ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH, 1996, z. 436, 175-181

INFLUENCE OF FERTILIZER APPLICATION ON MICROSTRUCTURE, MINERALOGICAL COMPOSITION, AND GRASS YIELD OF KARELIAN SOILS

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Accepted February 5, 1996

A b s t r a c t. Changes in chemical properties, mineralogical composition and microstructure of the taiga surface-gley forest and cultivated soils were studied. The cultivated soil was previously drained, limed and manured. Different dozes of NPK were applied during 5 and 20 years. Perennial grasses were grown on the plots studied. Long- term application of small dozes of NPK (40-100 kg ha^{-1}) contributed to a biological transformation of arable horizons and formed a high quantity of biogenic pores and aggregates. Improvement of water permeability and drainage caused removal of the organo-mineral compounds from the upper horizons. These compounds were accumulated near drains. In our experiments, optimal dozes of NPK applied to form biogenic aggregates were N120 P120 K120 and N240 P240 K240. The higher dozes of NPK caused an increase in both the humus and iron removal and destruction of aggregates. Mineralogical composition was determined by the X-ray and immersion methods in fractions: >0.01, 0.01- 0.001, and <0.001 mm. The higher and non-balanced dozes of NPK contributed to the changes in minerals containing the biophilic elements (micas, chlorites, amphiboles) in the coarse-textured fractions of soils. The fertilizer's potassium was fixed by labile clay minerals and transformed to a weakly available form for plants. Dozes of N120 P120 K120 were optimal. These dozes did not cause noticeable changes in minerals, but resulted in significant grass yield.

K e y w o r d s: drained soils, fertilizers, micromorphology, mineralogy

INTRODUCTION

Man activity on agroecosystem with the aim of raising the productivity of agrocoenosis and soil fertility gets not always an adequate response by the system. The reason of it is not enough information on the functionning of main components of agro-ecosystem, soil and agrocoenosis, on their change as affected by man production activity.

Cultivation of soil brings about essential changes in many soil processes and first of all in full character of interaction between the living phase and the mineral part of the soil. Biophilic elements allenated with the crop are compensated but partly by root litter and fertilizers. As a consequence of it there should be biota activity directed to extraction of the lacking nutrients out of organic matter and minerals.

When studing mineral composition of cultivated soil, main attention is devoted to investigation of the behavior of clay minerals as the most active part in soil. The majority of authors' state potassium-fixation by labile minerals and an increase of the mica component content [1-3]. In several papers they show an increased quantity of smectite minerals at great dozes of nitrogen fertilizers [2]. The behavior of chlorites is determined by the mineral composition of coarse soil fractions, duration of agricultural utilization, composition of fertilizers applied [1,3].

Micromorphological investigation of the taiga-forest soil as affected by man production activity showed some changes in soil structure, the character of decay of vegetation remains, changes in composition and mobility of the plasm [4,5].

The aim of the present paper was to clarify the combined influence of drying and applying fertilizers on microstructure and state of clay and clastogenic minerals of various dispersity. Soils being typical as an object of reclamation were chosen for our investigation.

MATERIALS AND METHODS

As an object of investigation there were chosen some taiga surfacegley soils on limnoglacial clays in the Korzin low-lying land in Karelia. Such soils develop under forests in superwetted conditions.

About 25 years ago the soil were cultivated and dried by open drains.

In 1979 closed drenage was laid, and they were regularly limed once every 5 years ($CaCO_3$, 5-6 t ha^{-1}). Manure in the form of peat- and dung composts as well as fertilizers (NPK 40-100 kg ha^{-1}) were inserted yearly.

Fields were mainly utilized for growing perennial grass. Two sections were made in the field: near the drain and between the drains, in the middle. In the same field some plot experiments were laid. Soil properties and perennial grass yield were being studied for 5 years as affected by various dozes of fertilizers. Liming ($CaCO_3$, 5 t ha^{-1}) and inserting manure (20 t ha^{-1}) were carried out before starting the experiment. Specimens to be investigated were chosen by boring in 3-fold iteration.

The following parameters were defined in soil sections: texture composition, physical-chemical and agrochemical properties, bulk chemical composition and Fe_2O_3, Al_2O_3, SiO_2 - contents in extracts after Tamm, Mehra, Jackson [after 6].

To study mineralogical composition of soil we applied the immersion (fractions of 0.25-0.05 mm) - and X-ray difractometric methods (0.05-0.01; 0.01-0.005; 0.005-0.001; <0.001 mm).

Agrochemical characteristics of soil specimens taken from plots were analysed yearly. The mineral composition of fractions being <0.05 mm was defined 5 years later after the experiment had been laid.

RESULTS

Morphological characteristics

Morphological observation showed that cultivation, drying and applying even small dozes of manure and fertilizers for a long time resulted in significant changes in the soil profile structure.

Morphology of forest soil was as follows:

O - Ag - AG - Bg - BCg.

Soil between drains differed from that of the forest one by lower gleyzation and higher humusation in the upper part of the profile which constitutes the arable horizon:

O - Aar - Bg - BCg.

Soil in the proximity of drains are characterized by a more differentiated structure as compared to the forest one:

O - Aar - Elg - Bgfa - Bg - BCg - BCgfa.

Thus, in the lower part of arable horizon in contact with a more dense illuvial horizon there were formed horizons. Elg and Bgfa. In the lower part of the profile there appeared horizon. BCgfa due to solutions rich in iron penetrating out of drains and because of the dead water above the drains.

Micromorphological observation indicates that in arable soil as compared to a forest one there arose some changes. In the arable horizon of cultivated soil both vegetative remains and humus of a more soft type than in forest soil are accumulated. Depth of the horizon processed by living organisms, the amount of biogenic pores and aggregates increased. However, with the increase of interaggregate porosity the quantity of aggregates of spongle structure, i.e., of intra-aggregate porosity, decreased. This fact seems to demonstrate the role of iron as an aggregate stabilizer.

Decrease in water impounding and improvement of water permeability of arable horizon resulted in a more active migration of substances in the latter towards drains, particularly in the soil between drains. Downwards the profile migration of solutions and suspensions proceeds along vertical cracks that are formed in soil when drying. As a result of such processes arable horizons become impoverished in thin-disperse particles. It is especially seen in the soil close to the drains where horizon Elg had been formed.

Formation of segregations (in upper profile part of arable soil) consisting of organo-mineral compounds and hydro-oxides of iron is caused by the increased contrast regime of wettening as well as by applying some additional organic substances and iron together with peat composts. Segregation proceeds much more intensive in soil above the drain where 3 horizons rich in iron are formed, namely: in the upper part of arable horizon (0-10 cm) in horizons Bgfa and BCgfa.

Observation about the arable horizon microstructure in our plot experiments showed no significant effect when applying low dozes of fertilizers. However, dozes N 120, P 120, K 120; N 240, P 240, K 240 led to an increased number of biogenic pores and aggregates in the upper 10-cm layer of soil. Micro- and macroporosity, humus content and the decay degree of vegetative remains increased. Along with that dispersion and mobility of organic matter increased too.

Great dozes of fertilizers (N 360, P 360, K 360) promoted appearance of non-uniform micro configuration of the layer. The size and amount of non-aggregated depigmentated zones with low porosity and humus content increased, Fe-segregation was more active.

Thus, our experiments showed that optimal dozes of fertilizers for soil structure condition were as follows: N 120, P 120, K 120 and N 240, P 240, K 240.

The data on textural analysis proved that soils are formed on some relatively uniform material. Variations in profile by Trusk's coefficient of segregation did not exceed 10 % from his value, which is within the limits of accuracy in our analysis. A relative uniformity of the soil-forming material in soil profile makes it possible to interpret the changes occurring in mineral composition, which is the result of the processes proceeding during soil formation.

Mineral composition

Mineral composition of 0.25-0.05 mm - fraction under the forest and in the meadow in the proximity of the drain is given in Table 1.

The main components of the fraction are quartz, feldspar (acid plagioclases, potassium feldspars), and ferrugineous and greatly changed mineral grains hard to define. The number of such grains is much higher in the soil near the drain than in the forest soil, the horizons of their maximum accumulation in the cultivated soil are the upper part of Aar (0-10 cm) and BCgfa.

The greater part of heavy fraction is made up of epidote-zoisites and hornblendes. The amount of them is visibly decreasing in the upper part of arable horizon. It may be explained due to the activity of biotas, for it is in this part of the arable horizon that roots are mainly concentrated.

The greatest changes in the profile of both soils are noticed in the content of hydro-oxides of iron (goethite, hematite). In forest soil the horizon of maximum enrichment with these minerals is the upper part of horizon Bg containing segregations of iron and a lot of Fe_{res} according to Bascomb [after 6]. In meadow soil near the drain the number of hydro-oxides of iron increases sharply in the upper part of horizon Aar (0-10 cm) as compared to the forest one. It seems to be related not only to penetration of the element together with composts that could contain some peat enriched with iron. This part of the profile is characterized by a high value of pH(H_2O) (6.0-6.5) and good aeration. Water running along the surface towards the drain may partly drop iron. Drying through evaporation, transpiration and freezing favors crystallization of hydro-oxides.

Thus, main changes in the mineral composition of the 0.25-0.05 mm- fraction are related to stimulation of weathering minerals containing biophilic elements: epidote-zoisites and hornblendes, as well as to accumulation of iron from manure and drain water. Maximum accumulation was noted in the upper part of an arable horizon in the form of iron hydro-oxides

Table 1. Mineral composition of 0.25- 0.05 mm fraction in the taiga surface-gley soils (% of grain number)

Minerals, soil position	Depth (cm)								
	5-10	10-15	20-30	50-60	110-120	0-10	10-20	20-30	110-120
	Forest					Meadow			
					Light minerals				
Quartz	58.5	40.5	45.0	35.0	47.0	32.0	30.0	27.5	21.0
Feldspars	34.5	29.0	27.5	22.0	37.0	37.0	37.0	24.5	16.0
Mica	1.0	-	-	0.5	-	0.5	-	-	-
Opal	1.0	-	-	-	-	-	-	-	-
Rock debris	-	0.5	2.0	2.0	1.0	-	-	-	2.0
Ferruginous grains	5.0	30.0	25.5	42.0	15.0	48.0	53.0	48.0	61.0
					Heavy minerals				
Magnetite, ilmenite	2.0	3.5	1.0	2.5	5.0	4.0	3.5	6.0	7.0
Goethite, hematite	2.0	17.0	2.0	-	1.0	42.0	1.0	5.5	1.5
Zircon	1.5	2.0	0.5	2.5	1.5	0.5	1.5	1.5	1.5
Garnets	0.5	0.5	-	-	1.0	0.5	-	0.5	1.0
Titanium oxides	-	-	1.0	0.5	2.0	-	1.0	1.0	1.0
Mica	-	-	-	-	0.5	-	-	-	-
Epidote-zoisites	54.0	42.5	53.0	60.0	52.0	33.5	51.0	55.5	52.5
Hornblendes	40.0	34.5	43.0	31.5	37.0	19.5	33.0	30.0	36.5

and ferruginous films on the surface of mineral grains. In the horizon BCgfa films on mineral grains present the form of accumulation.

Quartz and feldspars prevail in the 0.05-0.005 mm - fraction. In small quantities there are chlorites (only in low horizons), micas, amphibols and kaolinite. The latter is likely to be present in the form of clusters on feldspars, a significant part of which is pelitizided. The principal changes in composition of those fractions when cultivating the soil are due to the weathering of micas. It concerns especially trioctaedric ones in the upper 30-cm layer close to the drain.

Thin-disperse soil fractions are mainly composed of clay minerals: illite, kaolinite, labile ones (in the upper horizons). However, an essential role especially in the 0.005-0.001 mm-raction is played by clastogenic minerals, such as quartz, feldspars, amphibols and chlorites. Degradation of mica minerals into 14 A-labile ones in the upper 30 cm-part of the profile, passing the stage of mixed-layer formations, is a distinguishing feature of forest soil.

In cultivated soil because of potassium - fixation from fertilizers there was observed agradation of 14 A-labile minerals into mixed-layer formations in the clay fraction and into 10 A- mineral in the 0.005-0.001 fraction.

Chemical composition

In 5 years after the plot experiments had been laid there occurred some changes as compared to the control. The value of pH and the content of exchangable cations increased. Hydrolitic acidity decreased not in all the variants of our experiment, and the degree of saturation by bases increased, respectively, not in every variant as compared to the control. Maximum changes of that value took place in the variant with N 120 P 120 K 120 and N 240 P 240 K 240. The greatest changes in the content of phosphor and potassium available for plants were observed in the variant with the highest dozes of NPK.

DISCUSSION

Processing the data on agrochemical analyses and taking into consideration the grass yield by the methods for mathematical statistics and factor analysis showed as follows. For the first 4-5 years of functionning agrocoenosis on soils of heavy texture when applying manure and lime changes significantly agrochemical situation.

It affected agrosystem stronger than applying fertilizers. Yet applying both of them, i.e., manure and fertilizers, appeared distinctly beneficial for raising agrocoenose productivity.

Determination of mineral content in fractions 0.05-0.005, 0.005-0.001 mm and <0.001 mm and correlation those data with the results of agrochemical investigation taking into account grass yield are given in Table 2. Essential changes in the content of coarse fractions may be explained by the weathering of minerals containing biophylic elements: micas, chlorites. As a result there occur mineral degradation to a smaller fraction, its destroying or transformation.

Mineral components of thin-disperse fractions are greatly influenced by their interaction with combined fertilizers. It is displayed in the relation between 14A-labile and 10A-stable phases. High dozes of potassium fertilizers particularly nonbalanced as to NPK contribute to potassium fixation in interlayer state.

As a result of it reflection intensity of 14 A decreases and that of 10 A becomes stronger and the ratio 10 A : 5 A raises. The latter points to strengthening potassium bonds in the interlayer space of micas, which is the result of some changes in the composition of tetrahedral layers.

Analysing Table 3 we may conclude that optimal doze of fertilizers ensuring to obtain high yields, good preservation of potassium entering together with the fertilizer as well as careful expenditure of nutrient store from clastogenic minerals is just the doze N 120 P 120 K 120.

High dozes of fertilizers stimulate biota development, they cannot ensure its nutrition in full value. Biota takes lacking elements from clastogenic minerals destroying them. The reserve of such minerals in soil is limited and cannot be filled up.

CONCLUSIONS

Transition of forest biocoenosis to agrocoenosis, soil drying, applying lime, manure and fertilizers have produced significant changes in the surface gley taiga soil of a heavy textural composition. It concerns both soil matter and soil forming processes.

Additional amount of manure at lowering the acidity and lower degree of superwetting made biota more active, which promoted aggregation of arable horizon and formation of a great number of biogenic pores. The optimal dozes of NPK for such processes were N 120 P 120 K 120, N 240 P 240 K 240.

Table 2. Agrochemical characteristics of the taiga surface-gley soil on experimental plots (depth 0-10 cm)

NPK doze			pH KCl	Hr* ($mol_c kg^{-1}$)	S** ($mol_c kg^{-1}$)	V*** (%)	Extracted by P_2O_5 ($mg\ kg^{-1}$)	Ca-lactate K_2O ($mg\ kg^{-1}$)
0	0	0	5.3	57.4	260	82	65	160
120	120	120	6.2	28.7	318	92	55	190
240	240	240	5.7	60.2	320	84	259	240
360	360	360	5.4	54.2	373	87	234	350
0	0	120	4.9	98.3	259	73	62	325
120	0	120	5.5	51.4	297	85	57	215
120	0	0	6.7	21.7	467	96	34	110
0	0	240	6.9	19.2	395	95	185	350
240	0	240	6.7	26.2	381	94	370	165
240	0	0	5.9	32.5	302	90	35	50

*Hr - hydrolitic acidity, **S - content of exchangable cations, ***V - degree of cation saturation.

Table 3. Mineral composition of texture fraction in the taiga surface soil on experimental plots

NPK doze			Green mass yield, (t ha^{-1})	K_2O extracted by 0.2 n HCl	Fraction (mm); intensity relation of mineral peaks (10^{-10}m)								
					0.5-0.005			0.005-0.001			<0.001		
					14*/10	10/4.21	10/5	14*/10	10/4.21	10/5	14*/10	10/4.21	10/5
0	0	0	14.0	0.88	0.3	0.2	2.2	0.3	0.2	10.0	0.4	0.2	1.5
120	120	120	28.3	1.52	0.3	0.2	3.1	0.4	0.2	2.7	0	0.4	2.6
240	240	240	22.3	1.23	0.2	0.2	3.2	0.6	0.5	6.9	0	0.7	4.7
360	360	360	28.7	3.16	0.4	0.2	2.1	0.6	0.3	3.1	0.3	0.7	4.5
0	0	120	12.0	1.95	0.3	0.2	2.0	0.7	0.2	2.0	0	0.3	1.2
120	0	120	28.3	1.65	0	0.1	0.9	0	0.3	2.9	0	1.0	6.5
120	0	0	16.8	1.27	0.2	0.2	10.0	0.2	0.2	2.8	0	0.6	4.3
0	0	240	29.5	1.47	0.4	0.1	2.5	1.0	0.3	2.3	0.6	0.4	10.0
240	0	240	23.3	3.81	0.2	0.2	3.2	0.6	0.5	6.9	0	0.7	4.7
240	0	0	28.1	1.27	0.4	0.2	2.2	0.1	0.4	8.1	0.2	0.7	3.6

*-labile

Reinforcing drainage at the expense of laying drainage pipes, and creating better water permeability of arable horizon resulted in a more active migration of water both in field and intra the soil profile. As a consequence, morphological changes in soil structure were the more pronounced, the nearer the drain. The above changes were caused by transfer of thin-disperse matter from the upper part of the profile up to isolation of horizon Elg having become lighter, and due to formation of horizons rich in iron - in the upper part of the arable horizon, at the boundary between the arable and a more dense illuvial horizons, and in the lower part of the profile in the drain area.

Changes in mineral composition of soil extended both to clastogenic and clay minerals. Those changes were connected with biota greater activity, with various watering regime and with bringing in some substances together with fertilizers. Biota activity stimulated the weathering of minerals containing biophylic elements, such as micas, chlorites, epidote-zoisites, hornblendes.

Deposition and crystallization of iron in the form of hydro-oxides are timed to the upper part of arable horizon. Those processes result from bringing in the element with peat composts and surface water, they occur as a consequence of a stronger contrast in wetting regime.

Formation of ferruginous films on mineral grains proceeds along the whole profile, the maximum being in horizon BCgfa having additional supply of water out of the drain or from dead water above the drain.

Changes in the composition of thin-disperse minerals occur due to some reasons: potassium leaving the interlayer position in mica, in case living organisms lack the element and because of potassium-fixation by labile minerals when there is an excess of potassium in soil solution. Those processes depend on the balance between fertilizer dozes by NPK and corresponding dozes of biota activity.

The optimal doze for our experiment was N 120 R 120 K 120. That doze promoted favorable changes in the aggregate state of soils. It did not cause any stimulation in destroying clastogenic minerals and ensured high yield.

Obtaining high grass yields with high dozes of fertilizers (360 360 360) caused unfavorable changes in soil, namely: humus mobility increased, aggregate state of soil became worse, the weathering of clastogenic minerals was more intensive.

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WPŁYW NAWOŻENIA MINERALNEGO NA MIKROSTRUKTURĘ, SKŁAD MINERALOGICZNY I PLON TRAWY GLEB KARELII

Zbadano zmiany właściwości chemicznych, składu mineralogicznego i mikrostruktury leśnej i uprawnej gleby glejowej tajgi. Stwierdzono, że zmiana użytkowania gleby z leśnej w uprawną z zastosowaniem drenażu, wapnowania, obornika i nawożenia mineralnego NPK spowodowała istotne zmiany we właściwościach glejowej gleby tajgi o ciężkim składzie mechanicznym. Zmiany te dotyczyły zarówno masy glebowej, jak i procesów glebotwórczych.

S ł o w a k l u c z o w e: drenowanie, nawożenie, mikromorfologia, mineralogia.