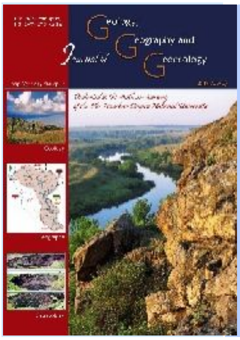

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Post-pyrogenic changes in the properties of grey forest podzolic soils of ecogeosystems of pine forests under conditions of anthropogenic loading

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Abstract. This article presents the analysis of results of experimental data of post-pyrogenic change of soils of ecological systems of pine forests.Ground fires transform the surface organogenic horizons of soils. The negative influence of low-intensity fires of different intensity on the change of humus stock, qualitative fractional composition of organogenic soil horizons and their chemical composition is shown.Post-pyrogenic transformations of physical and chemical soil characteristics are found, which are not simply their corresponding reaction to the pyrogenic effect, but a clear signal reflecting the state of the soil immediately after the fire, taking into account its strength and intensity, and after a certain period of time. There is a certain dependence of the degree of pyrogenicity on the duration of the effect of fire on the soil. The recent influence of a medium intensity fire on the soil is marked by a clear reaction of the complex of its properties.Physical and chemical properties of soils after fires deteriorate: humus burns, the content of nitrate nitrogen decreases.Forest fires sharply change the morphological state of the upper part of the soil profile. The nature of the surface horizons of soils changes, a new pyrogenic horizon is formed, which differs from natural analogues in terms of physical and chemical properties and the content of ash elements. Under the influence of fire there are changes in such properties as: pH, content of exchange cations, gross and moving forms of nitrogen, etc.The heavy metal concentration in surface horizons increases several times and exceeds the background values due to the mineralization of forest litter and herbaceous vegetation from the combustion and subsequent migration of chemical elements , which presents an environmental hazard.The change in the chemical composition of soils can create conditions for the impossibility of the existence of a root ecosystem, its death, and development, after a certain time, of another modified ecogeosystem.

Key words: pine forests, grass fires, biogenic pyrogenic horizons of soils, physical and chemical properties of soils, trace metals.

Постпірогенні зміни властивостей сірих лісових опідзолених ґрунтів екогеосистем соснових лісів в умовах техногенного навантаження

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Анотація. Наведено аналіз результатів експериментальних даних постпірогенної зміни ґрунтів екогеосистем соснових лісів. Низові пожежі трансформують поверхневі органогенні горизонти ґрунтів. Показано негативний вплив низових пожеж різної інтенсивності на зміну запасу гумусу, якісного фракційного складу органогенних горизонтів ґрунтів і їх хімічного складу. Виявлено постпірогенні трансформації фізико-хімічних показників ґрунтів, що є не просто їх відповідною реакцією на пірогенний вплив, а чітким сигналом, що відображає стан ґрунтів, як відразу після впливу пожежі, з урахуванням їх сили і інтенсивності, так і через певний період часу. Спостерігається певна залежність ступеня пірогенності від давності впливу пожежі на ґрунт. Недавній вплив пожежі середньої інтенсивності на ґрунт відзначений чіткою реакцією цілого комплексу її властивостей. Фізико-хімічні властивості ґрунтів після пожеж погіршуються: вигорає гумус, зменшується вміст нітратного азоту. Лісові низові пожежі різко змінюють морфологічний стан верхньої частини ґрунтового профілю. Змінюється характер поверхневих горизонтів ґрунтів, нерідко формується пірогенний горизонт, який за фізико-хімічними властивостями і вмістом зольних елементів відрізняється від природних аналогів. Під впливом вогню виникають зміни таких властивостей, як: pH, вміст обмінних катіонів, валових і рухомих форм азоту та ін. Концентрація ВМ у поверхневих горизонтах підвищується в декілька разів і перевищує фонові значення внаслідок мінералізації лісової підстилки та трав'янистої рослинності від згорання і подальшої міграції хімічних елементів, що являє екологічну небезпеку. Зміна хімічного складу ґрунтів може створювати умови для неможливості існування корінної екогеосистеми, її загибелі і розвитку через певний час іншої модифікованої екогеосистеми.

Ключові слова: соснові ліси, низові пожежі, біогенні пірогенні горизонти ґрунтів, фізико-хімічні властивості ґрунтів, важкі метали.

Introduction. Forest fires cannot be considered one of the main soil-forming factors, but at the same time they have both direct and indirect effects on the formation of soils. The literature contains some studies which prove the significance of pyrogenic load on soils and prove the role of pyrogenic impact on the evolution and functioning of soil in forest ecosystems (Aleksandrovskiy, 2007, Chevyichelov, A.P. 2002, Bento-Goncalves, 2012, Doerr SH & Cerda A. 2005, Krasnoschekov, 2014). Transformation of morphological and chemical properties of soils in pine forests after fires was studied by Shahmatova Y. U. (Shahmatova 2008).

More and more works appear, in which authors consider fire as an important factor in soil formation, which has various effects on the formation of the soil cover in forest ecosystems. At the same time, the pattern and the extent of pyrogenic impact on soil can be different depending on the physical-geographic conditions, type of forest, initial soil properties, and also the type and intensity of the fire.

Some work has also been done on describing the peculiarities of the changes in morphological, physical-chemical and chemical properties of soils of pine forests in the first months after a fire. This research has revealed the changes in morphological structure of forest litter, its density and changes in chemical properties. The formation of soils in a post-fire period is related to the pyrogenic transformation of the organogenic horizons, therefore their changes are indicators of the fire‘s impact on soil. A new diagnostic dynamic organogenic pyrogenic horizon (O_{pir}) forms, which by its physical-chemical properties significantly differs from the natural unchanged analogues. During combustion of the organic substances, large amounts of ash compounds are released from the upper horizons, which automatically changes the reaction of the environment, the amount of humus, content of nitrogen, number of exchangeable cations (Dyimov et al., 2014).

The analysis of the presence of polycyclic aromatic hydrocarbons (PAHs) indicated that the concentrations of chrysene, fluorene, naphthalene, pyrene, and anthracene in the horizon O_{pir}increased significantly compared to the pine forest in the territory unaffected by the technogenic impact. The total content of polycyclic aromatic hydrocarbons (PAHs) in the horizon O_{pir} increased mostly due to the increase in the share of two- and three-nuclei PAHs (naphthalene, fluorene). Mineral horizons of soils in burned areas are enriched with the most mobile amphiphilic fractions of the organic compound, which is manifested in the increase both in total and relative content of hydrophilic fractions which are possibly represented by the products of combustion of plant remains (Dyimov et al., 2014).

Forest fires also cause changes in geochemical peculiarities of ecogeosystems due to the migration via smoke and the further wash-out of the nutrients from the soil, and changes in hydrothermal regime. Change in abiotic conditions leads to transformation of the range and qualities of the ecologic niches in the burned area, loss of structural relationships between the environment and the spatial structure of the soil cover. In such conditions, the previous soil fauna is unable to perform its ecological functions, and the areas damaged by fire can be places where other species migrate to within the ecogeosystem (Gongalskiy, 2015).

The impact of fire on the components of ecogeosystems significantly varies and was studied by a number of researchers, but remains uncertain. Once again, we should mention that the geoecological assessments of the impact of the fires on natural complexes in general are currently absent in the literature. At the same time, there are detailed studies on the effects of the fires on particular components of the ecosystem, or generalized characteristics of post-fire formation of vegetation, which reveal indirect results of this impact. Currently, most results of post-pyrogenic studies focus particularly on vegetation as the most important and dynamic component and indicator of natural complexes. At the same time, various indirect effects of the fires on the environment through post-pyrogenic changes in the content and the structure of phytocenoses can be much significant than the direct effects.

The **objective** of this study was to analyze the post-pyrogenic changes in the properties of soils in the ecogeosystems of pine forests in Kharkiv Oblast in the conditions of technogenic load and assessment of "pyrogenicity" (extent and duration of its manifestation) in the soil.

To achieve the goal, the following tasks had to be solved:

Study the impact of the pyrogenic factor on the main physical-chemical properties of grey forest podzolic soils in pine forests of Scots pine. Determine the peculiarities of transformation of the chem-ical properties of soils affected by the pyrogenic
facor.

Conduct a comparative analysis of the peculiarities of distribution of mobile compounds of heavy metals (HM) in undisturbed soils and in pyrogenic soils.

Material and methods. The formation of soils in the post-fire period is related to the pyrogenic transformation of organogenic horizons, therefore their changes are an indicator of the fire‘s mpact on the soil.

Generally, fires affect all components of ecogeosystems, including their regime of functioning and evolution. A significant role must be played by soil as a lithogenous base for any natural complex.

The plantations which are most severely damaged by the fires are forest areas near large urbanized centers in the conditions of technogenic load. In Kharkiv Oblast, one of such objects of forest area is "Zhovtnevy lishosp" state enterprise of the Kharkiv Oblast administration of forestry and hunting (KOAFH), which is located near Kharkiv. Over the recent years, the area of the fires in the territory of this forest land continues to increase up to 30 ha each year. Therefore, as the object of study, we chose a part of a pine terrace near the Uda river within the territory of “Zhovtnevy lishosp”state enterprise.

For the study, we selected sample (experimental) plots (SP).

SP №1 was a flattened area of insignificantly declined slope of the facies of pine terrace with grey forest podzolic soil under the pine forest dominated by Scots pine (*Pinus sylvestris* L.) and grass-forb association with domination of greater celandine (*Chelidonium majus* L.) in the grass stand, leafy spurge(*Euphorbiavirgata* Waldst.), yellow bedstraw(*Galium verum* L.) and blue lettuce (*Lactuca tatarica* L.). On the plot, there were recorded and clearly seen the signs of fire which occurred 4-5 years ago: pines were affected by the fire up to the height of 1-2.5 m, the forest litter was damaged and in some places, the signs of the sources of fire and the areas with no vegetation were seen. The total area of the fire was around 0.8 ha. The fire which occurred within SP №1 was evaluated as a fire of the first degree for the tree stand was damaged insignificantly. Much more significant damage was caused to the undergrowth and shrub-herbaceous cover.

Sample plot №2 was selected because that area was affected by a forest fire of the third degree ten years ago, and now, the only signs of that fire are some pine trunks burned up to the height of 2-3 m. It is a plot of declined facies with grey forest podzolic soil under the pine forest of Scots pine (*Pinus sylvestris* L.) and domination of grasses (Gramineae). There was sparse growth of Canadian hawkweed(*Hieracium umbellatum* L.), leafy spurge(*Euphorbia virgata* Waldst.) and greater celandine (*Chelidonium majus* L.).

Sample plot №3 is located in 200-300 meters to the south-east of sample plot №1. It has a phytocenotic plant community similar to the sample plot №2. Unlike the previous facies, there are no signs of the fire. Its distinctive characteristic is the presence of intact forest litter of up to 10-12 cm thickness, which consists of dry pine branches, dry needles, strobili (pine cones)and dead remains of grass vegetation.

The grey podzolic soils we studied were the soils of a Scots pine forest with domination of grasses. On SP №1, the forest fire took place in 2013, SP №2 was affected by fire in 2008. After the fires, no pyrogenic impacts were observed in the territory. The last samples were collected in 2018 - 5 and 10 years after the forest fires (Table 1).

On each plot, we collected several samples of soil from the depth of up to 15 cm, and analyzed mean values. For all samples, we determined pH of the water extracted from soil using potentiometric method, content of humus and total nitrogen using Turin‘s method, granulometric composition using Kaczyński‘s method, mobile forms of phosphorus and potassium using Machigin‘s method [Spirina & Soloveva 2014]. The concentrations of mobile forms of heavy metals (HM) were determined using nuclear-absorptional method on a S-115M (*Russian* - C-115M) spectrometer.

Study on the acidity of soils. During the study of acidity of the soils, we determined the following pattern: acidic values of pH were determined for the litter in the old burned area, and pH was closer to the norm in the newly burned area. In general, after the fires, changes of acidity towards alkalinity were observed in the burned areas in organogenic horizons. In soil of newly burned areas, increase in the content of potassium cations in organogenic horizons occurs (Table 1).

The results of the study of acidic-alkaline conditions in the researched soils revealed increase in pH in soils affected by the fires. Therefore, in the control sample of the upper layer of grey forest podzolic soils (SP №1), pH equaled 4.1. In the similar soil of the experimental plot (SP №2), the reaction changed towards alkalinity after the fire (pH = 4.8).

Table 1. Analysis of pH of the soil environment

	year	SP№2*	SP№1**	Control
pH	2008	4.8	-	4.1
	2013	4.6	5,1	4.2
	2018	4.3	4,7	4.2

*The fire occurred on the plot in 2008
**The fire occurred on the plot in 2013

In 2013, there was observed a steep increase in pH of the environment on SP №1. Acidity on the plot slightly increased, but three years after the fire, it was still higher than the values of the control.

In 2018, change in pH towards acidity was observed on both plots. On SP №2, 10 years after the fire, the reaction of the environment practically reached the values of the control.

As a result of the combustion of the litter, pH in the upper layer of 0-10 cm changed towards neutral conditions to 4.8 and 5.1 compared to 4.1–4.2 in the control. The values of this parameter in other horizons were close to neutral.

The tendency towards increase in pH of soils after fires could be explained by the fact that the ash water-soluble compounds, after penetrating the soil, saturate the absorption complex with alkaline earth elements and cause change in the reaction of the environment to the neutral range. An important role in determining the pH values belongs to the time elapsed since an area had burned . In soils of old burned areas, pH values are close to the control, which was also mentioned by other researchers (Gyininova & Syimpilova 1999, Tsibart & Gennadiev 2008).

Physical-chemical analysis of the soils. Favourable conditions for forest growth in the conditions of saturation of soil with main elements up to 50-80%, the content of easily soluble compounds of potassium and phosphorus is higher than 5 mg per 100 g of soil. Pine grows well at absorption capacity of 7-12 mg-equ .At the same time, growth of most tree species becomes inhibited in highly acidic or alkaline soil.

Four-five years after the low-intensity forest fire (SP №1, 2013), the composition and the structure of the surface organogenic horizons changed. During that period, a 3-4 cm layer of litter formed on the surface which was completely burned during the fire. However, on the plots not affected by the fire, this layer composed completely of recently fallen needles, including large needles, bark, reaches 10-12 cm. In the fraction composition, large fragments dominate (brushwood, bark, strobili) - 77.1%. The needles and grass equal 17.5 and 5.3% respectively. The organogenic pyrogenic horizon is 3.6 cm thick.

The analysis of the area after the fire which took place 10 years ago (SP №2, 2018) revealed that the layer of forest litter increased to 5.2 cm. Fraction composition had the following structure: fraction (knots, bark, strobili) – 70%. Needlesandgrassequal 28.1 and 1.9% respectively (Fig. 1).

The soils are characterized by low content of humus in the upper accumulatng horizon. As the depth increases, its content steeply decreases, which is typical for this type of soil, the largest amount of total nitrogen is typical for organogenic horizons (Table 2, Fig. 2). Therefore, the impact of a ground fire causes the humus horizons of grey podzolic soils to respond with loss of nitrogen as a result of its partial combustion in the organic compounds.

A number of researchers indicate that in soils affected by fire, the humus content sometimes increases. This phenomenon can be explained by the intensification of the sod processes after the combustion of tree vegetation, and also decomposition of unburned remains of roots, needles, branches in the first hour after the fire.

In the studied samples, the humus content in the burned areas was lower compared to the control during quite a long period of time.

One of the main sources of organic compound and ash elements for soil is the forest litter. Ground fires lead to partial or complete combustion of forest litter, which further affects the organogenic characteristics of soils, first of all their upper horizons.

The older the burned areas, the lower the values of pH, content of exchangeable cations and humus. This is related to the fact that the reaction of the soil to pyrogenic impact diminishes (Fig. 2).

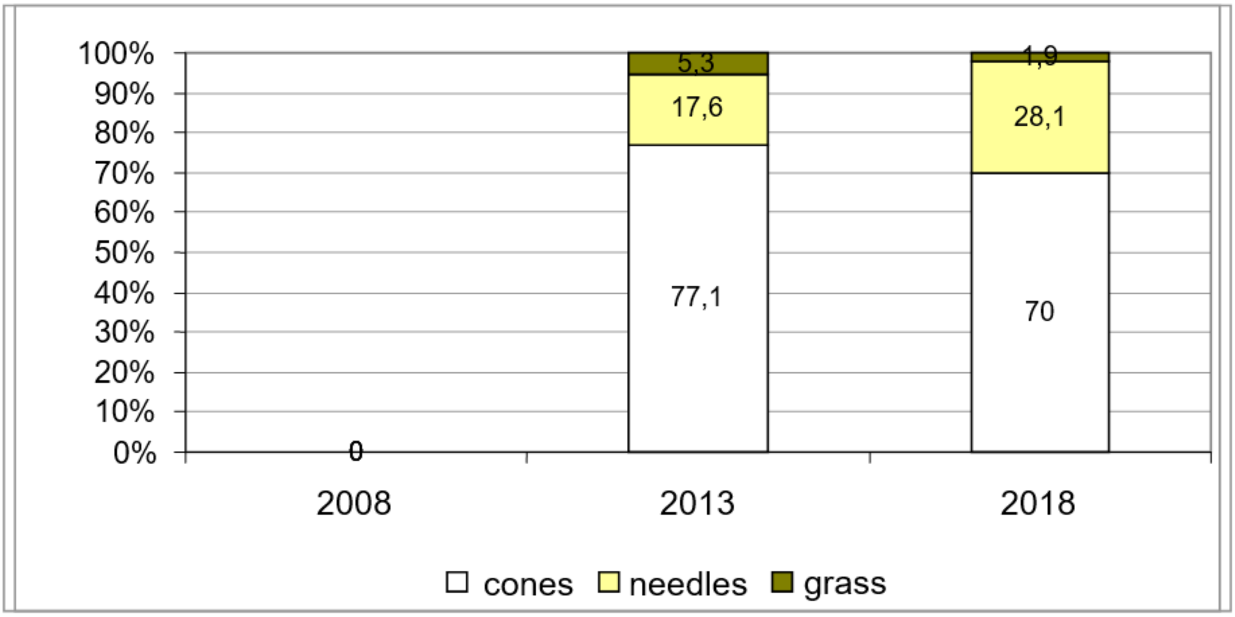

Fig. 1. Fraction composition of forest litter, % (SP №2)

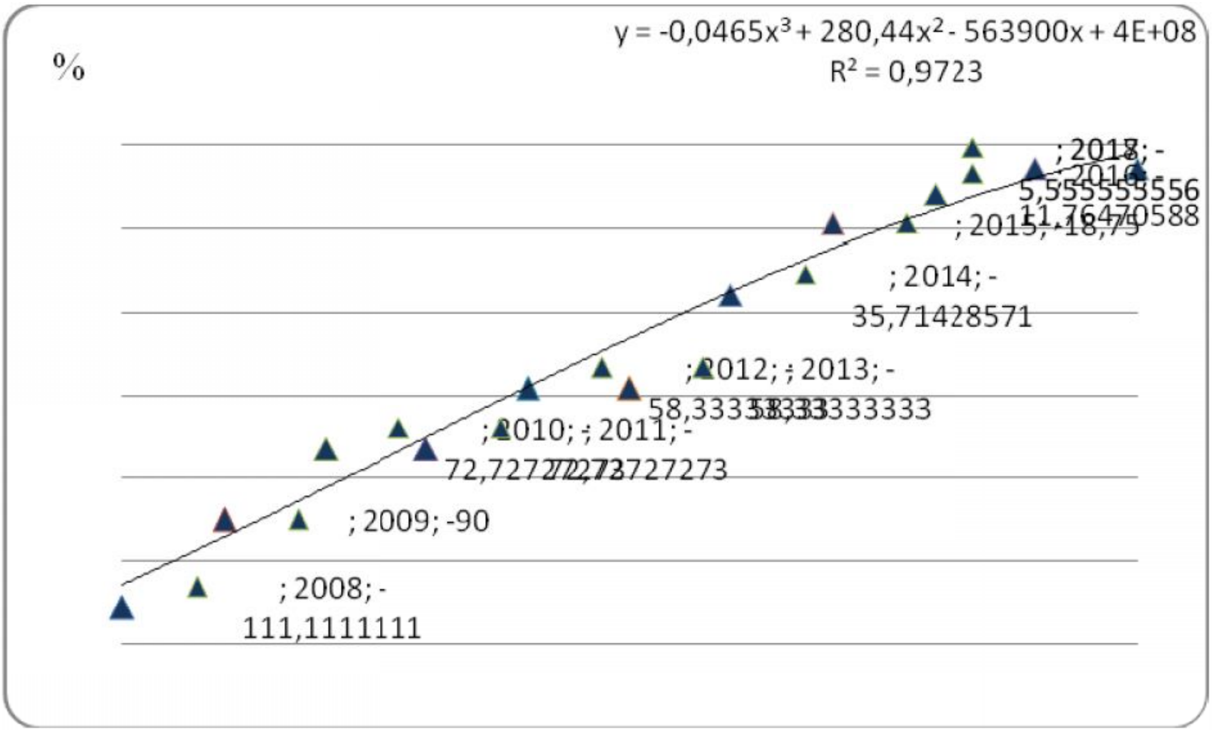

Fig. 2. Decrease in the humus content in the soils after forest fire (SP №1) compared to the control, %

Granulometric composition of grey forest podzolic soils in general is represented by sandy fractions. The content of sand in the horizons ranges from 71 to 97.2%.

The temperature of the ground layer of air in the felled areas of pine forests reaches around 50°C, which often causes death of young plants. A biological feedback occurs between the humidity and temperature of soil. Similarly to humidity, the temperature depends on the exposition of the slopes. As the steepness of the slope increases, the soil humidity in the same types of forests diminishes.

Therefore, the meteorological ecological factors after the fires provide a possibility of natural recovery of the coniferous trees, except for days with high temperature on the soil surface, mostly in summer.

Studying possible changes in the main properties of soils in particular areas of ground affected by fires, the change in chemical properties of soils in pine forests after the fires was proved and named "pyrogenicity of soils" by Y. U. Shahmatova (Shahmatova 2015), indicating the response reaction manifested in change (transformation) of a whole complex of soil properties.

Table. 2 Physical-chemical properties of soil

Parameter		SP№2*	SP№1**	Control
2008				
Exchangeable cations, Milliequivalents /meq./100g of soil	Ca^{2+}	7.2	-	12.6
	Mg^{2+}	4.1	-	7.1
Humus		0.9	-	1.,9
Nitrogen		0.4	-	0.1
2013				
Exchangeable cations, meq./100g of soil	Ca^{2+}	9.2	10.1	12.5
	Mg^{2+}	4.4	5.6	7.0
Humus		1.1	1.8	1.9
Nitrogen		0.2	0.4	0.1
2018				
Exchangeable cations, meq./100gofsoil	Ca^{2+}	10.2	10.8	12.1
	Mg^{2+}	5.6	6.5	7.1
Humus		1.8	0.6	2.0
Nitrogen		0.2	0.1	0.1

*SP №2 was affected by fire in 2008

**SP №1 was affected by fire in 2013 , there are no data for 2008

The literature contains data which prove that after fires, chemical elements accumulatein the soil (Nesgovorova et al., 2014) which in further migrate to the lower horizons of soil and become washed out in neighbouring elementary landscapes or accumulate in the podzolic horizon. This phenomenon can be explained by accumulation of ash elements formed during the combustion of the tree stand. As the alkalinity decreases, the complex compounds of iron, magnesium, silicon, potassium become mobile. In soil, they do not settle, but exist in a form available for the plants and can be consumed by their roots (Nesgovorova et al., 2014).chemical elements

Analysis of the content of heavy metals. According to the obtained data, in soils of SP №1, which was affected by the fire relatively recently, the concentrations of mobile forms of all analysed HM have increased values compared to the soil unaffected by the fire and the soil affected by the fire over 10 years ago. Therefore, Pb content in the upper soil horizon of 0-15 cm increased after the fire by almost 8 times, Ni - by over 6 times, Zn - by 3 times. The concentrations Cu, Cr and Fe increased less significantly (1.7 to 1.1).

We studied the probability of formation of non-soluble or mobile compounds of heavy metals by developing logarithmic concentration diagrams (LCD) (Buts et al., 2018). The heavy metals introduced to the environment can form poorly soluble hydroxides. Also, in the content of soil water, there is a possibility that the metals would form hydroxocomplexes with different amounts of hydroxide ions. The range of sedimentation of hydroxides and the area of prevalence of soluble hydroxocomplexes were studied by developing LCD.

Because the study included a comparative analysis of HM content in the soils of the ecosystems undamaged by the anthropogenic load and their anthropogenic modifications, we used the coefficient of concentration (K_C):

$$K_C = \frac{\kappa_i}{K_i} \quad (1)$$

where κ_i – content of chemical element in the studied object; K_i – content of chemical element in the object of ethalon system.

The indicators of the post-pyrogenic gechemical changes in the studies soils were the results of nuclear-absorption analysis (Fig. 3).

This indicator reflects the extent of the concentration of a chemical element in the studied object or its content in the components of ecosystems in the control.

By the coefficient of concentration, the content of mobile forms of HM in the studied soils of SP №1 andSP №2 are higher than the values of SP №3 in all studied samples. The highest values of $K_C$were determined for Cr, Ni and Pb. Excess in HM concentration in the soils of the studied ecogeosystems, in our opinion, could be caused by technogenic emissions of the industries of Kharkiv and of motor vehicles. There were excessive concentrations of HM in soils of SP №1, which were affected by the pyrogenic factor. This fact should be related to the mineralization of forest litter and herbaceous vegetation, caused by the combustion and further migration of chemical elements in the layers of soil.

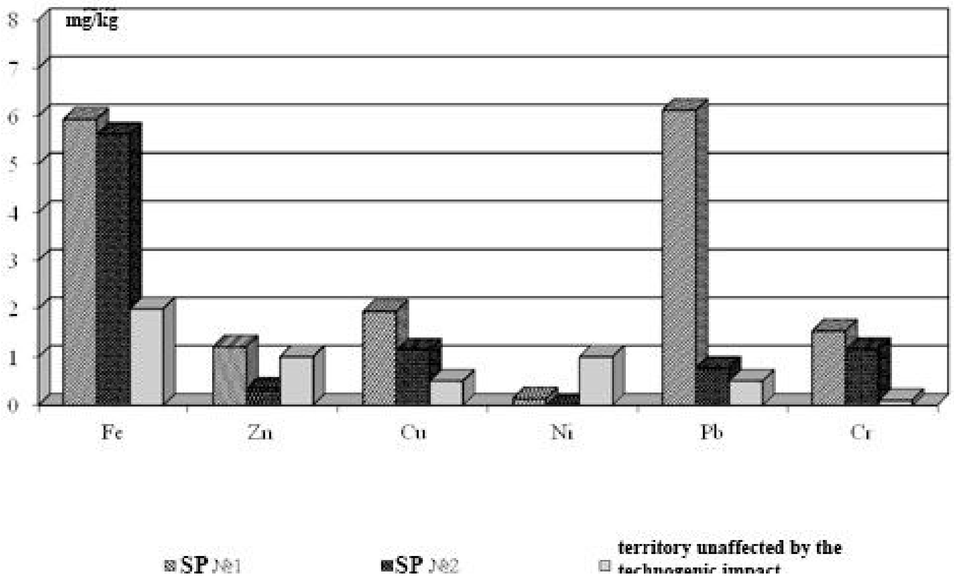

Fig. 3. Content of mobile forms of heavy metals and their values in the control in the soils of the studied ecosystems

In general, taking to account the toxicity of these HM and closeness of the experimental plots to the human settlements, we can state the ecological hazard for the studied ecogeosystems, including hazard for humans.

The results can be used for predicting the geochemical migration of heavy metals in soils as technogenic consequences of disasters caused by pyrogenic factors.

Developing LCD for most microelements (Buts et al., 2018), both necessary for normal viability and growth of plants and heavy metals which can have a toxic effect allows one to predict their migrational ability or ability to accumulate. The range of maximum settlement of poorly-soluble hydroxides is summarised in Fig. 4 Also, we indicated the conditions, in which the heavy metals would have the least solubility in the soil environment, i.e. the conditions, in which their accumulation is the most possible.

In acidic environments (Fig. 4, 5), the solution has ions of Me^{z+}or particles of the type $[Me(OH)_{(z-1)}^{+}]$, in alkaline environments – $[Me(OH)_n^{z-}]$. In acidic soil (4.5 <pH <5.8), all metals, except Fe(II), are present in soluble form and easily migrate and accumulate in plants.

Increase in pH contributes to the fixation of Cd, Co, Mg, Fe(II), Fe(III), Mn, Ni. (Buts et al., 2018).

Conclusions. We found post-pyrogenic changes in physical-chemical parameters of grey forest podzolic soils, which could be considered not only their response to the pyrogenic impact, but a clear signal which reflects the condition of soils both straight after the fire, including extent and intensity, and after a certain period of time. Therefore, there was seen a particular dependence of the extent of pyrogenicity on the age of impact of the fire on the soil. The impact of a fire of average intensity which took place not long ago on grey forest podzolic soils was seen in a clearly manifested reaction of the entire complex of its properties. The soil in the area burned 5 years ago had lower reaction of the studied parameters. If no fire recurs, in 10 years, no signs of pyrogenic impact will be found in the soils.

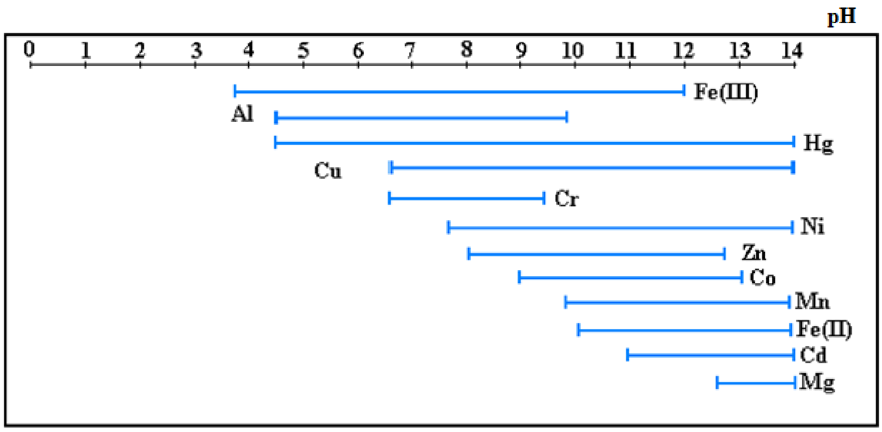

Fig. 4. Range of maximum settlement of hydroxides or hydroxocomplexes of chemical elements

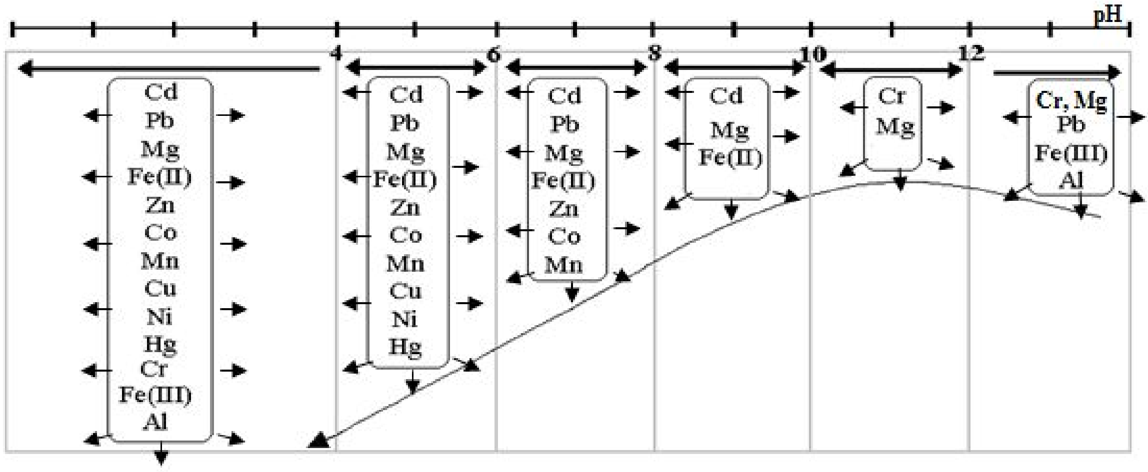

Fig. 5. Migration of the compounds of chemical elements to the environment during changes of pH of soil as a result of fire

Physical-chemical parameters of grey forest podzolic soils after fire decrease because the amount of nutrients in soil decreases: humus burns out, the content of nitrate nitrogen diminishes. The fires, on the one hand, facilitate the penetration of seeds into the soil, but worsen the conditions for growth and development of pines. The content of humus in the upper layer (0-15 cm) of grey forest podzolic soils after a ground fire reduces due to combustion of organic compounds in the upper soil horizon.

Ground forest fires rapidly change the morphological type of the upper part of the soil column. As a result, the pattern of the upper soil horizons changes, in particular, often a new pyrogenic horizon forms, which in its physical-chemical properties and the content of ash elements differs from the natural analogues. The fire causes changes in such properties as: pH, content of exchangeable cations, total and mobile forms of nitrogen, etc. However, it should be taken into account that the behaviour and content of HM in studied soils can be conditioned, apart from the impact of fire, also by geochemical conditions in the region - speed of water migration and biological consumption, relief of the area.

Concentration of HM in the upper soil horizons of pine forest terraces increases several times and exceeds the control parameters due to the mineralization of forest litter and herbaceous vegetation caused by combustion and further migration of chemical elements, causing an ecological hazard.

Further study on the changes in the properties of soils caused by the pyrogenic factor has a significant theoretic and practical significance for developing scientific approaches to recovering ecogeosystems after the fires.

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