Chronosequential alterations of properties of post-agrogenic Chernozems of the Kursk steppe zone of Russia under self-restoration

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Abstract
The focus of this chronosequential study was on the vegetation succession, profile morphology, soil nutrient dynamics, soil organic carbon (SOC) stocks, and dynamics of functionally different SOC pools of post-agrogenic Chernozems under self-restoration of the Kursk steppe zone of Russia. The ages of abundance of the post-agrogenic soils were 8, 19, 37, and 59 years. After 59 years of self-restoration the vegetation succession reached the climax stage with dominance of *Stipa pennata* and *Arrhenathum elatius*. In 59 years self-restoration SOC stores increased in the upper 0.5m from 78.9% to 95.3% of the virgin Chernozem. In the cosequence cation exchange capacity (CEC) increased. No significant changes were found in respect of C/N ratios, pH, exchancheable cations, base saturation, and amounts of plant available nutriens. The investigation in respect of functionally different SOC pools of post-agrogenic Chernozems under self-restoration reveal a dominance of OC in the fine silt and clay fractions (36-68% of SOC). Hence the passive C pool was found to be dominating. The free particulate organic matter (POM) fraction was 1-7% of SOC and the occluded POM fraction was 20-58% of SOC. As also found for the others the fraction of the occluded POM (20–58% of SOC) increased during self-restoration, but the rate of occluded POM after 59 years of self-restoration didn't reach the level of the virgin Chernozem.

Keywords: Self-restoration, Chernozem-chronosequence, soil organic carbon (SOC) stocks, SOC pools, Russia

Introduction

Until recently, much arable land was abandoned in many countries world-wide due to different reasons (wars, economical and ecological crises, intensification of agriculture) (Ramankutty 2006; Lyuri *et al*. 2006). Most abandonment was found in Russia, reaching over 200,000 km^{-2} in the early 1990s (Vuichard *et al*. 2008) and 578,000 km^{-2} in the years 1961-2007 (Lyuri *et al*. 2008). As a consequence, the soils of these abandoned sites went into the process of natural restoration or self-restoration without any direct human impact.

The focus of this chronosequential study was on the vegetation succession, profile morphology, soil chemistry, carbon (SOC) stocks, and dynamics of functionally different SOC pools of post-agrogenic Chernozems under self-restoration of the steppe in the European part of Russia.

Materials and Methods

The study was done in the area of the V.V. Alekhin Central-Chernozem Biosphere State Reserve at 51^0N and 36^0E, which is situated about 18km south of the city of Kursk (Russia). The ages of self-restoration of the post-agrogenic soils were 8, 19, 37, and 59 years. One actual arable soil and one natural soil, never been cultivated, were included in the study as a control. Subsequent sampling sites were chosen according to appropriate information from topographic maps, and personal communications with colleges from the Central-Chernozem Biosphere State Reserve.

Carbonate content, pH, CEC, plant available K and P were determined according to Schlichting *et al*. (1995). The procedure of the physical fractionation to obtain free particulate organic matter (POM), occluded POM and the grain size fractions was done according to Steffens *et al*. (2009). Carbon and nitrogen contents in dry soil pellets were determined after combustion and spectrometric measurements with a C/N/S analyser (CHNS-Analyser Flash EA) as total C and N, within the density fractions $<1.8 g/cm^3$ (free POM and occluded POM) as well as within the grain-size fractions sand, silt, and clay.

Results and Discussion

After 8 years under self-restoration the soil showed the typical crump structure for virgin Chernozem whereas the vegetation changed from crop to a rural appearance of *Agropyron repens*. The former ploughing boundary was still present, also in soil being 19 years in self-restoration, whereas it was not nor visible from

then. After 37 years of self-restoration a species-rich transitional stage in the vegetation succession was achieved, and 59 years after abandonment the vegetation succession reached the climax stage with dominance of *Stipa pennata* and *Arrhenathum elatius*.

After 59 years of self-restoration SOC stores increased in the upper 0.5m from 78.9% to 95.3% of the virgin Chernozem (Figure 1). The chronosequence also showed increasing SOC contents in the upper 0.5m from 33.4 to 43.4g/kg in the mean (Table 1). The increasing of SOC content was especially high in the first 10cm of the soils from 39.2 to 78.2g/kg. Because of concurrent increasing carbon and nitrogen contents in the chronocequence the C/N ratios showed no alterations. Changes in chemical properties were found in respect of CEC, which increased from 33.8 to 39.7cmol/kg during self-restoration. The significant correlation (R^2=0.88) between CEC and SOC content indicated that the increase in CEC resulted from increasing SOM. Beside no changes in soil chemical properties, which comprises pH, carbonate content, exchangeable cations, and plant available phosphorus and potassium, were found.

Table 1. Characteristic chemical properties of the studied soils being 8, 19, 37 and 59 years under self-restoration, of an actual arable land, and of a "Natural" Chernozem, never been cultivated

Depth	C	N	C/N	$pH_{(H2O)}$	$CaCO_3$	Exchangeable cations				Σ	CEC	BS	K_2O	P_2O_5
						Na	K	Mg	Ca					
cm	g kg^{-1}				g kg^{-1}	$cmol_c$ kg^{-1}						%	mg $100g^{-1}$	
Arable land														
10	39.2	2.8	13.8	6.2	0.2	< 0.3	0.33	1.9	18.52	20.8	33.8	61	14.35	2.22
20	38.8	2.7	14.1	6.1	0.2	< 0.3	0.11	2.3	17.56	19.9	33.6	59	10.63	1.23
40	31.4	2.3	13.4	6.4	0.2	< 0.3	0.06	2.5	39954	24.0	29.7	81	7.72	0.27
55	21.0	1.4	14.5	6.9	11.4	< 0.3	0.07	1.8	27.43	29.3	25.5	100	7.98	0.17
86	9.6	0.8	11.4	8.3	14.0	< 0.3	0.07	1.5	29.95	31.5	19.3	100	8.84	0.16
125	9.9	0.5	19.8	8.5	11.2	< 0.3	0.08	1.6	22.81	24.4	16.5	100	nd	nd
8 years														
10	42.0	2.7	15.6	6.2	2.5	< 0.3	0.37	2.3	18.14	20.8	31.1	67	20.53	1.68
20	39.5	2.5	15.5	6.0	3.2	< 0.3	0.13	2.1	17.3	19.5	30.8	63	9.82	1.27
30	31.2	1.6	19.5	6.6	3.5	< 0.3	0.06	1.9	18.1	20.0	29.7	67	7.69	0.33
55	19.9	1.0	19.0	6.9	3.9	< 0.3	0.07	1.5	16.1	17.6	26.6	66	8.27	0.14
75	12.4	0.3	35.6	6.7	80.7	< 0.3	0.07	1.1	14.2	15.4	23.9	64	6.49	0.06
130	6.4	nf	nd	7.9	141.0	< 0.3	0.08	1.2	22.8	24.1	11.7	100	nd	nd
19 years														
10	41.6	3.1	13.4	8.0	13.6	< 0.3	0.15	1.4	30.9	32.5	36.0	90	10.40	0.80
20	38.7	2.9	13.4	8.2	20.2	< 0.3	0.07	1.3	28.7	30.0	31.5	95	7.20	0.33
30	29.9	1.9	15.4	8.3	39.1	< 0.3	0.06	1.3	29.7	31.0	29.8	100	6.54	0.12
50	22.2	1.3	16.5	8.4	81.5	< 0.3	0.06	1.3	18.9	20.2	24.6	82	6.05	0.06
80	16.9	0.5	30.8	8.5	118.4	< 0.3	0.05	1.1	14.1	15.3	20.1	76	5.79	0.06
120	13.1	0.3	37.6	8.5	133.9	< 0.3	0.06	1.2	21.9	23.2	16.3	100	5.85	0.06
150	9.2	nf	nd	8.5	132.0	< 0.3	0.06	1.6	34.7	36.3	13.7	100	nd	nd
37 years														
10	55.0	4.1	13.4	6.6	0.7	< 0.3	0.19	2.5	19.3	22.0	36.2	61	10.60	0.37
20	45.4	3.0	14.4	6.5	0.4	< 0.3	0.08	1.8	15.1	17.0	33.9	50	7.43	0.21
40	39.5	2.5	15.8	6.4	0.3	< 0.3	0.07	1.7	16.3	18.1	32.9	55	7.25	0.16
55	30.8	2.1	14.7	7.0	0.9	< 0.3	0.08	1.4	15.0	16.5	28.5	58	7.89	0.14
80	23.9	1.3	17.7	7.6	3.0	< 0.3	0.08	1.2	13.7	15.0	24.3	62	8.24	0.15
130	21.5	0.5	39.1	8.3	87.8	< 0.3	0.07	0.9	21.6	22.6	16.6	100	6.17	0.06
150	8.4	nf	nd	8.5	122.7	< 0.3	0.08	1.2	28.6	29.9	12.1	100	nd	nd
59 years														
10	54.7	4.0	13.5	6.2	0.9	< 0.3	0.42	2.3	17.1	19.8	39.7	50	18.84	0.31
20	45.1	3.1	14.5	6.5	0.9	< 0.3	0.11	2.1	19.8	22.0	36.5	60	8.66	0.17
50	39.1	2.6	14.8	6.6	2.7	< 0.3	0.09	1.9	16.7	18,7	32.8	57	8.64	0.14
100	18.6	1.2	15.5	6.8	15.8	< 0.3	0.08	1.4	29.1	30.5	22.8	100	9.48	0.15
130	6.0	nf	nd	8.5	137.0	< 0.3	0.09	1.3	20.1	21.5	15.2	100	nd	nd
"Natural" Chernozem														
10	78.2	6.1	12.7	6.6	0.8	< 0.3	0.73	3.5	26.1	30.3	44.1	69	26.48	0.61
20	52.6	3.8	13.7	6.6	0.9	< 0.3	0.12	2.7	20.2	23.0	38.0	61	8.04	0.27
60	38.2	2.5	15.1	7.2	2.0	< 0.3	0.1	1.6	17.2	18.9	32.1	59	7.58	0.18
80	23.2	1.1	21.1	7.9	1.2	< 0.3	0.08	1.3	13.8	15.2	26.1	58	7.80	0.11
120	17.2	0.9	19.2	8.3	53.6	< 0.3	0.09	1.1	35.1	36.2	20.8	100	6.72	0.07
140	5.6	nf	nd	8.6	160.1	< 0.3	0.07	0.9	23.3	24.3	10.2	100	nd	nd
170	4.4	nf	nd	8.6	122.5	< 0.3	0.08	1.2	21.6	22.9	8.5	100	nd	nd

nf – not found nd – not determined

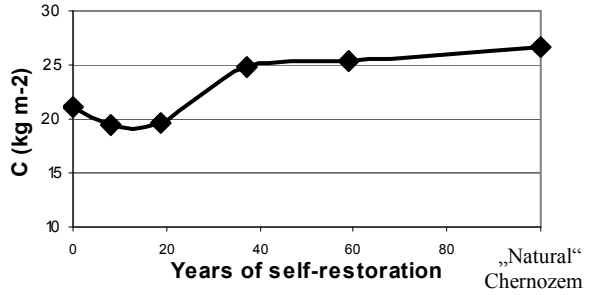

Figure 1. Soil carbon stores in the upper 0.5m of the studied soils being 8, 19, 37 and 59 years under self-restoration, of an actual arable land, and of a "Natural" Chernozem, never been cultivated

Table 2. Free particulate organic matter (POM) of the density fraction <1.8g/cm^3, occluded POM of the density fraction <1.8g/cm^3, and OC within the grain size fractions of the studied soils being 8, 19, 37 and 59 years under self-restoration, of an actual arable land, and of a "Natural" Chernozem, never been cultivated

Depth	Sand		Silt		Clay	Free POM of the density fraction <1.8 g cm^{-3}	Occluded POM of the density fraction <1.8 g cm^{-3}
	0.2-0.063mm	0.063-0.020mm	0.020-0.0063mm	0.0063-0.002mm	<0.002mm		
cm	% of soil						
Arable land							
10	0.003	0.02	0.04	0.17	1.40	0.12	1.69
20	0.005	0.02	0.04	0.17	1.85	0.07	1.26
40	0.005	0.01	0.02	0.15	1.30	0.03	0.88
50	0.002	0.01	0.01	0.10	1.18	0.03	0.68
8 years							
10	0.006	0.03	0.07	0.27	1.70	0.28	1.70
20	0.004	0.02	0.06	0.23	1.61	0.10	1.46
30	0.004	0.02	nf	nf	1.14	0.08	1.40
55	0.001	nf	0.01	0.07	0.99	nd	0.56
19 years							
10	0.005	0.03	0.05	0.19	1.37	0.11	2.19
20	0.007	0.04	0.07	0.2	1.62	0.04	1.18
30	0.010	0.07	0.04	0.17	1.69	0.02	0.94
50	0.020	0.07	0.06	0.15	1.36	0.01	0.71
37 years							
10	0.01	0.09	0.10	0.40	1.88	0.3	1.92
20	0.006	0.06	0.09	0.38	1.86	0.13	1.43
40	0.005	0.03	0.04	0.32	2.35	0.06	0.77
55	0.004	0.01	0.03	0.16	1.80	0.07	0.61
59 years							
10	0.006	0.13	0.07	0.28	1.84	0.57	2.65
20	0.004	0.07	0.07	0.24	2.16	0.10	1.90
50	0.002	0.02	0.05	0.25	2.26	0.07	1.03
"Natural" Chernozem							
10	0.02	0.09	0.08	0.63	2.42	0.6	4.05
20	0.005	0.06	0.09	0.33	2.20	0.35	1.85
60	0.002	0.03	0.03	0.16	1.46	0.15	0.95
80	0.004	0.02	0.02	0.06	0.95	0.05	0.75
120	0.007	0.07	0.08	0.15	0.74	0.04	0.51

The investigation in respect of functionally different SOC pools of post-agrogenic Chernozems under self-restoration reveal with 36-68% of SOC a dominance of organic carbon (OC) in the fine silt and clay fractions (Table 2). This fraction showed a tendency to increasing during self-restoration, hence indicating an increase

of passive OC. An increase during self-restoration was also found in respect to POM, but the amounts were with 1-7% of SOC comparatively low. The fraction of the occluded POC was 20–58% of SOC. Although it also increased during self-restoration, the rate of occluded OC after 59 years of self-restoration didn't reach the level of the virgin Chernozem.

Conclusion

Self-restoration of post-agrogenic Chernozems in the Kursk steppe zone of Russia was characterized by reaching the climax stage for the vegetation after 59 years. Even quicker was the development towards Chernozem typical morphology, by loosing the ploughing features and gaining the crump structure, overall indicating a fast recovery from agriculture. But our results in respect of SOC and SOC fractions showed clearly, that the restoration process is not completed after 59 years: although a distinct increasing carbon sink functioning occurred, the question of when or ever the SOC dynamics of virgin Chernozems will be reached remains open. To fill this gap more investigations are required, which should also include other soils of other climate zones.

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