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Monitoring Humus Content of Chernozems (Black Soils) and Soil Water Pollution Rate in the Pre-Ural Forest-Steppe of the Republic of Bashkortostan

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Abstract: The current state of the anthropogenically transformed chernozems was monitored. The study was conducted in the forest-steppe of the Bashkir Pre-Urals. The monitoring has revealed worse soil fertility, which in turn negatively affects the environment, causing water pollution as a result of the anthropogenic transformation of black soils. The paper presents monitoring results of humus content in the chernozem (black soil) transformed under anthropogenic impacts for 1965-2016. The study data demonstrates that a single lifting of planting material results in the total of carbon removed from the soil in different soil subtypes and different strata within the range of 198 to 839 kg and over per each million of seedlings. These processes bring about a significant reduction in soil organic matter, depletion of nutrients. Application of pesticides and other chemical treatment practices have a negative effect on the quality of soil water. To improve the situation it is necessary to apply grass arable rotation methods as well as phyto-reclamation practices combined with a science-based system of fertilizers.

Key words: Soil water pollution, ecology, monitoring, rhizospheric soil, humus, organic matter, soil texture, mineral nutrients, green manure.

Introduction

Evolution of soils and soil cover is based on active anthropogenesis. The process results in changes in natural ecosystems and largely depends on the character of anthropogenic impacts, characteristics of the ecosystem properties, and their resistance to different impacts.

Soil fertility is known to be associated with the content of humus in soil. Soil humus is the basis of soil biology, absorption capacity and biological activity of soils (Kashtanov, 2000).

Many years' experience shows that the use of pesticides in the world is an integral part of modern crop growing technology. It is impossible to produce the necessary foods for the population without pesticide application. The potential to migrate in the soil profile and thus pose a risk of groundwater pollution is an important environmental feature of pesticides. The ill-considered anthropogenic impacts and disrupted balance of natural environmental links in the soils result in negative humus mineralization processes, increased acidity or alkalinity, faster salinity accumulation and strengthened restoration processes. All of the processes worsen soil properties and may bring about local degradation of soil cover in extreme cases. High sensitivity and vulnerability of the soil cover are due to the limited buffering and low resistance of the soil to

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environmentally unfriendly impacts. It takes a long time and large investments to restore the disturbed soil cover.

In terms of environmental effect, humus acts as a source of non-polluting and rationally balanced nutrients (Kumari and Ravindhranath, 2018). Energy accumulated in both fine grained soil and organic matter (humus as an integral part of organic matter) is the basis of the potential soil fertility. About 4.106-26.106 kcal/ha of energy is found to enter the soil with dead organic matter.

Arable farming results in lower humus content, which, in turn, affects the hydrophilic-to-hydrophobic volume ratio. Lower hydrophobic rate of humus is associated with larger share of hydrophilic fractions, increases the humus migration ability, and affects the structurization potential, which, in turn, tends to change the total of physical properties of soil and results in worse soil fertility (Dostova, 2015).

Soil fertility in Tyumen region demonstrates a positive trend (mainly because unproductive soils were taken out of rotation). At the same time, as one of the major objectives is obtaining higher yields, application of insufficient amounts of mineral and organic fertilizers that do not provide a positive balance of mineral nutrients, may bring about worse fertility rates of arable soils in the future (Kotchenko and Voronin, 2016).

Regions that experienced significant changes in soil cover due to anthropogenic activity should have reference soils picked out within small natural sanctuaries. The reference soils might serve as baseline variants to be compared with contaminated and degraded soils. The main trends of natural evolutionary processes involved in anthropogenic-industrial changes in the study soils may be thus established through the monitoring (Chernova and Bezuglova, 2016).

Discrepancy between the values of the lithogenic potential of humus accumulation and the actual humus content in soils was revealed in the soils of the Turano-Uyuk basin. The difference was due to the soil texture features and particular organic matter decomposition processes in cryogenic conditions. To eliminate or minimize the impact of the main degradation factor, deflation, especially in chernozems, it is necessary to carefully design and arrange protective forest belts (Domozhakova and Sokolov, 2016).

There is a stable dependence between the humus content in the top soil of leached Chernozem and the balance value. This relationship enables the change of the soil fertility index to be predicted in the grain crop rotation (Kulikova et al., 2017).

Relationships between humus and soil functions were studied. Tasmanian soils were studied for relationships between the organic carbon of the soil and other inherent dynamic properties of the soils, among the soil carbon reserves, components and controlling factors. The dynamic nature of soil organic matter is considered as a target index, the change rates and trends on different soil orders and under different management, as well as correlation with the physical, chemical and biological properties of the soil (Cotching, 2018).

As the ability of the soil to recover from disturbances is important for the proper functioning of agroecosystems, the effect of physical resilience in subtropical soils due to the organic matter content, texture and mineralogy was studied (de Andrade Bonetti et al., 2017). Both undisturbed soil core and disturbed soil samples were taken from two depths from three soils under no-tillage in long-term field experiments: two Oxisols and one Ultisol. Soil core samples were subjected to wetting-drying cycles and the soil physical attributes (bulk density, total porosity, macro- and micro-porosity, and air permeability) were identified before and after soil compaction or wet-dry cycles. Organic matter and clay contents were greater in the Oxisols, with iron oxides, reducing the stress level (de Andrade Bonetti et al., 2017).

Soil organic matter is an important component of soil that controls Se bioavailability. Organic matter can immobilize Se by both biotic and abiotic mechanisms as well as reduce its bioavailability. The release of organic matter-immobilized Se through mineralization should not be overlooked. Soil organic amendments also have diverse effects on Se bioavailability (Li et al., 2017; Ermakov, 2017).

Humus is the most important natural resource of our planet. Humus has similar, worldwide characteristics, but varies with abiotic controls, soil type, vegetation inputs and composition, and the soil biota (Eldor, 2016). It contains carbohydrates, proteins, lipids, phenol-aromatics, protein-derived and cyclic nitrogenous compounds, and some still unknown compounds. Protection of transformed plant residues and microbial products occurs through spatial inaccessibility-resource availability, aggregation of mineral and organic constituents, and interactions with sesquioxides, cations, silts, and clays. The concepts discussed in the study have implications for today's challenges in nutrient cycling, biogeochemistry, soil ecosystem functioning, pollution control, feeding the expanding global population and global change (Eldor, 2016).

Soil organic matter was closely associated with soil quality, but cultivation generally caused a decline in soil organic matter, reducing soil quality and releasing carbon dioxide into the atmosphere (Swanepoel et al., 2016). Internationally, countries are expected to reduce their greenhouse gas (GHG) emissions, and compile and update GHG inventories. Carbon sequestration and greenhouse gases emission dynamics under various management systems and for different climatic regions, as well as how field crop production can play a role in mitigating climate change, are poorly understood. Intensified monitoring by multi-institutional collaboration is recommended to address this issue.

Studies showed that humic substances in soil organic matter are important for soil stability and soil ecosystem services (Schaeffer et al., 2015). These studies reviewed opinions on soil organic matter and humic substances that are nowadays considered not to differ in molecular diversity. Methodological approaches to characterize relevant structural and mechanistic pictures of soil organic matter such as the priming effect, clay mineral catalysed reactions and the various mechanisms by which natural and xenobiotic chemicals are protected in soil are briefly illustrated by examples. As it was found, the soil organic matter (de)stabilization can cause a subsequent release and mobilization of nutrients from the soil organic matter (Vodyanitskii, 2015).

Thus, the soil organic matter is one of the main factors impacting soil fertility. This is why researchers, farmers and foresters focus their attention on humus. Recently, the interest in humus has increased dramatically due to intensive soil damaging, which resulted in higher rates of soil degradation, dehumification in particular.

Soil dehumification is caused by the following factors: disturbed balance (biological cycle) of mineral and organic substances in soil due to losses, without appropriate replenishment; organic matter dissolved and removed with surface and soil waters as a result of deflation and harvesting practices; insufficient application of organic and mineral fertilizers; insufficient monitoring of soil cover; water and wind erosion of soils; disruptions in agrotechnical soil conservation tillage methods (dry soil tillage, poor crop rotation practices); waterlogging and secondary salinization of soils in irrigated areas due to the rising soil and ground water and accidents on main pipelines; and mechanical effect of heavy machinery. For the past decades researchers have drawn their attention to the state of humus in chernozems (black soils) in terms of degradative dehumification of chernozems. The problem of the decreased humus reserves in black soils is often considered a national ecological disaster. It is known that chernozems that used to have larger humus volumes are losing humus to a much greater extent than humus poor subtypes. As the content of organic matter in soils decreases, the dehumification rate decreases.

The major objectives of agrarian science and agricultural production are prevention of humus losses in soils, humus reserve replenishment, humus content stabilization and improving humus quality. The aim of the study was to analyse monitoring results on humus content of the homogeneous layer of agricultural chernozems and reveal causes of black soil degradation under anthropogenic impacts.

The desire to get the maximum from the soil led to degradation of the soil composition. The monitoring addressed the following points: humus change rate (the rate might be different depending on the properties of the soil – the initial content of humus, particle size distribution – soil texture, etc.), range, age, number of varieties grown (the amount of the parted biomass and rhizospheric fine-grained soil), the technology used and agricultural practices (crop rotation, green manure cropping, number of tillage practices, irrigation, etc.) and frequency and dose of organic and mineral fertilizers applied.

Humus is the main source of energy. It is essential in soil formation processes, especially in the biochemical transformation of organic matter in the soil and in ensuring the life of soil microorganisms (Churagulova, 2003; Ishbulatov et al., 2011).

Studies aimed at analysing anthropogenic effects on ecosystems which have always remained relevant. Therefore, the results of monitoring humus of agricultural black soils were studied, and the main causes behind the soil degradation due to anthropogenic impacts were revealed.

Methods

Development of methods and techniques of soil conservation as well as up-to-date forecasts of changes in soils under either anthropogenic impacts or climatic or environmental changes should be based on both soil organic matter losses and mechanisms involved in the losses and assessed using various methods (Orlov et al., 1996).

Our research considered studies performed on the basis of standard guidelines in soil science and agricultural chemistry. All agrochemical laboratory tests were done in the republican forest-soil chemical laboratory under the Ministry of Forestry of the

Republic of Bashkortostan, Russia. Researchers of the real estate cadastre and geodesy department participated in the study. The study was based on the findings of the thorough soil and agrochemical monitoring. Trace elements are known to play an important role in the growth and development of plants. However, some of them are dangerous pollutants of the environment. These are heavy metals—copper, zinc, nickel, lead, cadmium, cobalt, chromium, molybdenum and mercury. Soils of the baseline and transformed plots were analysed for trace elements. The analysis evaluated the extent to which the environment, food resources and agricultural products were polluted with heavy metals. Biometric indices of plants and analytical data of soils were processed using variation-statistical methods (Arinushkina, 1961; Shyshov et al., 2004).

The changes in soil properties under anthropogenic factors were studied in four permanent monitoring study areas. All of the agricultural practices involved in the study were carried out at a high agrotechnical level. The research objects were soils and standard seedlings grown in the following four nurseries of the state public institution of the Republic of Bashkortostan 'Forestry management' using data of soil and agrochemical studies:

1. Tolbazinskiy plot in Sterlitamak forest area (sector No. 69; 4 km from Tolbazy village in the southwest, the total area of 8 hectares).
2. Chishminskiy plot in Ufa forest area (sector No. 43; 3.5 km from the railway station of Chishmy to the West; 0.9 km from the village of Irik to the North, the total area of 20 hectares).
3. Buzdyakskiy plot in Tuimazy forest area (500 m from Buzdyak village to the East, the total area of 6.6 hectares).
4. Alsheevvskiy plot in Belebey forest area (sector no. 81; 12 km from Raevka railway station to the south-east, the total area of 4 hectares).

Seedling nurseries typically use heavy farm machinery, so the soil is subjected to intensive mechanical tillage: levelling, plowing, cultivation, mulching, lifting of the planting material, etc. (Mudarisov et al., 2017; Aipov et al., 2018). Moreover, the practices imply removing rhizosphere, fine-grained soil rich in humus, enzymes and microorganisms, from the soil i.e. removing the most biologically active root soil and mineral nutrients.

Results and Discussion

The study results have shown that under the anthropogenic impact the topsoil underwent significant changes in humus. Humus content stands as the main index of soil fertility.

Soil is one of the most conservative components in the biosphere, the most static component, so it tends to restore slowly. Fertilizers and pesticides applied in farming deteriorate the physical and chemical properties of the soil and its absorption capacity. Xenobiotics that get to the surface waters from the soil adversely affect living organisms.

The study identified and described chernozems (black soils) that belong to the humus accumulative group of the post-lithogenic soil formation class. They formed on the quaternary deluvial carbonate loams and clays. The study chernozems were distinguished by dark humus horizon in the profile. The dark humus horizon formed in the upper part of the humus horizon of natural soils through replacement of phytocenoses with cultivated vegetation, i.e. after about 50 years of agricultural use.

The following dominant subtypes of agricultural black soils were studied:

- Black soils of clay-illuvial, podsolized, medium-power, high-humus content, clay type. Genetic horizons represented by the following formula—PU-AU-AUe-B1-C (Tolbazinskiy plot).
- Black soils of clay-illuvial, podsolized, medium power, heavy clay-loam type. Genetic formula—PU-AU-B1-C(ca) (Chishminskiy plot).
- Black soils of clay-illuvial, orthic, leached, medium-power, heavy clay-loam type. Genetic formula—PU-AU-B1-C(ca) (Alsheevskiy plot).
- Black soils of migrational mycelial, orthic, carbonated, medium-power, heavy clay-loam type. Genetic formula—PU-AU-BCA-C(ca) (Buzdyakskiy plot).

Ecological and forestry indices and yields of coniferous and deciduous seedlings per unit area (Table 1) were studied.

Table 2 and Figure 1 present data on the total of nutrients removed from soil with coniferous and deciduous seedlings and the soil removed from nurseries together with the seedlings. It was found that the total removed with 1.5 million 2-year-old seedlings of Scots pine was: 12.1 t of soil mass, 2.46 t/ha of organic matter, 1446 kg of humus, 839 kg of carbon, 7.2 kg of gross nitrogen, 24.5 kg of phosphorus and 201.6 kg/ha of potassium. The total of soil components removed from the soil with one million of 1.5-year-old seedlings of European white birch was in the same range.

Changes of humus in soils were revealed based on statistically significant data. They were obtained through

Table 1: Ecological and forestry indices and yields of coniferous and deciduous seedlings

Species	*Age, years*	*Ecological and forestry indices*		*Seedling yield, mln pcs per ha*
		Seedling height, cm	*Diameter of root neck, mm*	
Black soils of clay-illuvial, podzolized, medium-power, high humus content, heavy clay-loam type (Tolbazinskiy nursery)				
Blue spruce (*Piceapungens* Engelm)	3.0	14.92±0.02	2.8±0.04	1.41
Siberian spruce (*Piceaobovata* Ldb.)	3.0	15.08±0.04	3.27±0.	1.62
Scots pine (*Pinussylvestris* L.)	2.0	16.98±0.02	3.26±0.03	1.40
Small-leaved linden (*Tiliacordata* Mill.)	2.0	16.8±0.06	2.9±0.02	0.50
European Oak (*Quercusrobur* L.)	1.0	21.0±0.04	3.1±0.05	0.52
Black soils of clay-illuvial, podzolized, medium-power, medium humus content, heavy clay-loam type (Chishminskiy nursery)				
Sukachev's larch (*Larixsukaczewii* Dyl)	2.0	23.3±0.02	2.9 ±0.03	0.80
European white birch (*Betulapendula* Roth.)	1.5	31.1±0.03	4.5±0.05	0.48
Black soils of clay-illuvial, orthic, leached, medium power, high humus content, heavy clay-loam type (Alsheevskiy nursery)				
European white birch (*Betulapendula* Roth.)	1.5	28.5±0.05	3.0±0.04	0.45
European oak (*Quercusrobur* L.)	1.0	19.3±0.05	3.5±0.06	0.70

Note: The seedlings were registered at the end of the growing season.

Table 2: Fine-grained humic soil (rhizosphere), organic matter, humus, total nitrogen, phosphorus and potassium removed from the soil with seedlings of woody plants (Churagulova, 2003)

Seedlings, age	*Rhizospheric soil*	*Soil organic matter*	*Humus*	*Carbon*	*Nitrogen*	*Phosphorus*	*Potassium*
	t/ha		*kg/ha*				
Pine, 2-year old	12.1	2.46	1446	839	76.2	24.5	201.6
Spruce, 2-year old	9.7	1.65	946	549	55.7	18.2	152.1
Spruce, 3-year old	9.3	4.84	342	198	32.6	15.6	186
Larch, 2-year old	9.6	2.44	1143	663	60.2	19.4	159.4
Birch, 2-year old	11.8	8.11	1404	814	73.9	23.8	195.8
Linden, 2-year old	7.8	2.5	928	538	48.9	15.8	129.5
Oak, 1-year old	5.1	2.4	607	352	31.9	10.3	84.5

Note: The amount removed from the soil was determined based on 1.0 million pcs/ha of birch, linden, oak seedlings grown and on 1.5 million pcs/ha of spruce, pine and larch seedlings.

direct comparison of humus content determined at various times (Figure 2).

The starting period of nurseries saw a general downward tendency in humus content. However, after reaching certain values, humus content values tend to stabilize, and subsequently may increase. The changes take the form of oscillations. The study showed that the rate of change was also subject to significant fluctuations: the black soils of clay-illuvial, podsolized, medium power, high humus content, heavy clay-loam type (Tolbazinskiy nursery) saw a decrease of 0.34% in humus volume per year, then its increase of 0.15% and a

Figure 1: Rhizospheric soil removed with one-year seedlings of Sukachev's larch (*Larixsukaczewii* Dyl) in the greenhouse, the control is presented on the right.

new decrease of 0.08% and an increase of 0.03% at the end of the study period. The black soils of migrational mycelial, orthic, carbonated, medium power, medium humus content, medium clay-loam type (Buzdyakskiy nursery) saw a decrease in humus during the first two periods at the rate of 0.10-0.06% per year, then a significant increase of 0.125%, a decrease of 0.22% and a significant decrease of 0.13% per year during the last observation period.

The sharp fluctuations in values are associated with the formation and functioning of the black soil subtypes under different conditions for different agricultural purposes, the use of different technologies, and the amount of organic substances removed with the rhizosphere and the plants in lifting of planting material.

The following processes can explain significant downward changes in humus: after plowing natural grasslands (virgin soil), conditions were created

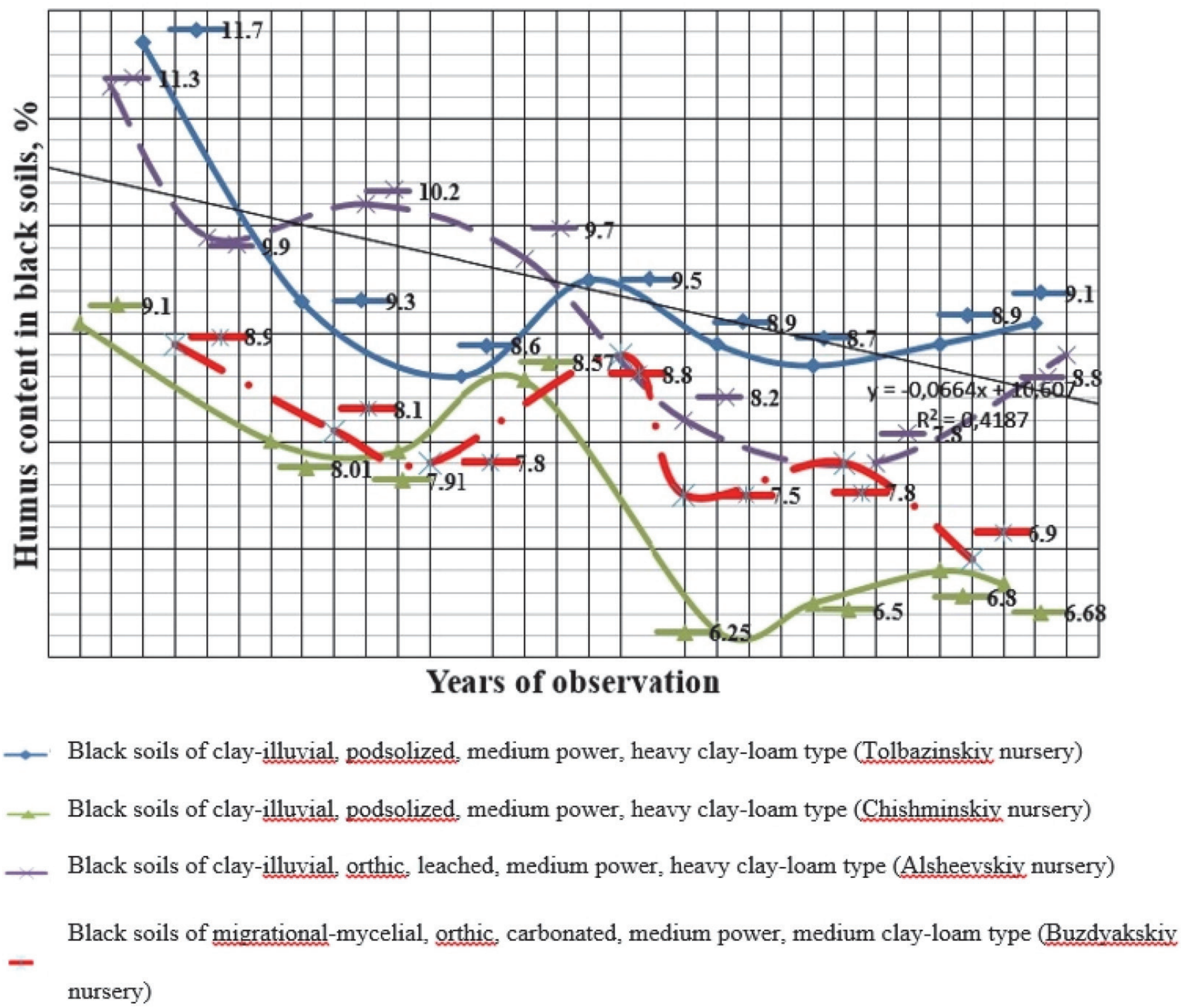

Figure 2: Dynamics of humus in topsoil.

for intensive mineralization of soil organic matter. Then, growing of plantings and seedlings resulted in nutrients and root soil intensively removed from the soil. Subsequently, the nurseries grew seedlings using irrigation practices.

Thus, growing planting material implies that a significant amount of root soil, rhizospheric fine-grained soil rich in humus, enzymes and microorganisms, i.e. the most biologically active basal soil and elements of mineral nutrition, is taken out from the nurseries. At the same time quantitative indices differ depending on the soil types and subtypes and soil texture. Coniferous and deciduous 1-year and 2-3-year-old seedlings remove different amounts of biomass and mineral nutrients from the soil.

The study data demonstrate that a single lifting of planting material results in the total of carbon removed (with phytomass and rhizospheric soil) in different soil subtypes and different strata ranging from 198 to 839 kg and over per each million of seedlings. Multiple repetition of the procedure in nurseries leads to significant losses of soil organic matter, depletion of nutrients.

Conclusions

Increased agricultural production tends to significantly change the economic and biological cycle of substances and as a result intensifies environmental issues related to functioning of agroecosystems, of surface and groundwater in particular. Water resources suffer from both toxic contamination and enhanced eutrophication. Since farming stands as a factor and a participant in the eutrophication processes, it may face an extremely harsh situation associated with water supply of residential areas, livestock complexes and irrigated areas. It is time to seriously address the issues of soil and water protection and take appropriate measures, eliminate implications of the technological advancement. We cannot rely on self-purification capacity of water any more: as the process takes too long.

Thus, the study revealed a decrease in humus in agricultural chernozems (black soils). The trend of degradation continues to exist. It is recommended that organic fertilizers be applied to enrich the soil with organic matter, elements of mineral nutrition, microorganisms, and biologically active substances—enzymes. Currently the region experiences a shortage of manure (decomposed organic feritlizer), i.e. animal waste on the farms. The following rates of organic mineral fertilizers should be applied for the entire period of growing seedlings in grass arable rotation given the soil contains the average humus rates: organic fertilizers, compost in particular—30-50 t/ha, nitrogen fertilizers—80-100 kg/ha per active substance.

Intensity and tendencies of anthropogenic processes in cultivated black soils were studied and assessed. The need to prevent negative phenomena was recognized. Grass crop rotation practices, rational selection of tree species and shrubs were found to optimize the properties of forest growing.

The comprehensive study of humus in black soils identified causes, trends and quantitative indices of inter-temporal changes. The findings contribute significantly to the development of the theoretical grounds for modelling soil behaviour under anthropogenic impacts and to the study of relationships within the 'plant-soil-plant' system.

The worsened state of humus adversely affects the quantitative and qualitative indices related to the yield of planting material, reproduced products and crop yields, including mainly industrial crops.

Soil is a biological agent for absorbing, destroying and neutralizing different contaminations. Soil contains half of all known microorganisms. Soil degradation results in irreversible changes of the cycle in the biosphere. These changes are not always positive. The in-depth study of the current state of agricultural chernozems (black soils) and objective assessment of the functioning processes may serve as the basis for ensuring food security and development of resource-saving technologies.

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