of the retrospective monitoring of soil agrochemical properties were subjected to statistical processing to verify the results reliability according to the Student's test at confidence levels equal to 0.01 and 0.05 [DOSPEKHOV 1985].

RESULTS AND DISCUSSION

Black soils are most widespread in a soil cover of the agricultural lands of the studied area: leached – 37%, typical – 15%, podzolized – 7%; as well as alluvials meadow – 24%, dark-grey forest soils – 9%, grey forest soils – 5%.

Comparison of agrochemical properties of soils according to the results of surveys carried out in 1982 and 2016 showed deterioration of the main characteristics of arable soil fertility (Tab. 1). As it is known, one of the

Table 1. Changes in the main indicators of arable soil fertility (1982–2016) *t* – Student's t-test

Indicator	Humus horizon thickness (cm)		± *SD*	Humus content (%)		± *SD*	pH in KCl		± *SD*	P_2O_5 (mg·kg^{-1})		± *SD*	K_2O (mg·kg^{-1})		± *SD*
	1982	2016		1982	2016		1982	2016		1982	2016		1982	2016	
Leached black soil $n = 32$, $t_{tbl} = 1.99$ ($p \le 0.05$), $t_{tbl} = 2.66$ ($p \le 0.01$)															
$X \pm x$	56.6±3.7	52.8±3.6	–3.8	8.5±0.5	7.0±0.4	–1.5	6.3±0.1	6.0±0.1	–0.3	93.6±15.7	84.8±11.3	–8.8	70.6±20.3	100.4±9.8	+29.4
t_{emp}	1.45			4.73			3.37			0.91			2.63		
Typical black soil $n = 23$, $t_{tbl} = 2.02$ ($p \le 0.05$), $t_{tbl} = 2.69$ ($p \le 0.01$)															
$X \pm x$	56.2±5.5	50.8±4.9	–5.4	8.0±0.4	6.8±0.3	–1.2	6.8±0.2	6.3±0.2	–0.5	84.7±10.3	81.7±13.4	–3.0	59.7±17.8	98.0±10.1	+38.3
t_{emp}	1.46			4.39			3.53			0.36			3.78		
Podzolized black soil $n = 16$; $t_{tbl} = 2.04$ ($p \le 0.05$), $t_{tbl} = 2.75$ ($p \le 0.01$)															
$X \pm x$	41.3±3.2	39.9±3.0	–1.4	8.2±0.7	6.4±0.9	–1.8	5.9±0.1	5.7±0.1	–0.2	78.8±24.5	66.4±10.2	–12.4	70.8±34.8	98.1±18.1	+27.3
t_{emp}	0.64			3.17			2.54			0.96			1.42		
Dark-grey forest soils $n = 16$ $t_{tbl} = 2.04$ ($p \le 0.05$), $t_{tbl} = 2.75$ ($p \le 0.01$)															
$X \pm x$	34.0±2.5	31.4±2.0	–2.6	6.7±0.7	5.8±0.6	–0.9	6.1±0.2	5.8±0.2	–0.3	78.4±24.2	103.1±27.7	+24.7	158.4±48.0	100.3±18.6	+58.1
t_{emp}	1.62			2.07			2.22			–1.37			2.30		
Grey forest soils $n = 17$; $t_{tbl} = 2.04$ ($p \le 0.05$), $t_{tbl} = 2.74$ ($p \le 0.01$)															
$X \pm x$	35.0±1.8	32.2±1.8	–2.8	4.2±0.5	3.5±0.3	–0.7	6.0±0.2	5.6±0.2	–0.4	47.8±13.5	63.1±21.2	+15.3	138.4±30.1	90.6±20.4	–47.8
t_{emp}	2.23			2.60			2.92			1.24			2.67		

Source: own study.

main criteria of soil degradation and soil fertility decrease is humus loss (dehumification), humus horizon thickness decrease, soil acidification and nutrient removal. During the 34-year period there was no significant decrease in the thickness of humus-accumulative horizons, but in all soils there was a tendency to reduce them, especially in leached and typical black soil. Most likely all arable soils were subjected to varying degrees of water and wind erosion with the smallest fractions being lost first and foremost [DE ORO *et al.* 2019; KIANI-HARCHEGANI *et al.* 2019; KOMISSAROV, GABBASOVA 2017; SOBOL *et al.* 2017]. This is confirmed by a significant decrease in the humus content of all soils. The maximum humus loss (22%) was observed in the podzolic subtype of black soils, humus losses in typical and leached soils were 15.0 and 17.6%, respectively.

It should be noted that among the non-eroded subtypes of black soils, the highest humus content is characteristic of typical black soils [GABBASOVA *et al.* 2016]. In 1982 there was the lowest humus content in this subtype and it could point to erosional feature. However, lower absolute losses in subsequent years (–1.2%) among subtypes indicate some decrease in erosion rates on typical black soils. Relatively lower dehumification was observed in dark grey forest soils (13.4%) and grey forest soils (16.7%) compared to black soils. The most fertile rich (rich humus) soils were subjected to dehumification.

Small but significant acidification (at $p \le 0.05$) of the medium reaction especially in typical black soils (pH decreased by 0.5) was due to long-term farm use of soils. The availability of labile phosphorus in the soils of the region in 1982 was "average" according to the classification of [ROZHKOV 2011], to date its content decreased, but remained in the same category. In 2016, the content of exchange potassium in all subtypes of black soils increased by an average of 32 mg·kg^{-1}, but the availability also remained at the "average" level. According to the data of 1982, dark grey soils and grey forest soils were characterized by high potassium content, but to date the availability of this plant nutrient has significantly decreased to the "average" level.

According to the research results, the area of agricultural land has changed as a result of land reform and land redistribution for various purposes. In 1982 agricultural land area was 124 thous. ha, and in 2016 it was102.8 thous. ha (Tab. 2).

Table 2. Changes in soil areas (S) according to humus content

No.	Soil type	Gradation	According to the results of			
			1982 soil survey		2016 soil survey	
			S (ha)	*S* (%)	*S* (ha)	*S* (%)
1	rich humus	> 9	69 361	55.9	12 700	12.4
2	middle humus	7–9	25 739	20.7	57 752	56.2
3	low humus	5–7	23 175	18.7	24 376	23.7
4	weakly humus	3–5	742	0.6	115	0.1
6	soils not included in the gradation	–	5 053	3.8	7 867	7.7
	Total		124 070	100.0	120 811	100

Source: own study.

More fertile rich hyperhumus soils went through dehumification process. According to the research of 1982 the share of soils humus content of which was more than 9% made 55.9% of the total area of agricultural land occupying 69.4 thous. ha. In 2016 this area went down to 12.7 thous. ha which made up 12.4% (Fig. 2).

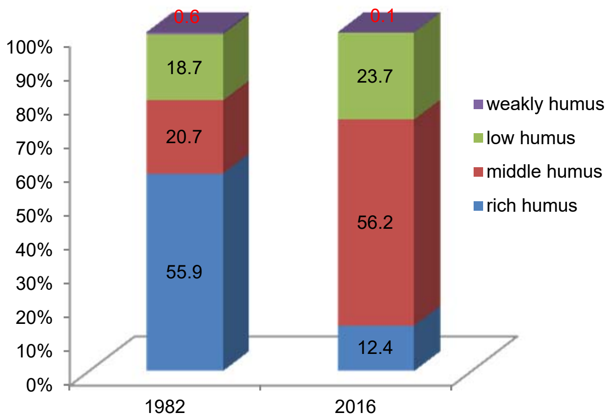

Fig. 2. Soil split by humus content; source: own study

The analysis of soil fertility indicators shows that in the studied land it is essential to apply organic fertilizers into the area of 14.6 thous. ha and to lime the area of 16.5 thous. ha. It is necessary to apply mineral fertilizers in appropriate doses to all soils, but the area of 24.6 thous. ha is badly in need of phosphorus fertilizers and the area of 22.1 thous. ha is need in potassium.

CONCLUSIONS

Retrospective monitoring of the soil state of the district showed that for a long period of farm use (1982–2016) in most cases, fertility indicators have changed for the worse: there was a tendency to reduce the thickness of humus-accumulative horizons, significantly ($p \leq 0.05$) decreased humus content, there was a small but significant acidification of the medium reaction and reducing labile phosphorus. Thus, the maximum humus loss was observed in the podzolic subtype of black soils (22%), humus losses in typical and leached soils were 15.0 and 17.6%, respectively. Relatively lower dehumification was observed in dark grey forest soils and grey forest soils – 13.4% and 16.7% respectively – compared to black soils. In 2016, the content of exchange potassium in all subtypes of black soils increased by an average of 32 $mg \cdot kg^{-1}$. The content of exchange potassium in black soils slightly increased, remaining within the average availability.

Accurate data on natural soil cover state and the state of soils' cover transformed as the result of agricultural activity are necessary for developing scientifically proved farming systems, land resources accounting and monitoring, land rational use and protection, as well as for increasing soil fertility. Formation of soil species and agricultural land explications allowed to make sure the digital soil map of the Republic of Bashkortostan is accurate.

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