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ECOLOGY

INFLUENCE OF OIL POLLUTION ON VARIOUS TYPES OF SOIL

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The impact of oil pollution on the physicochemical properties of various types of arid-land zonal soils and their ability for self-purification are evaluated. A vegetation experiment based on bioindication principles concerning the reaction of crops to an oil-contaminated environment indicated that crops with varying sensitivities can sprout and grow on oil-contaminated soils.
***Keywords**: oil and oil products, zonal soils, oil contaminants.*

The petroleum industry is the main factor behind global disturbances of many natural components such as the earth and atmosphere, relief and soil, surface and groundwater, and flora and fauna. Oil-polluted soils and ground are hazardous to the environment. The scale and toxicity of oil pollution represent a global hazard and are second only to radioactive contamination with respect to degree of environmental hazard [1]. Oil and oil products can poison and kill organisms and degrade soils. Soil pollution by oil is one of the most dangerous natural consequences of human activity because oil recovery is associated with destruction and pollution of not only the oil fields but also agricultural and forest lands adjacent to them [2]. Destroyed lands lose their agricultural value. The soil profile is transformed. The morphological and chemical properties of the soil are altered.

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Soil composition is very significant for cultivating crops that rely on the soil containing all essential macro- and microelements. The soil humus composition is changed by oil so that the soil becomes a poorer nutritious substrate for plants. Hydrophobic oil-product particles hinder access of moisture and oxygen to the roots [3]. Numerous studies found that soil (1 kg) contained bacteria (10^9) and microbes (10^{10}). Their numbers change because of oil pollution. The complex of soil microorganisms is deeply disturbed [4]. The condition of the polluted soil is aggravated by the fact that it is less mobile and lacks a natural cleansing factor such as dilution so that anthropogenic pollution that falls on the soil is accumulated and its effects, summed [5]. Oil pollution results eventually in the formation of unusual natural complexes for the zonal conditions. Populations of certain plant species and animal communities disappear. The plant species diversity decreases [6]. Currently in Russia, the approximate allowable amount of oil in soil is set at 1 g/kg [7].

Environmental problems of oil fields are caused by human economic activity, including the development of the oil and gas refining industry and hydrocarbon feedstock processing. Therefore, studies of the effects of oil pollution on the soil and crops are relevant.

The goal of the research was to assess comprehensively the effects of oil pollution on the physicochemical properties of various types of soil and crop development.

The experiment spanned 2007-2015 and used lysimetric plastic vessels of area 0.25×0.25 m in triplicate using the methods of Dospekhov (1985), Moiseichenko et al. (1996), and Molostov (1966) [9-11]. One vessel of each soil type acted as a control (without contamination). The three other vessels were treated with oil (2.5, 5, and 10 L/m^2). Oil for the tests was obtained locally [12].

Zonal soils from the Russian semi-arid zone (light-chestnut, light-chestnut sodic, floodplain, brown semi-arid, alluvial) were investigated.

Soil samples were analyzed for oil-product content using IR spectrometry (IRAffinity-1). The soil chemical properties were analyzed for cation-exchange capacity (mg-eq/100 g) and aqueous pH value. Soil physical properties were analyzed for bulk weight, specific weight of the soil solids, and porosity [13]. Table 1 presents the results.

Monitoring of changes in the total oil hydrocarbon contents of the soils found that their contents at an oil dose of 2.5 L/m^2 were highest (0.58-0.6 g/kg, 2010) in samples of light-chestnut and light-chestnut sodic soils. The values were much less for alluvial, brown, and floodplain soils and varied from 0.3 to 0.32 g/kg. The oil hydrocarbon contents of all types of soil decreased to 0.3 g/kg by the end of the test (2015) with the lowest amount in brown soil (0.17 g/kg).

Oil hydrocarbons also declined considerably during the study at oil doses of 5 and 10 L/m^2.

Three years after the start of the tests, the lowest hydrocarbon contents in soil samples with an oil dose of 5 L/m^2 were recorded in brown (sandy loam) (4.3 g/kg), floodplain (light loam) (4.8 g/kg), and alluvial soils (light loam) (4.9 g/kg).

The highest oil hydrocarbon contents at an oil dose of 10 L/m^2 were observed in light-chestnut (13.8 g/kg) and light-chestnut sodic soils (11.4 g/kg).

Eight years into the test (2015), the contents of oil hydrocarbons in samples with an oil dose of 5 L/m^2 decreased considerably for all soils (brown, 1.08; floodplain, 1.2; alluvial, 1.23 g/kg). The hydrocarbon contents in light-chestnut and light-chestnut sodic soils decreased to 1.45 and 1.53 g/kg. The contents of total oil hydrocarbons at an oil dose of 10 L/m^2 also decreased considerably in all studied soils. Their contents in floodplain soil were 1.58; brown, 1.7; alluvial, 1.95; light-chestnut sodic, 2.85; and light-chestnut, 3.45 g/kg.

Table 1

Soil type	Oil dose, L/m^2	Wheat				Rye				Perennial grasses	
		germination rate, %	morphological characteristics: shoot length, cm	morphological characteristics: root length, cm	vegetative mass (straw), kg/m^2	germination rate, %	morphological characteristics: shoot length, cm	morphological characteristics: root length, cm	vegetative mass (straw), kg/m^2	germination rate, %	vegetative mass (straw), kg/m^2
Floodplain	control	66	40.11	12.70	0.077	70	61.6	12.80	0.082	26	0.048
	2.5	91	23.70	9.00	0.050	75	85.3	13.80	0.061	53	0.024
	5.0	66	26.22	11.23	0.021	70	33.4	10.20	0.037	23	0.017
	10.0	43	14.16	9.00	0.006	50	15.0	9.00	0.019	13	0.009
$LSD_{05\ (abs)}$	—	—	—	—	0.005	—	—	—	0.007	—	0.004
Light-chestnut	control	75	35.29	11.70	0.090	45	52.2	12.50	0.090	20	0.052
	2.5	66	27.20	8.50	0.041	35	59.3	12.70	0.058	40	0.036
	5.0	58	15.26	10.12	0.022	30	35.0	9.50	0.027	23	0.025
	10.0	66	13.80	8.00	0.007	30	10.5	6.40	0.018	40	0.018
$LSD_{05\ (abs}$	—	—	—	—	0.007	—	—	—	0.006	—	0.007
Light-chestnut sodic	control	91	30.80	10.47	0.079	50	80.0	14.50	0.088	43	0.049
	2.5	50	26.60	9.00	0.060	40	84.0	16.00	0.064	13	0.030
	5.0	40	19.00	9.00	0.022	50	25.7	9.25	0.029	46	0.019
	10.0	41	21.13	11.00	0.007	35	11.3	6.54	0.016	36	0.013
$LSD_{05\ (abs}$	—	—	—	—	0.009	—	—	—	0.006	—	0.004
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*

(to be continued)

Table 1 (continued)

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Brown	control	83	29.25	11.07	0.076	60	57.3	10.70	0.088	40	0.050
	2.5	75	22.24	11.17	0.059	65	37.4	9.90	0.054	20	0.040
	5.0	66	12.50	7.25	0.024	65	36.3	9.00	0.028	26	0.023
	10.0	33	18.12	8.00	0.006	40	12.7	6.60	0.016	13	0.008
$LSD_{05\,(abs)}$	—	—	—	—	0.005	—	—	—	0.006	—	0.005
Alluvial	control	53	13.50	7.12	0.079	55	61.0	11.25	0.083	23	0.048
	2.5	58	30.00	11.00	0.047	40	57.1	10.20	0.048	23	0.032
	5.0	41	21.37	10.05	0.022	35	47.2	9.20	0.022	16	0.018
	10.0	33	19.15	9.15	0.007	40	11.3	6.25	0.016	20	0.008
$LSD_{05\,(abs)}$	—	—	—	—	0.006	—	—	—	0.002	—	0.003

The experimental results established that brown soils in addition to floodplain and alluvial soils were more resistant to oil pollution. These soils had enough buffering capacity to cope with the pollution and self-repair over time.

Light-chestnut (heavy loam) and light-chestnut sodic soils (medium loam) had heavy compositions, insufficient access to oxygen, and low microbiological activity. Therefore, their capability for self-repair was less and dropped sharply with increasing oil pollution.

Analyses of the chemical properties of the studied soils showed that the cation-exchange capacity changed substantially at an oil dose of 2.5 L/m^2 on floodplain soil by 8.72; on brown, by 7.8 mg-eq/100 g. The changes were insignificant on light-chestnut, light-chestnut sodic, and alluvial soils.

The greatest change of cation-exchange capacity was observed in brown soil at an oil dose of 5 L/m^2 (10.03 mg-eq/100 g). The values increased at an oil dose of 10 L/m^2 from 11.53 mg-eq/100 g in 2010 to 24.32 mg-eq/100 g in 2015.

The carbon content increased significantly in all studied soils during self-repair. The increase averaged 1.5 times at an oil dose of 2.5 L/m^2. The pH values in all studied soils were practically constant and varied on the average from 7.3 to 7.8.

Physical properties of the soils were analyzed to show that the soil specific weight decreased in light-chestnut and light-chestnut sodic soils by 0.01-0.02 g at an oil dose of 10 L/m^2. The changes were insignificant in these soil types at lower doses (2.5 and 5 L/m^2). The specific weight was practically constant for floodplain, brown, and alluvial soils. The specific weight of the soil solids decreased sharply at an oil dose of 10 L/m^2 in light-chestnut and light-chestnut sodic soils. This parameter decreased insignificantly for all other soil types at all pollution levels. The porosity increased by 2.3% compared with the control in light-chestnut sodic soil at oil doses 2.5 and 5 L/m^2. The porosity of the other soil types decreased by an average of 1-1.5%. Thus, it was noteworthy that all chemical and physical properties of the soils were changed to one extent or another.

Plants are an equally important component of any ecosystem. They are the main producers that assimilate solar energy and transform it into complex organic compounds. Plants provide bases for food chains, dominate any landscape, and experience the effects of industrial pollution earlier than organisms located at higher trophic levels. Plants characterize best their local habitat because of their sessile life style. This is highly valuable because of the uneven distribution of industrial pollution [5, 6, 14, 15].

Vegetative experiments were carried out to provide a biological indication of changes of oil-polluted soil functional properties using crops with different sensitivities to unfavorable environmental factors. Cereals (wheat, rye, barley) and perennial grasses were cultivated in triplicate on clean and oil-polluted soils (2.5, 5, 10 L/m^2). Mineral fertilizers were applied to all vegetative vessels before sowing. Plants were additionally watered during vegetation so that the humidity in the vessels was at 70 % of the lowest moisture capacity. Reactions of plants to oil pollution of the soils were assessed visually during vegetation and also from the obtained biomass.

According to the results, mineral elements were less available to plants in oil-polluted soils because of their immobilization by microorganisms due to a high C/N ratio, coating of soil particles with oil, prevention of the dissolution of mobile species, and negative effects of oil on bacteria involved in the soil nitrogen cycle [16-18]. Several studies noted that plants growing on soils with oil bitumen were extensively damaged by pests causing gallogenesis [19]. According to others, the population of phytopathogenic micromycetes increased in soil affected by petrochemical emissions [20]. The number of soil fungi producing toxins that suppress and kill plants increased with oil pollution [21-23]. As a rule, even low soil concentrations of oil and oil products can cause plants to falter and die. According to some reports, all herbaceous plants perished at a leakage volume of 1.1 L/m^2, i.e., with an oil content of 0.5% in a 15-cm soil layer. Plants usually stop growing with a soil oil content of 3500 mg/kg of soil (0.35%). It was found that seed germination was not inhibited even with a soil oil concentration of 0.37 g/kg although the accumulation of aerial biomass decreased [24].

The duration of soil oil-pollution effects on plants is another important feature because of the slow self-cleaning of contaminated soils. Several studies found that the restoration period for plants with high oil pollution could be 10-20 years and more. The survivability of plants on contaminated soils depended on the depth of the roots, replacement rate of leaves falling because of the pollution, and presence of underground protective organs or stems (rhizomes) [25-27].

Our tests on zonal soil types found that oil pollution slowed cereal growth and development. Wheat germination on light-chestnut sodic soil fell from 44 to 56%; brown, from 10 to 40%, as the oil-pollution dose was increased. Developmental delay was observed during the seedling-to-tillering and tillering-to-booting phases, when intensive growth and generative organ formation occur, especially in brown and alluvial soils at oil doses of 2.5 and 5 L/m^2. Spikes did not form on all soil types at oil doses of 5 and 10 L/m^2. Morphological features of the cereal crops such as root and stem length varied depending on the oil dose and soil type. Growth was inhibited on all soil types. The highest wheat yield at an oil dose of 2.5 L/m^2 was obtained on light-chestnut sodic (0.06 kg/m^2) and brown soils (0.059 kg/m^2); at an oil dose of 5 L/m^2, on brown soil (0.024 kg/m^2); and at an oil dose of 10 L/m^2, <0.006-0.007 kg/m^2 on all soil types (Table 1).

Rye gave the greatest yield at an oil dose of 2.5 L/m^2 on light-chestnut sodic soil (0.064 kg/m^2); at an oil dose of 5.0 L/m^2, on floodplain soil (0.037 kg/m^2) and light-chestnut sodic (0.029 kg/m^2). The yield deviated most from the control (54.8-73.4%) on alluvial, light-chestnut, and light-chestnut sodic soils at an oil dose of 5 L/m^2. The yield at an oil dose of 10 L/m^2 was greater on floodplain soil (0.019 kg/m^2) than on the other soils where it varied from 0.016 to 0.018 kg/m^2. The yield deviated from the controls by 78.0-81.8%. Barley did not give a yield on any test soil.

The biological indication properties of perennial grasses growing on oil-polluted soil showed that the percent germination was highest on floodplain (53%) and light-chestnut soils (40%) at an oil dose of 2.5 L/m^2. Germination was lowest at an oil dose of 2.5 L/m^2 in light-chestnut sodic soil (13%). Germination in this soil was 46% at an oil dose of 5 L/m^2. The highest germination at a dose of 10 L/m^2 was recorded in light-chestnut and light-chestnut sodic soils (40 and 36%, respectively). High tillering and heading were noted in light-chestnut, light-chestnut sodic, and floodplain soils in the controls and at an oil dose of 2.5 L/m^2.

Higher yields of perennial grass biomass (dry) were obtained on brown (0.04 kg/m^2), light-chestnut (0.036 kg/m^2), and light-chestnut sodic soils (0.03 kg/m^2) at an oil dose of 2.5 L/m^2 (Table 1). The yield at this dose dropped from 20 to 50% depending on the soil type. The yield at an oil dose of 5 L/m^2 was from 0.025 kg/m^2 (in light-chestnut soil) to 0.017 kg/m^2 (in floodplain soil). The yields decreased relative to the controls by 51.9-64.5%. The yield of biomass at 10 L/m^2 was low for all soil types, e.g., from 0.018 kg/m^2 (in light-chestnut) to 0.008 kg/m^2 (in brown and alluvial soils). The yields decreased relative to the control from 65.3 to 84.0% depending on the soil type.

Thus, long-term studies of zonal soils polluted with various oil doses (2.5, 5, and 10 L/m^2) showed that the pollution changed the whole set of soil physicochemical properties. Brown (sandy loam), floodplain (light loam), and alluvial soils (light loam) that could self-clean and self-restore over time were most resistant to the effects of oil pollution. Experiments with various crops on contaminated soils showed that the plant biomass yield decreased smoothly as the oil-pollution dose was increased. Perennial grasses and rye were more resistant to the effects of soil oil pollution. They gave biomass yields even on light-chestnut and light-chestnut sodic soils that are less capable of self-cleaning. Thus, these plants could be recommended for reclamation of oil-polluted areas.

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