

Change of forest soils under human factors (the Komi Republic, Russia)

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Abstract

Timber, oil and gas industries play a dominant role in disturbances of forest soils. The greatest changes of soils happen in first 5-10 years after cutting. The cutting areas are characterized by different disturbances and various rates of renewal. Temporary soil over-moistening in first years after cutting and secondary succession of vegetation influence soil morphology, soil properties and humic substances at cutting areas. Changes of soil and soil cover of the Komi Republic under impact of oil and gas industry are presented.

Key Words

Forest soils, anthropogenic changes of soils, cutting, oil and gas mining impact on soils

Introduction

The Komi Republic (KR) is located in the North-East of European Russia, its area is more than 40 million hectares. Bioclimatic conditions are not favorable for agriculture, but soil resources are of great importance for forestry (Zaboeva 1975). The European northeast is characterized by about 50 % forest-cover (State 2009). The total area of forest resources land is 36 million ha (or 86 % area of the KR). Soils of the podzolic type are dominant in well drained forest landscapes: gley-podzolic soils in northern taiga subzone, typical podzolic soils in middle taiga and sod-podzolic soils in the southern subzone. Soils of this groups are of great importance for forestry. Quite productive spruce and pine forests grow on such sod-podzolic soils. More than a half of the area covered by podzolic-boggy soils predominated on watershed sites under green-mosses and sphagnum dark coniferous forests (Zaboeva 1975).

Soil transformation (changes in morphological and physicochemical parameters) in the KR is connected with timber-harvesting and oil-gas industry. Agricultural lands (tillage, greenland and pasture) are insignificant and cover 418 thousand hectares – 1.0 % of KR total area (State 2009). In forest landscapes the specificity of soil and soil cover formation under native forest vegetation has been studied by now (Zaboeva 1975; Rusanova 1987; Lodygin *et al.* 2007; Soil..2001) and also under agriculture (Zaboeva *et al.* 1988; Kanev and Mokiev 2004). Problems linked with soil changes result from forest harvesting and oil - gas mining and pipeline have been less studied. The main objectives of the present research were to study some properties of podzolic soils in chronosequences of clear-cuttings, to evaluate the impacts of cutting on soil organic matter and the impact of oil and gas industry on properties of forest soils.

Materials and methods

Human-induced changes in soils have been studied in the northern and middle taiga subzones of the republic. Influences of harvesting operation have been estimated in middle taiga in two chronosequences: soils of the first series formed in loamy sediments (Ust’Kulom district, Komi), the second - in lithologically discontinuous deposits (sand underlayed by morain loams at depths of 40-50 cm) (Prilyzskii district, Komi). Soils of first chronosequence in clear-cutting sites (only “felling” sites without any mechanical disturbances of ground cover and soils as well) presented by: plot 1 – soils under native spruce forest; plot 2 – soils under 6-year-old clear cutting; plot 3 – soils under 38-year-old clear cutting. Soils of second chronosequence of clear-cuts presented by: plot 1 – soils under native pine forest; plot 2 – soils under 12-year-old clear cutting; plot 3 – soils under 23-year-old clear cutting. Additionally mechanically disturbed soils were investigated (tractor road and timber loading platform). Soils were described according to the Russian system of Soil Classification (Classification 2004). Analytic methods were used in accordance with the “Theory and practice of soil chemical analysis” (2005).

Results

Influence of timber cutting

Significant areas of forests (more than 20% of total KR area) were cut during the second half of the 20th century (1930 -1990s). Nowadays about 5 - 8 million m³ wood is harvested annually (State 2009), mostly by clear cut. Reforestation of cutting areas is by secondary birch and aspen stands. According to Lal (2005) forest ecosystems contain a huge carbon content stored in soils as accumulated organic carbon. It is very

important to understand the mechanisms of change in soil organic matter during secondary succession after forest cutting.

In the cutting area soil changes and restoration rate of physicochemical properties depend on the texture of soil-forming sediments, season of cutting, quality and technological characteristics of harvesting operations. Greatest changes of soil cover are affected by heavy forestry machinery during harvesting operation (Rosnovsky, 2001). This type of disturbances is very common for tractor road and timber loading platforms covering about 30 % of the cutting area. In these sites the upper soil profile consists of piling layers which appear to be a mixture of mineral soil and logging slash (stems, branches, etc.) and the ground cover vegetation.

The operation lead to conservation of dead ground vegetation and logging slash in buried at depths of 30 to 100 cm. The bulk density of upper horizons increases at this sites, pH decreases by 1-3 pH units (in comparison to control sites) as does microbiological activity. During first years after cutting reforestation is suppressed at these sites.

For the rest of the cutting area (without mechanical disturbance of ground and soil cover) soils changes result in temporary paludification and reforestation of forest vegetation. More intensive paludification processes develop in the soils of young cutting areas (5-10 years old) and lead to increasing spatial variation of morphological and chemical soil properties, gley processes activation, mobilization and segregation of Fe-compounds. Litter decomposition decreased under the hydromorphic regime resulting in decreasing capacity of forest litter and nitrogen depletion (Table 1).

Table 1. Changes of some characteristics of forest litter in chronosequences of clear-cuts

	Podzolic soils in silty loams			Podzols in lithologically discontinuous deposits		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
Thickness (cm)	5.5±0.8*	5.8±0.6	4.1±0.4	5.9±0.6	12.8±1.9	8.2±0.8
Litter density (g cm ³)	0.11±0.02	0.10±0.01	0.15±0.02	0.11±0.01	0.08±0.01	0.10±0.02
pH _{H2O}	4.3±0.1	4.4±0.1	5.0±0.2	4.1±1.0	4.5±0.9	4.6±1.4
Ctot (%)	42.2±1.0	42.0±1.1	37.6±2.5	33.9±3.3	35.4±14.0	29.7±7.0
Ctot (1000 kg/ha)	25.53	24.36	23.12	23	33.9	25.0
Ntot (%)	1.64±0.09	1.45±0.05	1.61±0.08	0.86±0.23	1.04±0.6	1.1±0.4
Ntot (1000 kg/ha)	0.99	0.84	0.99	0.50	0.57	1.16
n	39	40	30	61	30	50

* confidence interval for mean value (p=0.05)

Soils of young cutting sites are also characterized by increasing chemical “aggressivity” and migratory ability of humic substances. In upper soil horizons we can observe an increase in hydrophilicity of alkali-soluble organic matter and water- and acid soluble organic compounds as well.

Changes in upper soil horizons under secondary succession after felling (with vegetation cover renewal) depend on texture (granulometric composition) of soil forming sediments. Soils formed in homogeneous sediments are characterized by a decrease in pH of forest litter and accumulation of biofilic components. Soil formed on lithologically heterogeneous sediments appear to have stronger changes in morphological and physicochemical properties.

Humic and fulvic acids extracted from soils a felling places are differentiated from substances of soils under native forests. Main distinctions are in elemental and amino acid composition of humic materials. At cutting sites the nitrogen content in humic acids is as much as 1.3-1.7 times higher as compared to those in native forest. Probably, changes in nitrogen concentration are explained by changes in the composition of forest waste.

Simplification of HA macromolecules structure in cut area soils results from temporary soil over-moisturing. This process is indicated by increasing H:C ratio (Table 2). Hydrolyzates of HAs extracted from ELhg horizons of cut area soils contain 154.9-145.1 g/kg amino acids which is as much as 4.5-4.8 times more compared to the same horizon of native forest soils. HAs extracted from the O horizon have 107.8-101.6 g/kg amino acids which is rather close to the values in native forest. Some residual hydromorphic the features remain even 36 years after tree logging as hardpan horizons and concretion aggregations in the upper soil.

Influence of oil and gas industry

Oil and gas industry impact on soil cover is connected with a considerable quantities of sites in the Komi

Republic (State 2009). Mining and oil and gas pipeline cause single-stage or repetitive impact on soil cover (Solntseva 1998).

Table 2. Elemental composition and molar ratios of humic substances (HSs) extracted from soils at chronosequences of clear-cutting (Podzolic soils in silty loams, Ust' Kulom district, Komi)

Plot	Horizon	Humic substances	C	N	H	O	H:C	O:C	C:N
			(g/kg)						
Plot 1	O	HAs*	536	28.0	40.6	396	0.90	0.55	22.32
	E	HAs	550	28.2	43.8	378	0.95	0.52	22.77
	O	FAs*	493	8.8	36.1	462	0.87	0.70	65.26
	E	FAs	483	18.1	43.3	456	1.07	0.71	31.08
Plot 2	O	HAs	526	33.8	44.2	396	1.00	0.57	18.15
	Ehg	HAs	566	43.4	57.1	334	1.20	0.44	15.19
	O	FAs	514	17.5	42.2	426	0.98	0.62	34.18
	Ehg	FAs	497	10.0	37.5	456	0.90	0.69	57.93
Plot 3	O	HAs	563	32.6	55.0	349	1.16	0.46	20.19
	E	HAs	510	47.6	47.2	396	1.10	0.58	12.49
	O	FAs	488	8.8	28.8	474	0.70	0.73	64.99
	E	FAs	474	14.9	47.3	464	1.19	0.73	37.01

* HAs – humic acids; FAs –fulvic acids.

Investigations of mining impact on northern and middle taiga subzone of the KR revealed the following:

1) Using of heavy tractors during first stages of construction of surface facilities for the well and pipeline routes, gasoline storage led to mechanical disturbances of native soils, deletion of upper (organogenic) horizons or burial under filled ground and creation of an anthropogenic landscape (Figure 1);



A



B

Figure 1. Human affected changes in podzolic soil profile (A) and local disturbances of soil and vegetation cover near gas producer (B).

2) Work of compressor station and well operation promotes hydrocarbons (mineral oil and oil products) pollution, easily soluble salts, heavy metals and other chemical components (acids, bases, surface-active substances) penetrate into soils and other landscape elements;

3) Carbon black, polycyclic aromatic hydrocarbons (including benzapirene) and sulphurous matters can enter the atmosphere under incomplete burning of accompanying gas and accumulate in upper soil horizons;

4) The Komi Republic is characterized by a humid climate with poorly-drained landscapes and swamp land domination. Chemical substances (hydrocarbons, acids, surface-active substance) inflow under such conditions are a very important factor for changes in morphological, physicochemical and biological soil properties. Consequences of this impact are determined by pollution duration, contaminant chemical characteristics and landscape peculiarities;

5) Contamination along gas and oil pipeline appears to be local and is usually registered visually as single spots.

Nowadays in the area of different oil and gas operations in the forest zone of the KR we can separate three degrees of soil degradation under human impact:

- **low degree** – integrity of soils are safe but some physicochemical properties changes
- **middle degree** – local disturbances of soil profile (upper soil horizons mainly) – mixing of soil horizons, burial some part of the soil, changes of primary soil process;
- **high degree** – total disturbance of soil profiles, removal of organogenic horizons, outcropping soil parent material.

Conclusion

In this article we present main reasons for changes in forest soils under human impact in the forest-covered area of the Komi Republic – one of Russian industrial regions. Timber industry plays a dominant role in forest soil disturbances. For middle taiga bioclimatic conditions, first years after logging are characterized by temporary soil over-moisturing. This changes not only morphological structure and physicochemical properties of cut site soils but also HS content and composition. Traces of temporary over-moisturing remain in soil 36 years after cutting. Change in tree species (spruce for mixed birch-spruce) causes a decrease in forest litter thickness and increases its density. Slow plant waste decomposition is due to excessive moisture (mostly during first after-logging years) which produces an increasing content of water- and acid-soluble organic compounds in soil organic matter (SOM). The hydrophilic part of SOM increases which accounts for its mobility.

Soils of logger-road and timber loading sites are transformed to a great extent. Physical changes in the soil of logger-roads occur down to a depth of 60 and down to 90 cm in timber loading sites. In the upper soil horizons of these soils humus content is abruptly changed and biological activity is suppressed. Transformation soils under the influences of oil and gas extraction and pipeline reflect the quality of work, peculiarities of landscape and soils properties. The three soil degradation degrees under human impact were separated. Changes in podzolic and podzolic-boggy soils with low humus content and weak buffer value formed under middle and north taiga climatic conditions are substantial.

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