Basic property analysis of sod-forest soil covered by a forest fire in the territory of Usmansky pinery (RF)

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Abstract. The paper deals with nine years analyzing of physical, physicochemical and chemical properties of sod-forest gley-eluviol soil in the territory of Usmansky pinery in European Russia exposed to large-scale fire in 2010. We discovered that in a layer of 0-10 cm there is a decrease in the content of the clay fraction by 6.15%, that is 63.4% in relative percentages, also the content of medium dust decreased by 0.16%, that is 3.02% in relative percentages and fine dust by 1.21%, that is 47.5% in relative percentages. It was revealed that in 2011 the year after the forest fire, the soil had higher pH_{H_2O} it went up from 4.12 (reference soil) to 5.36 (pyrogenic soils) and lower hydrolytic acidity, which decreased from 6.38 (reference soil) up to 5.98 (post-pyrogenic soils 2018) [mmol (eq) / 100 g of soil] compared to 2010. Due to fire the humus content decreased from 3.93 (reference soil) up to 2.82 % (post-pyrogenic soils 2018), decrease of exchange cations from 8.16 up to 7.65 [mmol (eq) / 100 g of soil]. From 2011 to 2018 there has been a decrease in the content of alkaline-hydrogenated nitrogen from 9.02 (reference soil) up to 6.06 (pyrogenic soils 2011).

1. Introduction

Forest fires are the main factor destabilizes ecosystems and regulates the formation of new post-pyrogenic biogeocenosis [1]. According to information provided by the Federal Forestry Agency and the Ministry of Emergencies, the area covered by forest fire amounted to 1 million hectares, and according to the World Fire Monitoring Center, based on images from space – 10-12 million hectares [2].

Modern changes in forest soils are associated with their development and use as agricultural land, destruction due to forest fires, as well as logging activities. Therefore, soils are transformed from natural to anthropogenic [3, 4]. An analysis of literary sources allowed us to conclude that the main number of studies aimed at pyrogenic changes in the soil cover are characteristic of the territory of Siberia. The modern works describing soil changes during fires in the European part of the Russian Federation are single, with a predominance of publications on the dynamics of vegetation during the post-pyrogenic successions. Therefore, studies aimed at identifying the dynamics of the physical, physicochemical and chemical properties of soils of the Usmansky pinery are so relevant.

The purpose of our work was to analyze the physical, physicochemical and chemical properties of the post-pyrogenic (within 9 years period after a forest fire) sod-forest gley-eluviol soil.
2. Materials and methods

We explored the Voronezh region’s soils of the Russian Federation: sod-forest gley-eluvial sandy soil, located in the territory of the Usmansky pinery in a forest-steppe zone which is the main forest in the center of Central Russian Upland and bordering the city of Voronezh (figure 1) [5].

The object of the study was sod-forest soil that created under century pineries on an eluvium of the indigenous main and ultrabasic, rich with primary minerals breeds. The samples of sod-forest soil were compared to reference soil – the soil of the same composition and basic properties taken from the Usmansky pinery, the area which was not affected by forest fire (n.l. 51°48’37.4” e.l. 39°23’42.6”)(GPS Navigator Garmin Oregon 750 2017 Taiwan China).

Soil samples were selected in 2011-2018 in the territory exposed to pyrogenic effects in 2010. It was laid 9 soil sections under the pine forest (in triplicate repetition) (n.l. 51°48’37.4” e.l. 39°23’42.6”). From the soil sections the selection was carried out layer by layer of 0-10 cm. In addition, on to reference soils that were not attacked by pyrogenic exposure, there were made 1 full-profile soil sections, revealing the soil-forming rock (in triplicate repetition) [6].

The particle size distribution of the soil was defined by a pipette method with processing by a sodium pyrophosphate [7]. In the samples we measured pH_{H2O} and hydrolytic acidity, Ca^{2+} and Mg^{2+}, total humus, nitrogen of easily hydrolyzable compounds, soluble phosphates and exchange potassium parameters [8-10].

pH_{H2O} was determined by the potentiometer. The method is based on measuring the voltage across the electrodes of the electrochemical cell in the absence of current. (Water distiller DE-25M EMO 2016 “Plant” (St. Petersburg Russia), Electronic scales "DEMCOM DL-312" (310 g / 0.01 gr) 2017 (Russia), PH meter / ion meter S500 Seven Excellence (S500-Fluoride, 2017 USA). Hydrolytic acidity of the soil was estimated by Kappen, in the interaction of CH_{3}COONa pH 8.2 with the soil. Total humus was determined by I. Tyurin in the modification of V. Simakov [11]. The method is based on the oxidation of carbon of humic substances up to CO_{2} 0.4 N. K_{2}Cr_{2}O_{7}, prepared on 0.6 N. H_{2}SO_{4} (Electric tile infrared 2016 Russia). Nitrogen of easily hydrolyzable compounds was determined in an alkaline extract according to the A. Kornfield method [11]. Method is based on the hydrolysis of organic compounds of the soil by 1 N NaOH. Soluble phosphates P_{2}O_{5} were detected by photocolorimetric determination after the interaction with 600 at 750 nm on spectrophotometer (Photometer flame PFA 378 2015 Russia). Exchange potassium in non-carbonate soils was estimated with a flame photometric determination based on the extraction of mobile phosphorus and potassium from the soil by 2 N CH_{3}COOH and subsequent determination of phosphorus in the form of a blue phosphorus-molybdenum complex on the photoelectric colorimeter (Photocolorimeter KFK-3KM Russia) and potassium – on a flame photometer with 766 at 770 nm (Photometer flame PFA 378 2015 Russia) [11]. The graphs are executed according to the obtained data using the Box Plot and Microsoft Excel programs.

3. Results and discussion

In 2011, it was revealed that after fires there is a change in the morphological properties, acidity and particle size distribution of soils [12]. Galoshchapova and Kalinenko in their work (2012) investigated the soils of fires, found that there is an increase of daytime peaks temperatures by 5-7 °C [13].

According to research by Dymov A. et al. in the soil after the fire, there are differences in the content of fractions by particle size compared to the usual background are observed with an increase in largest fraction 1-0.25, at some decrease in the fraction of fine sand. Possibly, it can be connected with processes of cementation and clutch aggregates which happen after the fires [14]. In addition, spatial heterogeneity of the distribution of sand fractions cannot be ruled out. At the same time the lower subhorizons of laying practically do not differ from the background areas.

We established that fine sand is the predominant fraction in the studied sod-forest gley-eluvial soil, which averages 53.0%. According to the particle size distribution, the studied soils are sandy loam. As a result of pyrogenic exposure in the 0-10 cm layer, a decrease in the silt fraction by 6.15% occurred, which in relative percentages is 63.4% relative to reference soils (figure 2). The content of average
dust decreased by 0.16%, which is 3.02% in relative percentages and fine dust by 1.21%, which is 47.5% in relative percentages. The content of the fraction of coarse and medium sand increased by 1.41% and 1.63%, which in relative percentages is 7.66% and 5.17%, respectively. Under a pine forest, the content of the fine sand fraction in pyrogenic soils increased by 6.30% in comparison with the reference ones, which is 11.7% in relative percentages (figure 3).

Bryanin S. V. (2014) investigated the effect of ash from a forest fire on soil cover. He found that alkali metals come with ash, which leads to alkalization of the soil solution [15].

Dymov A. et al. (2018), showed decrease in acidity in the organogenic horizons, enrichment of the mineral horizons nitrogen and carbon in soils of North taiga pine forests lichen and the covered in green moss, taken place the fluent local fires in the territory of the Kola Peninsula [14].

According to Dymov A. et al. the alkalization of litter is largely associated with the influence of coal formed as a result of the fire, since some of the low molecular weight organic compounds present in the soil solutions of fires can be sorbed on its surface. But at the same time, there is a tendency in pyrogenic soil to increase the acidity of mineral horizons [14].

Edval S. A. et al. in 2015 defined that soils of forest landscapes regulate the chemical composition of surface and ground waters [16]. According to Kawahigashi et al., 2011 the response of the environment and the morphological properties of soils change as a result of pyrogenesis.

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**Figure 1.** Geographic location of Usmansky pinery (RF).

**Figure 2.** Ratio of various fractions in sod-forest soils (the background site) of a pine forest in a layer of 0-10 cm in %.

**Figure 3.** Ratio of various fractions in sod-forest soils (the pyrogenic site) of a pine forest in a layer of 0-5 cm in %.
In 2011 there was offset indicator pH\textsubscript{H2O} from strongly acidic – 4.12 to acidic – 5.36 in the sod-forest gley-eluvial soil located under a pine forest, due to the fact that the ash neutralizes organic acids of the top soil horizons. In 2018 we noted a certain stabilization of values pH\textsubscript{H2O} and the pursuit of their meanings in the background (table 1, figure 4). On the pyrogenic soils after a forest fire, we observed a decrease in hydrolytic acidity. In sod-forest gley-eluvial soil in 2011, hydrolytic acidity decreased by 7.38%, which is a result of alkalization of the solution of the upper 0-10 cm layer. In 2012, it increased compared to 2011 by 4.24%, and by 2018, acidity decreased under pine forest compared to the baseline by 6.12% (table 1, figure 5). The pyrogenic factor had an effect on the content of exchange cations, in the direction of their decrease, due to the transfer of part of the exchange bases to the insoluble form of \text{СаСО}_3. The content of exchange cations of \text{Ca}^{2+} and \text{Mg}^{2+} in the 0-10 cm layer of sod-forest gley-eluvial soil under a pine forest decreased by 6.25% relative to background soils (from 8.16 mmol (equivalent) /100 g of the soil to 7.65 mmol (equivalent) / 100 g of the soil). Compared to 2011, the content of exchange cations in 2018 increased slightly (table 1, figure 6).

### Table 1. Statistical indicators of physic-chemical properties in reference soils.

| Depth, cm | n  | pH\textsubscript{H2O} | H\textsuperscript{+} | Ca\textsuperscript{2+}+Mg\textsuperscript{2+} | mmol (eq) / 100 g of soil |
|----------|----|----------------|---------------------|--------------------------------------|--------------------------|
| 0-10     | 3  | 4.12±0.21     | 6.38±0.82           | 8.16±0.62                            |

Note: n\textsuperscript{1} is a number of samples; x\textsuperscript{2} is an arithmetical mean; x ± s\textsubscript{x} is an arithmetical mean with a mistake of an arithmetical mean.

Soucemarianadin et al., 2014, in the current climate fluctuation environment, changes in soil organic matter take on a special role. [17].

Dymov A. et al. proved that in the litter of lichen pine forests the carbon content is 32-44%, in mineral horizons it does not exceed 0.8% [14]. In the podzols of the illuvial-iron pine forests of lingonberry-green moss in the litter, the carbon concentration is 43-45%, in the mineral horizons less than 0.15%. In the litter of podzolic soils, the carbon content is 41-45%, in mineral horizons less than 1.4%. Peat-podzols under pine forests of semi-hydromorphic landscapes contain 33-48% of the litter and less than 0.4% of carbon in the mineral horizons. The profile distribution of carbon in mineral horizons is gradually decreasing. Similar patterns have been identified for the distribution of total nitrogen.
Figure 6. Content of exchange cations in 0-10 cm layer of sod-forest gley-eluvial soil (statistical processing).

Figure 7. Content of humus in 0-10 cm layer of sod-forest gley-eluvial soil (statistical processing).

In the studied pyrogenic soils, a tendency to a decrease in the humus content in the layer of 0-10 cm was revealed. The maximum losses were established in 2011 in sod-forest soil located under the forest - by 1.53%, which is 38.9% in relative percentages (in the background, the humus content is 3.93%, in the area exposed to fire - 2.40%). In 2018, the content of humus under pine forest increased by 22.3% compared to 2012 (table 2, figure 7).

Tarasov P. A. et al. (2011) and Krasnoshekov Yu. N. et al. (2013) revealed that phosphorus and potassium are transported from organogenic horizons in soils under fires. In the course of fires, the material and energy exchange between the atmosphere and the soil changes [18, 19].

The content of alkaline hydrolysis nitrogen in pyrogenic sod-forest soils under a pine forest in a layer of 0-10 cm in 2011 decreased by 32.8% compared to background soils (from 9.02 mg / 100 g of soil to 6.06 mg / 100 g of soil). This is due to the fact that at temperatures around 500 °C, most of the organic nitrogen compounds are destroyed [20]. By 2018, the content of alkaline hydrolysis nitrogen under pine forest increased by 15.4% compared with 2012 (table 2, figure 8).

Table 2. Statistical indicators of chemical properties in reference soils.

| Depth, cm | n  | Humus, % | N_{alk.hyd.} | P_{2}O_{5} | K_{2}O |
|-----------|----|----------|--------------|-----------|--------|
|           | $\bar{x} \pm s_{x}$ | mg/100 g soil |
| 0-10      | 3$^1$ | 3.93$^2$$\pm$0.18 | 9.02$^3$$\pm$0.76 | 6.09$^3$$\pm$0.75 | 8.02$^3$$\pm$0.71 |

Note: $n$ is a number of samples; $\bar{x}$ is an arithmetical mean; $\bar{x} \pm s_{x}$ is an arithmetical mean with a mistake of an arithmetical mean.
According to Dymov A. (2017), in deciduous phytocenoses, as compared to the background spruce, there is an increase in the supply of potassium, phosphorus, iron, sodium and especially calcium, magnesium, manganese. An increase in manganese supply, together with a change in the hydrothermal regime, contributes to the intensification of the formation of concretions in the top mineral horizons of soils under the felling [4].

A year after the forest fire in 2011, the content of $\text{P}_2\text{O}_5$ in the sod-forest gley-eluvial soil increased by 14.3% compared to background soils (from 6.09 mg / 100 g of soil to 6.96 mg / 100 g of soil). In 2018, under pine forest, the $\text{P}_2\text{O}_5$ content decreased by 6.8% compared to 2012, gradually approaching the background value (table 2, figure 9).

The year after pyrogenic exposure, the $\text{K}_2\text{O}$ content in the sod-forest gley-eluvial soil increased by 7.82% compared with the background (from 8.02 mg / 100 g of soil to 8.51 mg / 100 g of soil). From 2012 to 2018, the $\text{K}_2\text{O}$ content decreased by 7.6% under pine forest (from 8.59 mg / 100 g of soil to 7.94 mg / 100 g of soil) (table 2, figure 10).
4. Conclusion

Forest fires of 2010 were the main destructive factor in the dynamics of sod-forest soils of the Usmansky pinery of the Central Chernozem Region (Russian Federation). The study of post-fire soil transformation is important for understanding the trends in soil regeneration. A comprehensive study of the forest soils of the Usmansky pinery made it possible to identify areas of modern pedogenesis in anthropogenically transformed sod-forest soils. So, the observation period of 2011-2018 for 0-10 cm a layer of sod-forest soils showed that there is a relief in particle size distribution due to the combustion of cementing organic material and sintering of silt fractions and fine dust, which causes gel dehydration, which occurs at a temperature of more than 220 ° C. Humus content decreased after pyrogenic exposure by 38.9%. In 2011, the content of alkaline hydrolysis nitrogen decreased by 32.8%, and by 2018 it increased by 15.4% compared with 2012. After pyrogenic exposure, alkalization of the soil solution and an increase in the content of ash elements P2O5 and K2O in the 0-10 cm layer occur due to their high content in ash formed after a forest fire. In 2012, the content of P2O5 increased by 14.3% compared to reference soils. In 2018, the content of P2O5 decreased by 6.8%, compared with 2012, gradually approaching the background value. In 2011, the content of K2O increased by 7.82% compared to the reference. From 2012 to 2018, the K2O content decreased by 7.6% under pine forest compared to 2011.

It was found that the content of Ca2+ and Mg2+ exchange cations is reduced due to the conversion of some of the exchange bases to the insoluble form of CaCO3. The content of exchange cations Ca2+ and Mg2+ in the 0-10 cm layer decreased by 6.25% relative to reference soils Compared to 2011, the content of exchange cations in 2018 increased slightly.

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