Properties, processes and regimes of soil solutions and surface waters

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Abstract. Soil solutions and the surface waters are characterized by properties, processes and regimes. Soil solutions of different soils and their surface water have different biological activity and change the activity of dissolved stimulants and inhibitors. The object of the study are soil solutions of the main types of soils obtained in the model experiments with the ratio of soils: water equal to 1:1 and 1: 2, soil solutions and surface water in the flooding of soils with water for 1 week – 3 months. The research method consisted in the assessment of pH, Eh, activity of K, NO₃, NH₄, Ca, Mg by conventional methods, assessment of concentrations of water-soluble compounds extracted from soils by ionite membranes, in the assessment of biological activity of solutions using biotests. The following is suggested for additional evaluation: the using of cation and anion membranes, determination of interrelation between the properties of waters, equation of pair correlation and multiply regression. The informative value of the gradient of surface water concentrations at different distances from the floor of the reservoir, at different depths of the overwatered soils is shown. The mobility of Ca, Mg, Fe, Mn in soils and the content of their water-soluble forms depends on both pH and Eh, whose influence on the content of water-soluble forms of the considered cations shows the effects of synergy and antagonism. The rate of change in the composition of soil solutions during soil flooding depends on a combination of soil properties, temperature, and duration of flooding. Soil solutions of different soils and their surface waters have different rates.

1 Introduction

The permafrost-taiga soils of Yakutia are a unique model for studying the features of soil formation in severe climatic conditions. The specificity of soil formation factors in Yakutia in the areas of development of permafrost and taiga soils leads to the specificity of soil-forming processes occurring there (cryogenesis, solifluction, thixotropy, formation of curums and bulging). Soils are characterized by a very high content of oxalate-soluble iron up to 1000 mg/100g, humate-fulvate humus and often with a humus content of 4-5% are

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characterized with light gray (for permafrost-taiga gley soils). Permafrost-taiga soils of varying degrees of hydromorphism and ironiness are distinguished. Acidic permafrost-taiga soils are mainly distributed, however, depending on the parent rocks, neutral soils are found, and in Yakutia, saline permafrost-taiga soils are found. A distinctive feature of permafrost-taiga soils is the presence of permafrost from a depth of 20 cm to 200 m. During agricultural use of soils, they thaw up to 0.5-3 m, depending on the granulometric composition of soils [1]. At the same time, the features of a number of processes occurring in permafrost-taiga soils have not yet been studied [5, 7], which was the purpose of the work performed. The development of scientific principles and methods for regulating soil water processes is an important area of agriculture that allows the efficient use of arable land. Soil solutions of different soils and their surface waters have different biological activity and change the activity of stimulants and inhibitors dissolved in them. In the modern scientific literature, much attention is paid to the study of soil solutions using various fundamental approaches to solve this issue [1-3, 5, 9, 10, 11]. However, they do not focus on the need to assess not only the chemical composition of waters, but also the processes and regimes that occur in them. Obviously, the information and energy assessment of soil solutions and surface water is important in practical and theoretical terms [4, 5, 7, 8, 10].

The purpose of the study was to trace the change in the concentration of soil solutions at different depths of water-flooded soils, at different distances of surface water from the soil level, with an increase in the duration of soil composting with excessive moisture.

2 Materials and methods

Soil solutions of the main types of soils obtained in model experiments with a ratio of soils: water equal to 1:1 and 1:2, soil solutions and surface water when the soil was flooded with water for 1 week - 3 months were selected as the object of the study [4, 6, 7]. The permafrost-taiga soils of Yakutia are analyzed, having, by definition of Sokolov I.A., the following names: P-1 - medium-loamy permafrost-taiga clay soil on heavy carbonate loams (a watershed plateau, larch forest); R-2 - permafrost-taiga clay podzolized soil on gravel; R-3 - permafrost-taiga illuvial-humus podzolized sandy loam soil; R-4 - permafrost-taiga illuvial-humus podzolized peaty sandy loam soil; R-5 - permafrost-taiga illuvial glandular humus, medium-loamy podzolized soil on buried deluvium. For comparison, the analysis took soddy-podzolic medium-loamy soils of varying degrees of hydromorphism on cover loams. The research methodology consisted of assessing pH, Eh, the activity of K, NO₃, NH₄, Ca, Mg by generally accepted methods, assessing the concentrations of water-soluble compounds extracted from soil by ion exchange membranes, and assessing the biological activity of solutions using biotests [3, 6-9].

3 Results and discussion

Soil solutions and surface waters are characterized by properties, processes and regimes, which, in turn, are identified by the transformation, migration and accumulation of matter, energy and information. Our studies have shown the promise of an additional assessment of soil solutions and surface waters using ion exchange membranes, assessing the content of positively and negatively charged complex compounds, aero ions, gas-discharge visualization method, in the determination of oxidants and antioxidants [6-8].

We propose an assessment of the composition of soil solutions and surface waters using cationite and anionite membranes placed in water. An example of determining the content of ions extracted from soil solutions of sod-podzolic soil by cationite and anionite

membranes is presented (Table 1).

Table 1. The content of ions extracted from soil solutions of sod-podzolic soil by cationite and anionite membranes, mg/cm²

Object	P ₂ O ₅	K ₂ O	Ca
Anionite membrane			
control	1.9	-	0.12
+NPK	2.6	-	0.11
Cationite membrane			
control	2.1	2.2	4.1
+NPK	2.7	5.1	3.6

As can be seen from the data presented in Table 2, in fertilized sod-podzolic soils, the activity of potassium and calcium is greater than in non-fertilized. However, complexes and associates that are presented in soil solutions, significantly increase the solubility of compounds and the concentration of ions in solutions, and change their ratio. From the presented data, the use of fertilizers affects the activity of calcium and potassium ions in soil solutions and their ratio (Table 3). Studies have shown a change in the properties of soil solutions and surface waters over time and in space, the information content of the relationships between the properties that characterize the state of water (Table. 4).

Table 2. Activity and concentration of potassium and calcium in soil solutions of sod-podzolic soils.

Option	m/l · 10 ⁻⁵		mg/100g	
	aK	aCa	K ₂ O	Ca
Control	2.2	510	0.2	1.2
+NPK	16.1	654	0.9	1.6

Table 3. Potash potential (pK - 0.5 pCa) in sod-podzolic soils at different doses of fertilizers

Option	pK – 0.5pCa
Without fertilizer	1.8
N ₁₂₀ P ₆₀ K ₈₀	3.0
N ₁₂₀ P ₆₀ K ₈₀ + manure 17 t/ha	2.5

Table 4. Relationship between the changes in water-soluble Ca, Fe, Mn from pH and Eh in the soils of the bed of the reservoir of the Boguchansky reservoir (n = 54), mg/l

Eh, mV according to silver chloride electrode (SCE)	pH	Fe	Mn	Ca
376 - 300 329.7±101.3	6.9±0.4	0.6±0.3	0.3±0.2	5.7±1.3
300 - 200 241.0±5.7	7.2±0.1	1.1±0.4	2.9±1.4	19.1±5.4
200 - 100 139.8±8.5	7.1±0.1	1.6±0.3	1.1±0.7	12.7±3.9
100 - 0 50.6±9.5	7.0±0.1	2.3±0.8	2.1±1.1	22.0±4.0
0 - -100 -54.2±18.7	7.1±0.1	6.0±2.9	9.2±1.7	38.5±1.0

Obviously, an increase in Fe, Mn in solutions with a decrease in Eh is due to the transition of Fe³⁺ to Fe²⁺ and Mn⁴⁺ to Mn²⁺. The increase in Ca content is apparently due to complexation and an increase in CO₂ in soil solutions, which is typical for composting soils

under conditions of overmoistening of more humus samples. The state of soil solutions is characterized by mathematical relationships between their properties (Table 5).

Table 5. Correlation coefficients of pH, Eh and the content of Ca, Fe, Mn in soil solutions of the soils of the bed of the reservoir of the Boguchansky reservoir (three months at W> 100% PPV).

Eh value	Ca	Fe	Mn
Y = f(pH)			
Low (n=12)	0.32	-0.41	-0.10
High (n=42)	0.31	-0.11	0.13
Y = f(Eh)			
Low (n=12)	-0.60	-0.41	-0.20
High (n=42)	-0.30	-0.34	-0.24

As can be seen from the data presented, the content of water-soluble Ca increases with increasing of pH and decreases with increasing of Eh. The content of water-soluble Fe, Mn mainly decreases with increasing of pH and Eh, which corresponds to theoretical regularities. However, in different pH and Eh ranges, these regularities differ. These regularities are characteristic for individual groups of soils and depend on the duration of the development of anaerobic conditions in soils (in the model experiment from 1 to 3 months).

At the same time, the mobility of Ca, Mg, Fe, Mn in soils and the content of their water-soluble forms depends on both pH and Eh, according to which the effects of synergism and antagonism are manifested on the content of water-soluble forms of the cations under consideration.

So, according to the data obtained, the content of water-soluble calcium and magnesium was expressed by the following dependence:

$$\text{Ca} = -124.6 + 21.5 \cdot \text{pH} - 0.09 \cdot \text{Eh}, r = 0.87; F = 13.8;$$
$$\text{Mg} = -130.2 + 23.9 \cdot \text{pH} - 0.07 \cdot \text{Eh}, r = 0.49; F = 5.7.$$

However, the joint pH and Eh dependence of the content of water-soluble iron and manganese was less significant due to a change in pH in a narrow range from 6.4 to 7.6. At the same time, the interval of change in Eh was much larger - from + 336 to - 91 mV according to the SCE. The content of water-soluble iron and manganese was expressed by the following dependence:

$$\text{Fe} = 7.8 - 0.7 \cdot \text{pH} - 0.01 \cdot \text{Eh}, r = 0.36; F = 2.9;$$
$$\text{Mn} = 4.4 - 0.04 \cdot \text{pH} - 0.01 \cdot \text{Eh}, r = 0.24; F = 1.2.$$

Obviously, in this case, it is necessary to take into account the complexation processes of iron and manganese with organic ligands of soil solutions. Soil solutions and surface waters differ significantly for individual groups of soils, soil and climatic conditions, and for individual geochemical provinces [1, 3, 5, 9, 11]. This determines their different biological activity and the effect on the biological activity of stimulants and inhibitors dissolving in them, fertilizers and ameliorants, the geophysical fields of the Earth, and magnetic fields created. Their composition is significantly affected by complex formation [2, 4, 10, 12].

As can be seen from the data presented in Table 6, the addition of humates to the soil solutions improved the development of biotests. However, this was manifested to a greater extent on soil solutions from the A_{pach} horizon, compared with solutions from the A₂ horizon. Humates also reduce the toxicity of saline soils. As can be seen from the data presented, the addition of 0.1 ml of 10⁻⁶ humate in 10 mg of saline solutions improved the development of the roots of the biotest with salinity of 5 g/l of water (Table 7). From which

it follows that soil solutions and surface waters have information and energy characteristics that can be optimized, including when using ultra low concentrations of humates.

Table 6. Effect of the composition of soil solutions on the biological activity of humates (0.1 ml 10⁻⁶ +7 ml H₂O), humate No. 5.

Option	pH	K ₂ O	Mg	Sprouted seeds, pcs	Roots, mm	max/ min	Stems, mm	max/ min
		mg/l						
H ₂ O	-	-	-	8	4.5±0.2	1.5	2.1±0.1	1.8
D ^P A _{pach}	8.2	3.2	1.0	8	4.8±0.1	1.4	2.6±0.1	1.4
D ^P A ₂	7.9	2.0	1.4	5	2.3±0.2	7.0	2.1±0.1	3.4

Table 7. Effect of humates and NPK on the toxicity of saline waters (watercress *Lepidium sativum* was used as a biotest).

Option	Roots, mm	Stems, mm	Number of sprouted seeds
1 g/l	5.1±1.9	44.2±15.3	5
1 g/l + humate №3 (10 ⁻⁶)	19.5±13.0	33.7±6.4	6
1 g/l + KNO ₃ ·10 ⁻⁴	3.3±0.8	31.3±6.3	9
5 g/l	3.7±1.0	15.7±2.8	4
5 g/l + humate №3 (10 ⁻⁶)	3.2±1.7	15.6±3.0	5
5 g/l + humate №3 (10 ⁻⁶) + KNO ₃	5.8±0.4	7.2±2.4	6

4 Conclusion

In conclusion, it should be noted that soil solutions, in contrast to aqueous extracts, are characterized by the presence of ions in certain concentrations and in ratios between themselves. Using the soil of Yakutia as a model, we propose an additional characterization of the composition of soil solutions using cation exchange and anion exchange membranes. The change in the concentration of soil solutions at different depths of water-flooded soils, at different distances of surface water from the level of soils, with an increase in the duration of composting of soils with excess moisture is shown. When dissolving stimulants and inhibitors in surface waters of different compositions and in soil solutions, the indicators of the biological activity of solutions change, which must be taken into account in industrial practice.

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