TRANSFORMATION OF SOIL PROFILE'S UPPER PART ON SOD-PODZOLIC LIGHT LOAMY SOILS UNDER THE CONDITIONS OF LONG-TERM SOIL IMPROVEMENT (ON THE OCCASION OF CENTENARY OF THE LONG-TERM FIELD EXPERIMENT AT RSAU-MTAA)

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Abstract: Prolonged use of mineral and organic fertilizers, combined with occasional lime application in case of both monocrop culture and crop rotation increases the initial level of soil cultivation in sod-podzolic loamy soil. The above ensures sustainable yield of winter grains of 4.5-5.5 t/ha, potatoes - 20-25 t/ha, perennial grass hay - 6-8 t/ha with soil degradation diminished to environmental standards.

Key words: soil profile, long-term experiment, humus, total nitrogen, mobile phosphorus, exchange potassium.

In 2012, the long-term field experiment at Russian State Agrarian University-MTAA (known abroad as "Moscow Stationary") had passed the 100-year landmark since it had been established. As to the number and importance of conducted research, this field experiment is included into the list of unique globally valued experiments in agronomical science. The first scientific and agronomical experiments on fertilizers were established in England soon after "The Minimum Law of Libikh". or the limiting factor related to the plants nutrients had been published in 1840. In the second part of the 19th century, "the wave of the field experimenting covered" other countries in Europe and North America.

In Russia, where manure and, in part, ash were the main fertilizers of the dominating three-field crops rotation, the main purpose of such experiments was, along with studying mineral plant nutrition, the promotion of new technologies in agriculture, demonstration of advantages of some fertilizer types and crop rotations.

The founders of scientific agronomy in Russia - A.T. Bolotov, A.N. Engel'gardt, I.A. Stebut, K.A. Timiryazev, N.I. Vavilov, A.G. Doyarenko and other prominent scholars considered field experiment to be the main method to study factors of plants life and soil fertility.

During the 100-year period, experts in various fields from Timiryazev Academy, other institutions and research organization, both Russian and foreign, conducted research within the frameworks of this Long-term field experiment.

The value of the these research results is proportional to the duration of the field experiment and increases in process of approach of the experimental plot to the ecophytocoenotic balance. In a long-term field experiment,Jhere is a partial compensation of effects' deviations of actions and interactions of studied and not studied but controlled factors that balances the basic background for all experimental variants. Under the conditions of long-term field experiment the effects of the actions, interactions and after-effects of cultural practices on the basis of various environmental factors are accumulated in the period of time that advocates to solve agricultural and environmental problems of a particular soil and climatic zone. The long-term field experiments allow monitoring of the humus content, nutrients content and circulation, including the content of microelements, the dynamic of the soil pollution with heavy metals, toxins and measures harmful for the biosphere and humankind. There is a a possibility to evaluate and predict potential negative consequences of these measures on the basis of the soil science and agronomical background of the long-term field experiments,. The effect of many biological and technological factors on the soil fertility and plant productivity becomes evident only after ten years.

Therefore, long-term field experiments are irreplaceable for educative purposes as a demonstrational materials and "live educational facilities'’. The above listed advantages of the long-term field experiments bring us to a conclusion to preserve them as "field laboratories”. The long-term field experiments have to be in free access for scientists all over the world [1, 2, 5, 7, 8].

Methodology

Agrotechniccd basis, conditions and methodology of the long-term field experiment. Experimental plot of 1,5 hectares was a part of the 12th field in farm crop rotation at Timiryazev Agricultural Academy. In the period of 1894-1901, the following crops were cultivated on this field with the double-sided north-west slope of 1°: winter rye with undersowed clover and timothy grass - grasses - grasses - oat with undersowed grasses - grasses - grasses - oat with undersowed grasses - grasses - grasses. The yield of grasses for hay within this period did not exceed 10-12 quintal^{-ha}. In 1902, the field was under the bare fallow. In the period of 1903-1911, the crop rotation was as follows: rye - potatoes - oat with undersowed grasses - grasses - grasses - oat - bare fallow - winter rye with undersowed perennial grasses - grasses of the 1st year. During the 18-year period before establishing the field experiment the manure fertilizing in doze of 36 t^{-ha} was implemented only in 1909, what caused the double increase of grass yield. Therefore, the plots of the field experiment were split on the grass turf ground.

Soil - sod-podzolic, long arable, acid, overflowed (Podsolluvisol as per FAO classification). Soil profile structure - double part: the upper part up to the depth of 40-50 cm is sandy, large-scale dusty loam; the lower part up to the depth of 3 m - light and medium loam with the sandy layers. Carbonate tracks (HC1 light bowling) are indicated at the third meter (Table 1).

Layout of the long-term field experiment. As the basis for the layout, an approbated analogue of the long-term field experiment in Goettingen (Germany) established by Dreksler to investigate the effect of separate and combined application of nitrogen, phosphorus and potassium on crops fertility was taken. In 1912, before sowing the summer crops, six fields were established, each divided into two parts by a 3-m long road.

At the first part of the field (field size - 1 400 sq. m), monocrops were cultivated: winter rye, potatoes, oat, clover, flax and bare fallow. At the other part (size of one field - 1 200 sq.m), the six-field crop rotation was implemented: bare fallow - winter rye - potatoes - oat with undersowed clover - clover - flax. Across the six fields with monocrops, 11 plots with various fertilization options were split: 1- N; 2 - P; 3- K; 4 - 0 (without fertilizing); 5 - NP; 6 - NK; 7 - PK; 8 - NPK + manure; 9 - NPK; 10 - manure; 1 1 - 0 (without fertilizing). The same optionts excluding the 10th and the 11th, were implemented on the fields with crop rotations.

The size of a registration plot was 100 sq. m, the size of an arable plot was from 127 up to 133 sq. m, accordingly. After applying lime to one half part of every field, the size of the registration plot was 50 sq. m.

Table 1

Average characteristics of arable soil layer fertility in 1972

Characteristics	Value
Physical sand (particles > 0,05 mm), %	46
Density of solid phase, g^{-cm3}	2.65
Soil density, g^{-cm3}	1.53
Maximum hygroscopics (mg), %	1.25
Field humidity, %	19.2
pH	5.2
Humus carbon (C), %	1.03
N (overal content),%	0.079
C/N	13
P2O5 (mobile), $mg^{-100gsoil}$	23.5
K2O (exchange), $mg^{-100gsoil}$	13.3
Content of exchange bases, mg-eqv$^{-100gsoil}$	9.7

Methodological changes in the long-term field experiment layout. As pointed out by V.E. Egorov [6] and B.A. Dospekhov [4], in the first 60 years after the long-term field experiment had been established there were no principal changes in its layout. However, in process of obtaining research results, the layout was improved in various ways. Since the "experimental scheme" concept assumes, first of all, particular options, three following changes of the basic layout are worth detailing:

1. Up to 1937, nitrogen in nitrate form (up to 1921 — Chilean saltpetre, then Norwegian saltpetre, from 1924 — natron saltpetre) was studied in the 8thoption. Nitrogen in ammoniac form (sulphate ammoniac) was studied in the 9th option (NPK from 1912). In 1938, lime was applied to all plots of the 8th option (one occasion doze - 2,5 t^{-ha}) and manure was applied in the doze of 20 t^{-ha}. This doze of manure was studied up to 1948 and in 1949 the final layout of the 8th option was formed - NPK + manure.
2. The first and the most important supplement to the layout was made by V.E. Egorov in 1949. It is connected with the introduction of lime as the 3rd studied factor into the layout. The doze of lime calculated on the basis of hydrolytic acidity was 4,57 t^{-ha} of limestone (83 % Ca + Mg in proportion of 2:1). New options were established by splitting basic plots into two parts. Crops yield was considered separately from the plots with and without lime implementation. At the same time the permanent fallow was studied only on the plots without lime application, whereas on the plots with lime application the crop rotation was studied. Since the 2nd rotation the crops rotation began to correspond to the basic crop rotation.
3. The first major change of the layout was made by A.G. Dospekhov in 1973. All plots of even-numbered fields with crop rotation were treated with the common form of fertilizers (NPK), in 1978 — with lime in the doze of 4,5 t^{-ha}. On odd-numbered fields studies of nine options of the basic layout with differential fertilizing both with and without lime application were continued. The introduction of new options greatly improved and enriched both the informational content and the scope of the research.

Cultural practice improvement. The most significant cultural practice improvements in the long-term field experiment are connected with the dozes of fertilizers and proportions of nutrients in these fertilizers. According to these factors, four periods within the 100-year period of the experiment are defined (Table 2).

Table 2

Fertilization system in the long-term field experiment (mineral fertilizers - kg^{-ha}, manure and lime -t^{-ha})

Period	Doze of fertilizers				Amount of fertilizers				
	N	P_2O_5	K_20	manure	N	P_2O_5	K_20	manure	lime
1 (1912-1938)	7.5	15	22.5	18	195	390	585	486	0
II (1939-1954)	75	60	90	20	1200	960	1440	320	9
III (1955-1972)	50	75	60	10	900	1350	1080	180	3
IV (1973-2012)	100	150	120	20	3800	5700	4560	760	18

Results

Regular applications of organic and mineral fertilizers along with occasional lime application still represent the most efficient method of chemical melioration of sod-podzolic soil and precondition for the increase of the arable soil efficiency. Results of the melioration are determined by various factors: basic soil characteristics, types, dozes and combinations of fertilizers and special requirements of cultivated crops. For the first 60 years after establishing the long-term field experiment, of anthropogenic inputs of different levels received by each of 240 plots have conditioned differences in humus and nutrient content that had noteworthy multiplied. (Table 3).

It is worth paying attention to the fact that the soil characteristics of fertilized plots of the six-field crops rotation with clover and fallow appeared to come short compared to the non-fertilized plots with perennial fallow land. Rye monocrop facilitated establishing favorable soil properties in comparison with those determined by the other monocrops or crops rotations. Humus content at the plots with other crops (2.02%) is close to the humus content (2.19%) at the plots with fallow land. Considerable losses of humus content during the 60-year period are indicated at the plots with potato monocrop (21 t^{-ha}) and

Table 3

Effect of long-term soil treatment (1912-1972) on the potential soil fertility (average dozes of fertilizers and ameliorants: $N_{36}P_{44}K_{51}$; manure - 16 t^{-ha}, lime* - 0,5 t^{-ha})

Soil properties	Perennial fallow land	Effect of monocrops and crops rotation implementation						
		Crops rotation	Fallow**	Rye	Potatoes	Oat (barley)	Clover	Flax
Humus content, %	2.19	1.76	0.89	2.02	1.49	1.77	1.70	1.84
P_20_5, mg-$^{1006ls°"}$	93	89	150	182	147	134	96	134
K_20, mg-$^{100\wedge0"}$	133	91	134	133	86	125	78	102
pH HCI	5.3	5.0	3.9	5.4	5.2	5.5	5.0	5.1

* lime application - once in every 6 years since 1949; ** in comparison with the plots without lime application.

fallow (36,1 t^{-ha}). Monocrops of summer cereals, clover and flax conditioned insignificant losses of the humus content.

The value and peculiarity of this long-term field experiment as a unique one in the world is due to the fact that since its foundation (1912), the fallowed plot has been split into smaller plots with different dozes of fertilizers. E.g., even in Rothamsted long-term field experiment, a fallowed plot was introduced in the scheme only in 1959 on a meadow with controlled cattle pasture.

Results of the researchs show a definite tendency towards decreasing the carbon content during the fallow treatment of sod-podzolic loamy soil, moreover, the rate of annual losses is determined by the dozes of applied mineral and organic fertilizers. Considerable losses were indicated at the plots without fertilizing where during the first 10-year period the carbon content decreased by 37.5% in comparison with the initial amount (1.20%). During the next decades, the rate of organic substance mineralization decreased. That was connected with the fact that the soil had reached the critical carbon content (0.48-0.52%) determined by the granulometric composition of this soil type. Application of mineral fertilizers in full dozes (NPK) decreased the carbon decomposition rate in soil and the level of carbon content was 0.81-0.89%. Annual manure application (on average 17.7 t^{-ha} during the 100-year period) defined steady or positive balance of carbon with the seasonal variations from 1.21% up to 1.27% on fallowed plots.

It is necessary to emphasize that during the period of global warming (1995-2010) the losses in carbon content decreased unrelated to the level of fertilization which is connected with the erosion processes both at the plots with fallow implementation and at horizontally adjacent plots (Figure 1).

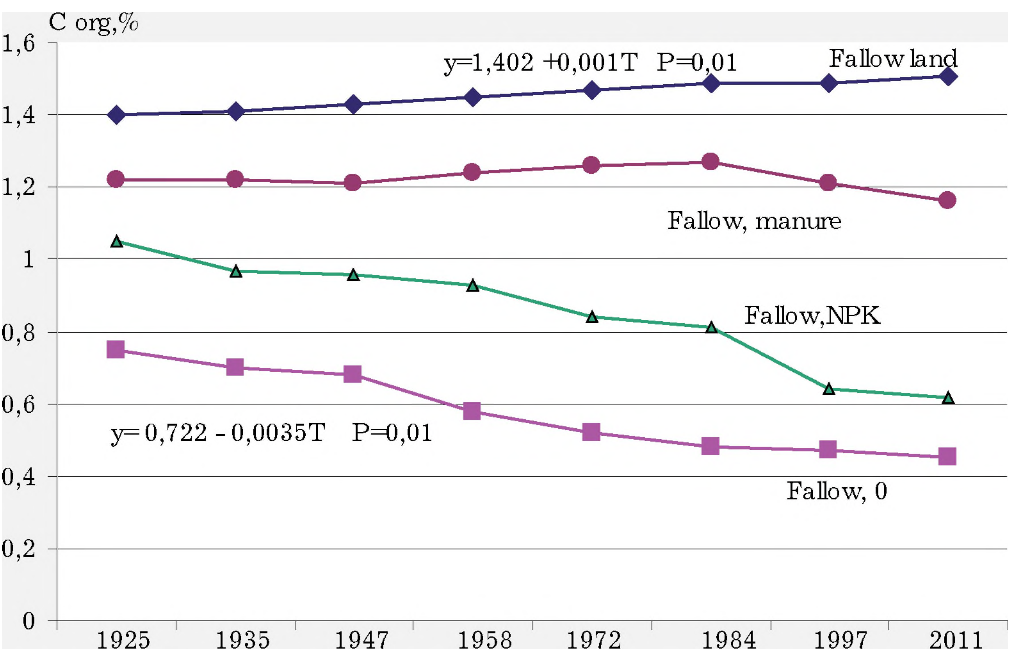

Fig. 1. Carbon content rate (C_{org},%) on the plots with permanent steam and adjacent fallow land

Under the conditions of biocoenosis of perennial fallow land, a distinct tendency of maintaining positive carbon balance was indicated. The carbon content during the 100-year period decreased up to 0.11% or 3.3 t^{-ha}.

As it was determined previously [2, 3, 5], long-term fertilizing and occasional lime application to topsoil are efficient methods of subsoil treatment even with constant ploughing depth of 20-22 cm. One-meter soil profiles at all monocrop plots and two plots with crop rotation were studied consistently in 1974 for the first time and then in 2011.

Results on the evaluation of the soil properties along the soil profile not only contributed to the general knowledge of soil treatment, but became the foundation for the science-based concept oftillage minimization and, first of all, partially, the implementation of "no tillage" soil treatment [1, 6]. Long-term soil cultivation causes changes in the morphological, physical and chemical soil properties, humus content and nutritient balance not only in the topsoil, but in lower layers as well.

Under the long-term crops cultivation the depth of the topsoil has increased by 6-15 cm in comparison with the fallow land soil and reached 24-30 cm. Morphological differences between the soil profiles from monocrop plots and those with crop rotation and the soil profiles from the plots with perennial fallow land are determined by long-term soil treatment, repeated fertilizing and occasional lime application in the conditions of crops cultivating.

Significant differences on humus, nitrogen, phosphorus and potassium content in the soil profiles from the plots with monocrops, crops rotation and perennial fallow land are indicated within the limits of the upper soil layer of 40 cm. A special effect of the long-term intensive treatment should be pointed out: considerable changes in the agrochemical characteristics of the subsoil of 20-40 cm than those of the topsoil. Subsoil of the arable land is known to have the humus content 2 to 3 times higher in comparison with the tillable layer, and the content of mobile forms of phosphorus and potassium - 8 to 10 times higher in comparison with the tillable layer (Table 4).

In tillable and one-meter-deep layers of comparable options from the plots with long-term crop rotation and from the monocrop plots, no significant differences in phosphorus and potassium balances were indicated. The effect of fertilizing on humus content, contents of mobile phosphorus and exchange potassium was indicated by insignificant differences determined by biological characteristics of cultivated crops. The minimum content of exchange potassium was found in the soil from the plots with potato and flax monocrops. The same content of exchange potassium was indicated in the soils from the plots with crop rotation. At the same time, potassium content was higher in the soils from the plots with rye and oat monocrops. Phosphorus content in the soils from the plots with monocrops, except clover, was significantly higher in comparison with the soils from the plots with crops rotation that was determined by the estrangement of the nutrition elements with main and side products.

Long-term application of mineral fertilizers, lime and manure appeared to change the soil characteristics up to the depth of 1 m. In the meantime, the scale of these changes in agrochemical properties are frequently higher in the subsoil than within it (Table 5).

Soil acidity has also changed due to long-lasting application of mineral fertilizers. Application of ammonia saltpetre and potassium chloride causes significant increase in exchange and hydrolytic soil acidity (Table 6). Occasional lime application (once every six years since 1949) slowed down the increase in soil acidity along the entire soil profile at non-fertilized plots, and at the plots with long-lasting application of mineral fertilizers - up to the depth of 40-60 cm.

Table 4

Changes in humus content, total nitrogen and exchange phosphorus and potassium in the soil profile of tillable land (manure + NPK) and fallow land in 60-year period after setting the long-term field experiment

Soil layer, cm	Perennial fallow land	Monocrops, without lime application					Crops rotation	
Humus, %								
0–20	2.19	1.06	2.30	1.96	2.16	1.71	2.16	1.93
20–40	0.46	0.53	1.40	0.89	0.96	0.80	1.30	0.85
40–60	0.31	0.26	0.39	0.28	0.21	0.26	0.38	0.21
60–80	0.07	0.18	0.32	0.22	0.16	0.16	0.28	0.16
80–100	0.05	0.12	0.15	0.14	0.14	0.15	0.13	0.09
N, $mg^{-100gsoil}$								
0–20	94	65	94	90	94	88	82	85
20–40	31	26	65	48	55	44	63	43
40–60	25	17	24	26	17	29	19	10
60–80	15	15	29	18	17	23	15	9
80–100	11	16	20	17	18	16	12	8
P_2O_5, $mg^{-100gsoil}$								
0–20	9.3	24.6	34.8	45.5	17.9	24.3	22.0	16.5
20–40	1.1	10.8	18.9	12.4	4.6	7.5	14.3	9.0
40–60	1.4	6.4	2.4	1.6	1.2	2.0	1.8	3.0
60–80	4.2	15.6	2.4	3.8	3.5	0.9	0.7	3.1
80–100	5.8	12.1	3.6	9.5	11.2	7.0	4.8	5.4
K_2O, $mg^{-100gsoil}$								
0–20	13.3	12.1	19.2	11.8	7.6	15.4	14.7	12.9
20–40	2.0	18.4	17.2	10.9	4.9	7.5	8.5	6.8
40–60	5.2	14.3	12.2	7.6	2.6	6.5	1.5	5.8
60–80	5.0	7.8	7.2	5.4	4.3	5.4	2.0	6.5
80–100	3.5	7.4	6.0	4.6	4.0	5.4	2.2	6.3

The negative effect of regular NPK application and crop cultivation on the changes in the acidity in the layer of 60-100 cm is indicated at the present time and proved by the high content of mobile aluminium toxic for the crops (Table 7).

Effects of crop rotations and monocrop cultivation on soil acidity in the upper part of soil profile (0-100 cm) do not differ significantly. The content of absorbed bases in the soil of the plots without lime application decreases up to the depth of 60-80 cm but the "gap" typical for the podzolic layer of fallow land, is not indicated (Figure 2).

Table 5

Effect of fertilizing on humus content, mobile phosphorus and exchange potassium contents in arable land (NPK +manure) and fallow land

Soil layer, cm	Fallow land		Permanently						Crops rotation without lime application	
			Fallow		Winter rye		Potato			
	1974	2011	1974	2011	1974	2011	1974	2011	1974	2011
Humus, %										
0–20	2.19	2.21	1.06	2.07	2.30	3.79	1.71	2.28	2.16	2.38
20–40	0.46	0.77	0.53	1.04	1.40	2.31	0.80	1.07	1.30	1.43
40–60	0.31	0.45	0.26	0.50	0.39	0.64	0.26	0.35	0.38	0.42
60–80	0.07	0.09	0.18	0.26	0.32	0.53	0.16	0.24	0.28	0.34
80–100	0.05	0.08	0.12	0.18	0.15	0.25	0.15	0.23	0.13	0.17
P_2O_5, $mg^{-100gsoil}$										
0–20	93	192	246	454	348	472	243	440	220	417
20–40	11	13	108	448	189	330	75	170	143	277
40–60	14	9	64	330	24	104	20	38	18	42
60–80	42	44	156	169	24	36	9	32	7	23
80–100	58	102	121	178	36	65	70	87	48	70
K_2O, $mg^{-100gsoil}$ *mg*										
0–20	133	473	121	513	192	600	154	365	220	417
20–40	20	90	184	524	172	557	75	570	143	277
40–60	52	115	143	505	122	390	65	252	18	42
60–80	50	113	78	492	72	172	54	128	7	23
80–100	35	158	74	395	60	168	54	140	48	70

For the time trend analysis humus, nitrogen, phosphorus and potassium contents in 1994 the soil samples from the depth of 40 cm were taken; in 2011 - partly the samples from the soil profiles of 1974 were taken repeatedly (Table 8).

Research conducted in 2011 detected the increase in 37-year period the humus content in the topsoil in the crops under the conditions of crop rotation due to increasing

Table 6

Effect of regular fertilization and occasional lime application under the conditions of crops cultivation on the changes in the ion-exchange soil properties in the one-meter layer

Soil layer, cm	Perennial fallow land	Crops rotation						Permanently, manure + NPK			
		Without fertilizing		NPK		manure + NPK		fallow	rye	flax	potatoes
		Without lime	lime	Without lime	lime	Without lime	lime				
pH_{HCl}											
0–20	5.53	4.19	6.23	3.86	6.27	4.15	5.96	3.69	4.80	4.18	5.50
20–40	4.39	4.10	4.70	3.90	5.61	4.10	5.31	3.76	4.82	4.14	4.61
40–60	3.90	4.55	5.05	3.96	4.10	4.36	4.00	3.80	4.66	3.76	4.73
60–80	3.75	4.91	4.70	3.70	3.76	4.09	3.76	3.80	3.85	3.65	3.72
80–100	3.86	5.18	4.41	3.60	3.91	3.98	3.59	4.17	3.54	3.82	3.96
Hydrolytic acidity, mg-eqv $^{-100gsoil}$											
0–20	2.20	4.37	1.13	6.67	1.23	5.19	1.76	4.97	2.80	3.63	2.07
20–40	2.38	4.47	2.57	5.98	1.84	4.62	1.92	4.28	2.14	2.68	2.36
40–60	4.14	1.75	1.31	5.61	3.02	2.12	3.80	3.55	1.61	4.32	4.14
60–80	4.57	1.50	1.80	6.83	5.66	3.02	5.37	3.41	3.52	4.61	3.67
80–100	3.26	1.15	1.98	6.69	3.56	3.16	5.48	2.43	4.32	3.05	2.65
Exchange acidity, mg-eqv $^{-100gsoil}$											
0–20	0.07	0.51	0.04	1.21	0.05	0.45	0.05	1.16	0.09	0.45	0.07
20–40	0.16	0.65	0.18	1.30	0.04	0.49	0.06	0.90	0.08	0.51	0.07
40–60	0.86	0.20	0.07	1.66	0.80	0.30	0.09	0.85	0.08	1.95	1.27
60–80	1.26	0.12	0.12	2.65	1.86	0.78	1.69	0.81	1.36	1.93	1.16
80–100	0.80	0.07	0.25	2.37	0.97	1.10	1.77	0.35	1.99	1.06	0.65
Content of absorbed bases, mg-eqv $^{-100gsoil}$											
0–20	8.6	4.4	10.0	4.7	11.9	5.5	10.4	3.3	5.3	3.5	4.1
20–40	3.9	4.0	4.3	4.8	8.5	4.8	7.5	6.2	5.1	2.1	3.0
40–60	8.7	3.6	4.2	4.6	6.7	4.4	8.3	8.5	5.6	6.0	8.4
60–80	8.3	5.9	8.0	8.0	9.8	5.4	11.2	9.9	7.2	8.3	7.6
80–100	6.1	6.6	8.7	8.6	7.4	6.0	11.2	9.8	5.5	7.1	9.1

Table 7

Comparable content of mobile aluminium in tillable land and fallow land, mg-eq-$^{1006ls°"}$

Options	Soil layer, cm				
	0-20	20-40	40-60	60-80	80-100
Fallow land	0.5	1.3	7.4	10.8	7.0
Arable land: NPK	11.6	12.6	16.2	25.6	22.9
NPK +lime	0.3	0.2	7.2	17.5	9.2

Table 8

Dynamic of humus content in topsoil and subsoil in 1974-2011

Years	Character-istics	Soil layer, cm	Crops rotation			Permanently, manure+NPK	
			No fertili-zation	NPK	Manure+NPK	Rye	Potato
1974	Humus,%	0-20	1.46	1.8	2.1	2.31	1.7
		20—40	1.19	1.41	1.32	1.41	0.8
	C/N	0-20	13.4	15.3	14.4	16.1	11.2
		20—40	11.2	14.0	12.3	12.9	10.6
1994*	Humus, %	0-20	1.82	1.81	2.18	4.6	1.98
		20—40	0.79	0.96	1.5	2.03	1.0
	C/N	0-20	14.9	13.5	13.8	19.4	14.0
		20—40	12.1	11.4	9.4	13.6	12.1
2011	Humus, %	0-20	1.62	2.38	2.81	3.79	2.28
		20—40	1.32	1.33	1.5	0.79	1.23

* Results are obtained at Berlin University by means of a non-invasive automatic device Strolein Cmat without preliminary destruction of the natural soil structure

the volume of crops remains: variants without fertilizing - increasing by 4.8 t^{-ha}, NPK - 17,4 t^{-ha}, common effect of crop remains and manure application (20 t^{-ha}) - 21.3 t^{-ha}.

In the subsoil the increase in the humus content on average by 3.9-5.4 t^{-ha} due to vertical migration of water soluble organic substances.

The same trends in changing the characteristics of soil fertility are observed in the lower layers (40-100 cm) of the soil profile's upper part (Figure 3).

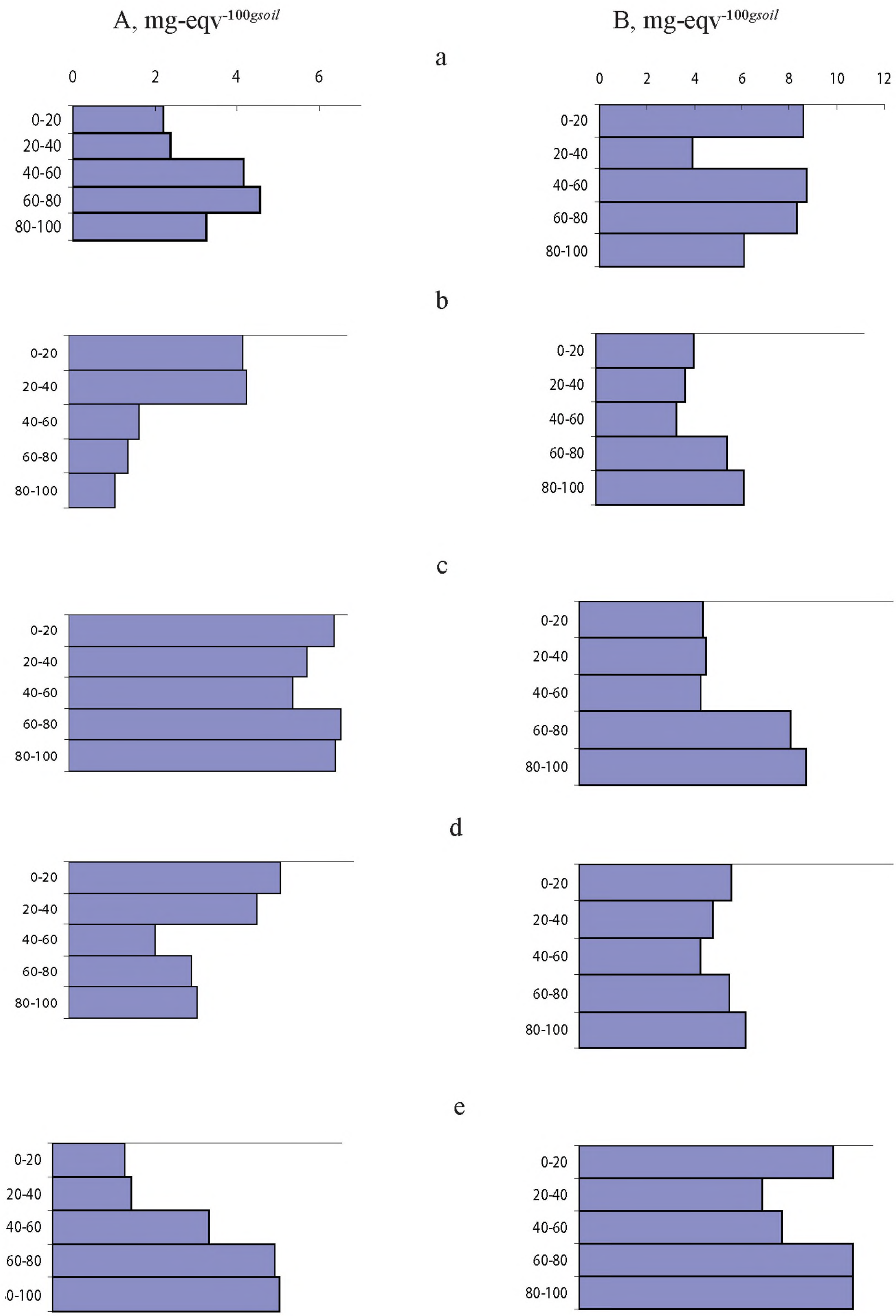

Fig. 2. Effect of long-term fertilizing and ameliorants application on hydrolytic acidity (A) and content of absorbed bases (B) in soil profile: a - perennial fallow land, b - without fertilization, c - NPK, d - manure + NPK, e - manure + NPK+ lime in 6-field crop rotation

The same trend in humus distribution in the soil profile of the fallow land plots is determined to have established within 100 years of the long-term field

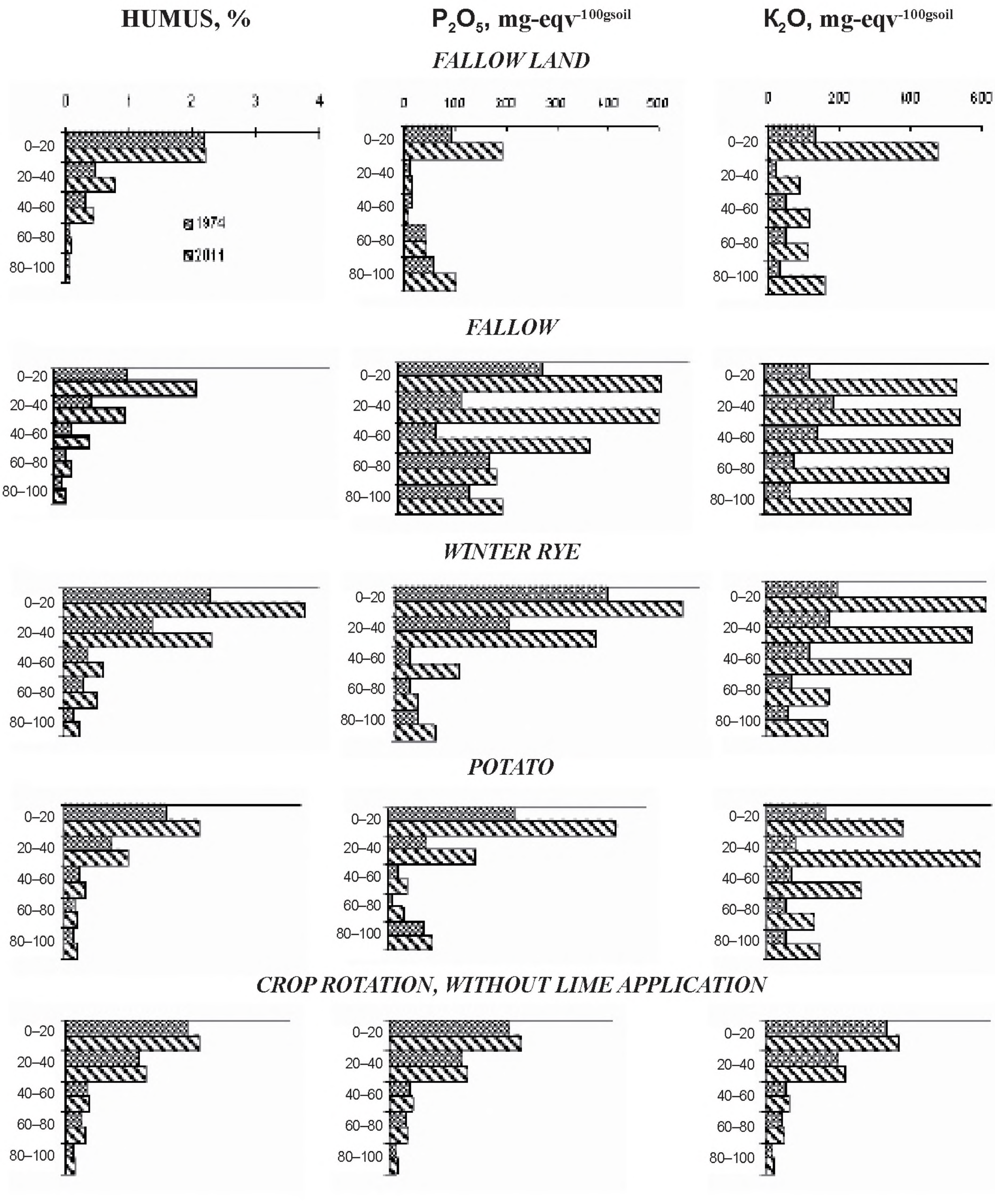

Fig. 3. Deviations in humus (%), mobile P_2O_5 and exchange P_2O_5 (mg-eqv $^{-100gsoil}$) in one-meter soil profile

experiment (2011). Humus content distribution in 2011 was of the similar pattern to that of 1974, but it increased insignificantly in the layer of 20-60 cm (0.14-0.21 %). The same trend in mobile phosphorus and exchange potassium distribution with double their content in all the layers was indicated.

Tillable land exposed to environmental and anthropogenic inputs of different degree (fallow, crops requiring tilling between the rows, dense seeding crops) reacted to changes in soil properties and regimes by significant increase in humus content and nutrient content throughout the entire one-meter soil profile, especially at fallow plots - humus content doubled, phosphorus and potassium contents increased by 5-8 times. In the meantime, potassium was equally dispersed accross the soil profile depth due to the migration process and mobile phosphorus was accumulated mainly in the layer of 0-40 cm. The monocrop of winter rye in comparison with that of potato and synergic effect of the crops in crop rotations caused more significant improvement of soil characteristics.

Improvement of soil characteristics in the root growing layer (0-40 cm) under the effect of crop cultivation, fertilizing and lime application during the 100-year period was indicated by increasing the agrocenosis productivity.

The mean yield of winter rye on the plots without fertilizing increased by 3 times during the 100-year period due to selecting more suitable varieties and improving cultural practices; at the plots with complete dozes of mineral fertilizers, the mean yield of winter rye increased from 0,9 t^{-ha} in the period of two first crop rotations (1912-1924) up to 2.5 t^{-ha} in the recent years.

The mean yield of potatoes insignificantly varied within the crop rotations: from 6.0-12.0 4 t^{-ha} at the plots without fertilizing up to 10.0-12.0 t^{-ha} during the first 36-year period of the research up to 20.0-25.0 t^{-ha} in subsequent years.

Conclusions

1. As a result of 100-year arable treatment, effect of soil treatment, fertilizing and crops cultivation, significant changes in agrochemical characteristics in one-meter profile of sod-podzolic loamy soil was indicated in upper part of subsoil that coincides with the podzolic layer which is unfavorable for crop cultivation. Scope and directions of changes in agrochemical characteristics of the soil are tightly connected with the intensity and type of topsoil treatment and mainly determined by lime application and regular application of organic and mineral fertilizers.

2. Principal differences in the formation of agrochemical characteristics in the soil of one-meter profiles from the plots of comparable options with crop rotation and monocrops have not been revealed. Specific effect of various crops cultivation and cultural practices were mainly indicated in humus content, content of total and exchange nutritious elements in roots growing layer of 0-40 cm.

3. Long-term ammonia saltpetre and potassium chloride application produces negatively affected absorption properties and the acidity of entire soil profile without lime application.

All types of acidity increase, the content of mobile aluminium significantly increases and total content of absorbed bases decreases when NPK is applied.

Occasional lime application slows down acidity increase along the entire soil profile at the plots without fertilizing thus creating favorable conditions for crops cultivation up to the depth of 4-60 cm at the plots with long-lasting lime application before fertilizing with NPK.

Negative effect of physiologically acid mineral fertilizers on soil acidity in the layer of 60-100 cm is not completely eliminated by occasional (once in six years) lime application.

4. Improvement of soil properties leads to the yield increase of the following crops: potato - 2.0-2.5 times, winter cereals - 3.0-4.0 times.

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ТРАНСФОРМАЦИЯ ВЕРХНЕЙ ЧАСТИ ПОЧВЕННОГО ПРОФИЛЯ ДЕРНОВО-ПОДЗОЛИСТЫХ ЛЕГКОСУГЛИНИСТЫХ ПОЧВ ПРИ ДЛИТЕЛЬНОМ ОКУЛЬТУРИВАНИИ (К 100-ЛЕТИЮ ДЛИТЕЛЬНОГО ОПЫТА ТСХА)

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Аннотация: длительное применение минеральных и органических удобрений в сочетании с периодическим известкованием как при бессменном возделывании полевых культур, так и в севообороте повышает исходный уровень окультуренности дерново-подзолистой легкосуглинистой почвы, что обеспечивает устойчивую урожайность озимых зерновых на уровне 4,5-5,5 т/га зерна, 20-25 т/га картофеля и 6-8 т/га сена многолетних трав при снижении степени деградации почвы до экологических нормативов.

Ключевые слова: почвенный профиль, длительный опыт, гумус, общий азот, подвижный фосфор, обменный калий.

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