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Short communication

Consequences of snowmelt erosion: Soil fertility, productivity and quality of wheat on Greyzemic Phaeozem in the south of West Siberia

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ABSTRACT

Snowmelt erosion is one of the reasons for the decreasing soil fertility in the most valuable agricultural lands in the south of West Siberia. The aim of this study was to examine the influence of long term soil use and degree of soil erosion on the main fertility indicators of Greyzemic Phaeozem (30-year fallow, non-eroded, slightly eroded, moderately eroded and strongly eroded). Soils were analysed for organic carbon (SOC), pH_w, cation-exchange capacity and total and available forms of nitrogen, phosphorus and potassium. Plants were analysed for sheaf and grain yield and NPK content of wheat. A decrease in the content of the total forms of carbon and nitrogen and an increase in the C/N ratio were observed with an increase in the degree of soil erosion. SOC losses in the ploughed layer of slightly, moderately and strongly eroded soils were 6.6, 13 and 27%, respectively, while the nitrogen losses were 5, 33, and 71%. The widest (37) C/N ratio was found in strongly eroded soil. The content of total phosphorus in the ploughed layer of slightly, moderately and strongly eroded soils decreased by 3.8, 23 and 15.4%, respectively, in comparison with non-eroded soil. Available forms of phosphorus and potassium increased with an increase in the degree of soil erosion, with the highest values found in moderately eroded soil. Exchangeable K/available K ratio, the overall mobility of potassium in the eroded soils also increased. The highest plant productivity was found on moderately eroded soil. A deterioration of the nitrogen regime led to a narrowing of the N/K ratio from 2.4 (grain) and 0.4 (straw) up to 1.9 (grain) and 0.3 (straw) for non-eroded and strongly eroded soils respectively. A critical decrease of soil fertility and plant productivity was found in strongly eroded soil.

1. Introduction

Water erosion damages considerably arable lands all over the world (Strauss and Klaghofer, 2001). Erosion as a result of snowmelt causes the largest soil loss in agricultural areas in northern countries (NJF Report, 2011; Su et al., 2011). Severe climatic conditions in Siberia, including the large quantity of snow, the creation of an ice-sheet in soil, the short-term period of snowmelt, the severe dissection of the territory are the main reasons for the intense erosion and change of soils nutrient regime in this region of Russia (Tanasienko et al., 2011; Viers et al., 2013; Wild et al., 2013). Chernozem-type soils occupy the main area of agricultural lands in Siberia (Tanasienko et al., 2011; Andreeva et al., 2011). The natural fertility of non-eroded soils is high, which gives potential winter wheat and barley yields up to 2.4 t ha^{-1}, without fertilisers in years with sufficient precipitation (Khmelev and Tanasienko, 2009). Soils subjected to erosion are characterised by a decrease in thickness of the humified layer (A + AB horizons), soil fertility and crop yield (Pimentel et al., 1995; Polyakov and Lal, 2004; Lal, 2010; Su et al., 2010). Studies on eroded Siberian soils mainly take into account soil morphology, structure and SOM content while the changes in NPK content are poorly investigated. Furthermore, intensive agriculture, accompanied by a large removal of nutrients without applying fertilizers, leads to the degradation of these soils. The aims of the present study were to investigate the influence of long term soil use (1) and degree of soil erosion (2) on main fertility indicators of a Greyzemic Phaeozem.

2. Materials and methods

2.1. Study area and soils

The study area was located (54°44′N, 083°17′E) in the south–east of West Siberia and was in the geomorphologic region of the Bugotac Hills near the settlement Morozovo. This territory is characterised by the denudation-accumulative type of relief, with

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higher depths of rivers and gullies (75–100 m) and longer slopes. Watersheds occupy approximately 20% of the total area. Watershed slopes have a gradient of 3–9°, and slopes near stabilised gullies were in the range of 15–35° (Tanasienko et al., 2011). Cropped area consists of cereals (70%), fodder (28%), industrial crops, potatoes and vegetables (2%). The snow water equivalent varies from 75 mm in very low-snow years to 180 mm in very high-snow years. For a detailed description of climatic conditions in Siberia see Tanasienko et al. (2011). The soils were classified (IUSS Working Group, 2014) as Greyzemic Phaeozem (Albic) (non-eroded or eroded). The soils were formed from loessial loams. The grade structure is loam (Tanasienko et al., 2013). Non-eroded ploughed soils occupy the watershed area in strips 350 m wide. Steepness of the plot varied from 0 to 1°. The depth of the $A_p + A_2B$ horizons was 63 cm. The middle part of the slope had ploughed slightly eroded soils, the $A_p + A_2B$ horizons not more than 50 cm. Slope steepness was 1–2°. The bottom part of a slope (700–780 m in width) had moderately eroded soils and partially strongly eroded soils. Slope steepness here is more than 3°. The thickness of the $A_p + A_2B$ horizons of the moderately eroded soils does not exceed 35 cm. As strongly eroded Greyzemic Phaeozems do not have an isolated humus horizon, their ploughed layer is characterised by a mixture of the horizons $A_p + A_2B + B_1$. The degree of soil erosion was defined according to the SOM layer depth and change of the morphology of the soil profile in comparison with the non-eroded soil (more information about diagnostic of soil erosion degree is given in Appendix A). In the area studied eroded soils occupy about 21% of arable land, 17.5% of this territory are slightly eroded soils, while moderately and strongly eroded soils occupy 3 and 1.7%, respectively.

2.2. Sampling and analysis

This study was conducted from 2009 to 2011 on a southern slope, using a 30-years fallow plot (non-eroded soil) and ploughed plots (non-eroded, slightly eroded, moderately eroded and strongly eroded soils). Fertilisers had not been applied to the ploughed plots since 2000. The average productivity of grain during this period was approximately 1.3–1.4 t ha^{-1}. During the period of investigation, the field was planted in spring wheat (*Triticum aestivum*). Two replicate plant samples were taken from within a 50 × 50 cm frame placed at four positions on the slope, according to the degree of soil erosion (non-eroded, slightly eroded, moderately eroded and strongly eroded soils). Soil samples from the studied soils were collected on the slope according to the degree of soil erosion. One soil profile was dug in each plot. Two replicate samples were taken in a horizontal sampling scheme with intervals varying from 10 cm up to 100 cm from different soil depths. The soil samples were air-dried, crushed, sieved and stored until analysis.

The soils were analysed for the following with different protocols: (1) soil organic carbon (SOC) – 0.1–0.2 g soil, reaction with 0.4 N $K_2Cr_2O_7$ in mixture with H_2SO_4 (Sokolov, 1975); (2) pH_w – in 1:2.5 soil:water solution (Sokolov, 1975); (3) total N (TN) – 4 g soil, digestion with 20 ml 95.6% H_2SO_4 (Sokolov, 1975); (4) total phosphorus (TP) – 0.5 g soil < 0.25 mm, digestion with 8 ml 95.6% H_2SO_4 + 0.8 ml 50% $HClO_4$ (Murphy and Riley, 1962; Warren and Pugh, 1930); (5) available phosphorus (AP) –20 g soil extracted by 0.03 N K_2SO_4, 5 min reaction time (Sokolov, 1975); (6) available potassium (AK) – 20 g soil < 1.0 mm, extracted by 40 ml 0.005 N $CaCl_2$, 1 h reaction time (Sokolov, 1975); (7) exchangeable potassium (Ex-K) – 5 g soil < 1.0 mm, extracted by 50 ml of CH_3COONH_4, pH 7, 1 h reaction time (Sokolov, 1975); (8) non-exchangeable potassium (Nex-K) – 2.5 g soil < 1.0 mm extracted by 25 ml 1 N HNO_3 with boiling, 25 min reaction time (Pratt and Morse, 1954) (Nex-K was defined as the amount of K extracted by boiling in HNO_3, minus the amount of K extracted by Ex-K); (9) total potassium (TK) – 0.5 g soil < 0.25 mm, digestion with HF-$HClO_4$-HNO_3 acid mixture (Methods, 1986) (all forms of potassium were determined with an atomic absorption spectrophotometer C 115); (10) cation-exchange capacity (CEC) -5 g soil, reaction with $BaCl_2$-$Ba(CH_3COO)_2$, pH 6.5 (Vorobieva, 2006); nitrogen, phosphorus and potassium content in plants (NPK) was determined after digestion in H_2SO_4–$HClO_4$ acid mixture (Ginzburg et al., 1963). The statistical analyses were carried out using ANOVA test.

3. Results and discussion

3.1. Surface soil properties (0–30 cm)

The change of fertility indicators during long-term soil use under the cultivation of monoculture (wheat) was estimated on the basis of the comparison of the data gathered earlier from this plot (Kovalev and Tanasienko, 1981) and from the present study. In the plough layer (0–30 cm) of non-eroded soil in comparison with the fallow plot, carbon, total forms of nitrogen and phosphorus decreased by 21, 22, and 4%, respectively (Table 1). SOC losses in the ploughed layer of slightly, moderately and strongly eroded soils were 6.6, 13 and 27%, respectively, while the nitrogen losses were 5, 33, and 71%. The widest C/N ratio (37) was found in strongly eroded soil. The content of total phosphorus in the ploughed layer of slightly, moderately and strongly eroded soils decreased 3.8, 23 and 15.4%, respectively, in comparison with non-eroded soil. The content of total potassium in moderately eroded soil increased by 0.1% in comparison with non-eroded soil. The content of available forms of phosphorus and potassium increased with the degree of erosion, with the highest values being found in moderately eroded soil. CEC, in contrast, had the lowest value in moderately eroded soil.

Table 1
Selected chemical properties (0–30 cm) of Greyzemic Phaeozems, West Siberia.

Locality	pH_w	SOC[a]	Total N	C/N ratio	Total K	Total P	Available P	Exchangeable K	CEC[b]
		%			%		mg $100 g^{-1}$		meq+ $100 g^{-1}$/%
30 years old fallow	7.1 ± 0.14	3.7 ± 0.11	0.27 ± 0.006	14	ND[c]	0.26 ± 0.019	0.03 ± 0.0005	9.6 ± 0.51	ND[c]
Non-eroded soil	7.1 ± 0.05	3.0 ± 0.05	0.21 ± 0.005	14	1.1 ± 0.005	0.26 ± 0.013	0.03 ± 0.0002	9.7 ± 0.72	30.7 ± 1.8/0.8
Slightly eroded soil	6.7* ± 0.08	2.8 ± 0.21	0.20 ± 0.011	14	ND[c]	0.25 ± 0.001	0.05* ± 0.0004	9.3 ± 0.89	30.2 ± 3.4/0.8
Moderately eroded soil	6.8* ± 0.01	2.6 ± 0.37	0.14* ± 0.010	19	1.2* ± 0.009	0.20* ± 0.008	0.09* ± 0.0009	11.4* ± 0.93	28.6 ± 2.9/1.0
Strongly eroded soil	6.8* ± 0.01	2.2* ± 0.04	0.06* ± 0.002	37	ND[c]	0.20* ± 0.029	0.06* ± 0.0062	8.4* ± 0.30	ND[c]

[a] Soil organic carbon (SOC).
[b] Cation Exchange Capacity (CEC)/level of saturation of CEC by exchangeable K.
[c] Not determined (ND).
* Value distinguished at 5% of significance level ($p \leq 0.05$) from values on non-eroded soil; values are mean (M) of two replicates ± standard deviation (M ± s).