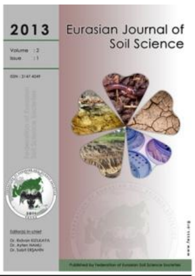
Eurasian Journal of Soil Science

Journal homepage : http://fesss.org/eurasian_journal_of_soil_science.asp



Transformation of upper part soil profile of sod-podzolic light loamy soils under the conditions of long-term soil improvement

(To centerary of the long-term field experiment at Russian State Agrarian University-Moscow Timiryazev Agricultural Academy)

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Article Info

Received : 05.01.2013
Accepted : 25.03.2013

Abstract

Arable sod-podzolic soils have the definite characteristics inherited from the virgin soils and obtained during the modern process of soil genesis under the influence of mankind activity. In arable soils hydrothermal conditions, biological turnover of nutrients change significantly that connected with their taking out with the yield and the compensation with mineral and organic fertilizers.

The period of agricultural treatment of the soils indicates the total influence of the intensification factors and causes the changes in characteristics, regimes and fertility not only of arable layer, but lower layers of the upper part of soil profile (0-100 cm).

Keywords: soil profile, long-term experiment, humus, total nitrogen, mobile phosphorus, exchangeable potassium

Introduction

In 2012 the Long-term field experiment at Russian State Agrarian University-MTAA known abroad as "Moscow Stationary" has the 100-year period of its establishing. As to the number and importance of the conducted researches this field experiment is included into the list of the unique experiments with the world value for the agronomical science. The first scientific and agronomical experiments on researching the fertilizers established in England soon after the publishing in 1840 "The Minimum Law of Libikh", or the limiting factor related to the plants nutrients. In the second part of the XIX century "the wave of the field experimenting covered" the other countries in Europe and in the North America.

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

The founders of the 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 scientists considered the field experiment as the main method for the research of the factors of plants life and the soil fertility.

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ISSN: 2147-4249

During the 100-year period the scientists of the various specialties from Timiryazev Academy, other institutions and research organization, both Russian and foreign, conducted researches at this Long-term field experiment.

The value of the results of the scientific researches is proportional to the duration of the field experiment and increases in process of approach of the experimental plot to the ecophytocenosis balance. In a long-term field experiment_there is the partial compensation of the 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 agrotechnical treatments on the basis of the variety of the environmental factors are accumulated in the time period that advocate to solve the agricultural and environmental problems of definite soil and climatic zone. The long-term field experiments allow monitoring the humus content, nutrients content and circulation, including the microelements content, the dynamic of the soil pollution with heavy metals, toxins and the means harmful for the biosphere and the humankind. There is the possibility on the basis of the pedo – and agronomical background of the long-term field experiments to evaluate and predict the possible negative consequences of the implementation of these means. The effect of many biological and technological factors on the soil fertility and plant efficiency becomes evident only after tens years.

Therefore, the long-term field experiments are irreplaceable for education purposes as a demonstrational materials and "live educational facilities". The listed advantages of the long-term field experiments allow coming to the conclusion to preserve them as "the field laboratories". The long-term field experiments have to be in free access for the scientists all around the world (Christensen Bent and Trentemoller, 1995; Dospekhov et al., 1976, 1980; Kiryushin, 1978; Puponin, 1984).

Material and Methods

Agrotechnical basis, conditions and methodology of the long-term field experiment

Experimental plot of 1,5 hectares was the part of the 12th field in farm crop rotation at Timiryazev Academy. In the period of 1894-1901 on this field with the double-sided north-west slope of 1° the following crops were cultivated: 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 as a hay within this period didn't exceed 10-12 quintal ha^{-1}. In 1902 the field was under the black steam. In the period of 1903-1911 there was the following crops rotation: rye – potatoes – oat with undersowed grasses – grasses – grasses – oat – black steam – 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^{-1} was implemented only in 1909 that caused the double increase of grasses yield. Therefore, the plots of the field experiment were splited on the grass turf ground.

Soil – sod-podzolic, long arable, acid, overflowed (Podsollivisol on 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. The carbonate tracks (HCl light bowling) are indicated in the 3rd meter (Table 1).

Table 1. Average characteristics of arable soil layer fertility, 1972

Characteristics	**Value**
Physical sand (particles > 0,05 mm),%	46
Density of solid phase, g cm^{-3}	2,65
Soil density, g cm^{-3}	1,53
Maximum hyhgoscopics (mg), %	1,25
Field humidity, %	19,2
pH	5,2
Humus carbon (C), %	1,03
N (general content),%	0,079
C/N	13
P_2O_5 (mobile), mg 100 g^{-1} soil	23,5
K_2O (exchangeable), mg 100 g^{-1} soil	13,3
Content of exchange bases, meq 100 g^{-1} soil	9,7

Scheme of the Long-term field experiment

As the basis for the scheme the approbated analogue of the Long-term field experiment in Goettingen (Germany) established by Dreksler to research the effect of nitrogen, phosphorus and potassium separate and combined implementation on crops fertility was taken. In 1912 before sowing the summer crops 6 fields were established, each divided into 2 parts by the road of 3 m length.

On the first part of the field (size of the field – 1 400 m^2) monocrops were cultivated: winter rye, potatoes, oat, clover, flax and black steam. On another part (size of one field – 1 200 m^2) the 6-field crops rotation was implemented: black steam – winter rye – potatoes – oat with undersowed clover – clover –flax. Across 6 fields with monocrops 11 plots with variants of the fertilizers were splited: 1- N; 2 – P; 3 – K; 4 – 0 (without fertilizing); 5 – NP; 6 – NK; 7 –PK; 8 – NPK + manure; 9 – NPK; 10 – manure; 11 – 0 (without fertilizing). The same variants excluding the 10^{th} and the 11^{th}, were implemented on the fields with crop rotations.

The size of registration plot was 100 m^2, the size of arable plot was from 127 up to 133 m^2 accordingly. After the lime implementation on the half part of all the fields the size of registration plot was 50 m^2.

Agrotechnology improvement

The most significant agrotechnological improvements in the Long-term field experiment are connected with the doses of the fertilizers and proportions of the nutrients in these fertilizers. According to these factors four periods within the 100-year period of the experiment's implementation are defined (Table 2).

Table 2. Fertilizing system in the long-term field experiment (mineral fertilizers – kg ha^{-1}, manure and lime – t ha^{-1})

Period	Dose of fertilizers				Amount of fertilizers				
	N	P_2O_5	K_2O	manure	N	P_2O_5	K_2O	manure	lime
I (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

Modifications in the scheme of the long-term field experiment

As pointed Egorov (1972) and Dospekhov (1975), in the period of the first 60 years after establishing the Long-term field experiment there were no principal changes in the scheme of the experiment. However, in process of obtaining the results of the researches, various improvements of the scheme were undertaken. As the concept "experimental scheme" means, first of all, concrete variants, it is worth detailing three following changes of the basic scheme:

1. Up to 1937 nitrogen in nitrate form (up to 1921 - Chilean saltpetre, then Norwegian saltpetre, from 1924 – natron saltpetre) was studied in the 8^{th} variant. Nitrogen in ammoniac form (sulphate ammoniac) was studied in the 9^{th} variant (NPK from 1912). In 1938 there was the lime implementation on all the plots of the 8^{th} variant (one occasion doze – 2,5 t ha^{-1}) and manure implementation in doze of 20 t ha^{-1}. This doze of manure was studied up to 1948 and in 1949 the final scheme of the 8^{th} variant was formed – NPK + manure.
2. The first most important changing to the scheme was carried out by Egorov in 1949. It is connected with the introduction into the scheme the lime as the 3^{rd} studied factor. The doze of lime calculated on hydrolytic acidity was 4,57 t ha^{-1} of limestone (83 % Ca +Mg in proportion of 2:1). New variants were established by the splitting of the basic plots into two parts. Crops yield was considered separately from the plots with lime implementation and from the plots without lime implementation. At the same time the permanent steam was studied only on the plots without lime implementation, and on the plots with lime implementation the crop rotation in time period was studied. Since the 2^{nd} rotation the crops rotation began to correspond to the basic crops rotation.
3. The first principal changing to the scheme was carried out by Dospekhov in 1973. On all the plots of the even fields with crop rotation the common form of the fertilizers was implemented (NPK), in 1978 the lime in doze of 4,5 t ha^{-1} was implemented. On the odd fields studying 9 variants of the basic scheme with the differential fertilizing both with lime implementation and without lime implementation was continued. After the introduction of the new variants both the informational content and the scope of the researches increased.

Results and Discussion

Systematical implementation of organic and mineral fertilizers along with the periodical lime implementation are 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 the various factors: basic soil characteristics, types, doses and combinations of the fertilizers, and the special requirements of the cultivated crop. In the period of the first 60 years after the establishing the Long-term field experiment the various levels of the anthropogenic input received by each of 200 plots determined the repeated differences in humus and nutrients content (Table. 3).

Table 3. Effect of long-term soil treatment (1912-1972) on the potential soil fertility (average dozes of fertilizers and ameliorants: N36P44K51; manure – 16 t ha^{-1}, lime* - 0,5 t ha^{-1})

Soil characteristics	Perennial fallow land	Effect of monocrops and crops rotation implementation						
		Crops rotation	Steam**	Rye	Potatoes	Oat (barley)	Clover	Flax
Humus content, %	2,19	1,76	0,89	2,02	1,49	1,77	1,70	1,84
P2O5, mg 100 g^{-1} soil	93	89	150	182	147	134	96	134
K2O, mg 100 g^{-1} soil	133	91	134	133	86	125	78	102
pH_{HCl}	5,3	5,0	3,9	5,4	5,2	5,5	5,0	5,1

* lime implementation – once in every 6 years since 1949
** in comparison with the plots without lime implementation

It is worth paying attention the fact that the soil characteristics of the fertilized plots of the 6-field crops rotation with clover and steam are inferior to the not-fertilized plots with perennial fallow land. Monocrop of rye determines the establishing the favorable soil characteristics in comparison with the soil characteristics determined by the other monocrops or crops rotations. Humus content on the plots with the other crops (2, 02%) is close to the humus content (2,19%) on the plots with fallow land. The considerable losses of humus content during the 60-year period are indicated on the plots with monocrop of potatoes (21 t ha^{-1}) and steam (36,1 t ha^{-1}). Monocrops of summer cereals, clover and flax determined not significant losses of humus content.

The value of the Long-term field experiment, as the unique one in the world, is determined by establishing, since its foundation (1912), the plot with the steam that splited into the plots with the different doses of the fertilizers. For example, the plot with the steam was introduced in the scheme of Rothamsted long-term field experiment only in 1959 on the meadow with cattle pasture.

Results of the researches show the definite tendency to decreasing the carbon content during the steam treatment of the sod-podzolic loamy soil, moreover the rate of the annual losses is determined by the doses of implemented mineral and organic fertilizers. The considerable losses were indicated on the plots without fertilizing where during the first 10-year period the carbon content decreased by 37,5 % in comparison with the basic level (1,20%). During the next decennials the mineralization rate of the organic substance decreased that connected with obtaining the critical carbon content (0,48-0,52%) determined by the granulate content of this soil type. Implementation of mineral fertilizers in full doses (NPK) decreased the carbon decomposition rate in soil and the level of carbon content was 0,81-0,89%. Annual manure implementation (in average 17,7 t ha^{-1} during the 100-year period) defined steady or positive balance of carbon with the seasonal variations from 1,21 up to 1,27% on the plots with steam implementation.

It is necessary to underline, that during the period of global climatic warming (1995-2010) the losses in carbon content decreased independently on the level of fertilizing that connected with the erosion processes both on the plots with steam implementation and on the horizontally adjacent plots (Figure 1).

Under the conditions of biocenosis of perennial fallow land the definite tendency of maintaining the positive carbon balance was indicated. The carbon content during the 100-year period decreased up to 0,11 % or 3,3 t ha^{-1} As it was determined previously (Dospekhov et al., 1975, 1976, 1980), the long-term fertilizing and periodical lime implementation of arable soil layer are the efficient methods of under arable layers treatment even with constant depth of ploughing of 20-22 cm. One-meter soil profiles on all the plots with monocrops and on two plots with crops rotation were studied systematically in 1974 at first time, secondly – in 2011.

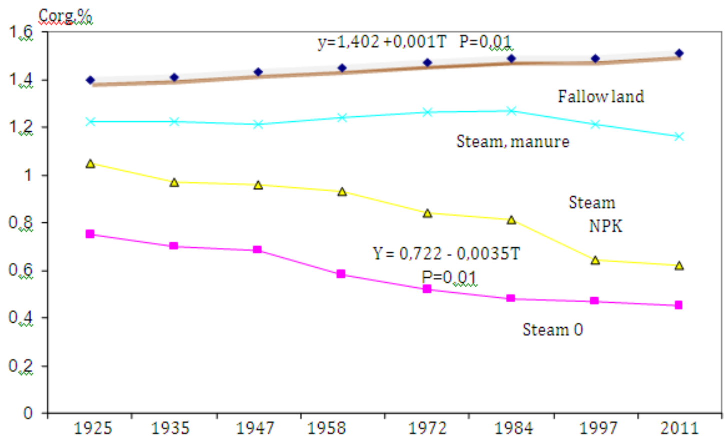

Figure 1.Carbon content rate (Corg,%) on the plots with permanent steam and adjacent fallow land

Results on the evaluation of the soil characteristics along the soil profile not only contributed to the general knowledge on soil treatment, but became the basis for the scientific view to the minimizing of the soil treatment, and, first of all, partially "non-tillage" soil treatment implementation (Christensen Bent and Trentemoller, 1995; Egorov, 1972). Long-term arable treatment causes changing in the morphological characteristics, physical and chemical characteristics, humus content and nutritious balance not only in the arable layer, but in lower layers as well.

Under the long-term crops cultivation the depth of the arable layer increased by 6-15 cm in comparison with the fallow land soil and obtained 24-30 cm. Morphological differences between the soil profiles from the plots with monocrops and crops rotation and the soil profiles from the plots with perennial fallow land are determined by long-term soil treatment, repeated fertilizing and periodical lime implementation in the conditions of crops cultivating.

The significant differences on humus, nitrogen, phosphorus and potassium contents 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. It is necessary to underline the special effect of the long-term treatment: considerable changing the agrochemical characteristics of the under arable layer of 20-40 cm than the agrochemical characteristics of the arable layer. Under arable layer of the arable land has the humus content in 2-3 times higher in comparison with the arable layer, and the content of mobile forms of phosphorus and potassium in 8-10 times higher in comparison with the arable layer (Figure 2).

In arable and one-meter layers of comparable variants from the plots with long-term crops rotation and from the plots with monocrops the significant differences in phosphorus and potassium nutritious balances are not indicated. Effect of fertilizing on humus content, contents of mobile phosphorus and exchange potassium was indicated by the not significant differences determined by the biological characteristics of cultivated crops. The minimum content of exchange potassium was in the soil from the plots with monocrops of potatoes and flax. The same content of exchange potassium was indicated in the soils from the plots with crops rotation. At the same time, potassium content was higher in the soils from the plots with monocrops of rye and oat. 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 determined by the estrangement of the nutrition elements with main and side products.

Lasting mineral fertilizers lime and manure implementation changes the soil characteristics up to the depth of 1 m. Meantime, the scales of changing the agrochemical characteristics are frequently higher in under arable layers than in arable layers.

Redistribution in humus content and nutrients content in the upper part of soil profile defined by the arable usage doesn't reflect the real level of fertility of the soil in comparison with the virgin soils. The precise characteristics of soil fertility, humus content and nutrients content are obtained in comparison of the profiles of virgin and arable soils that are equal in depth.

These characteristics describe the profile of 0-30 cm that in our researches is taken as the arable layer and that accumulate the significant mass of crops rests and implemented fertilizers.

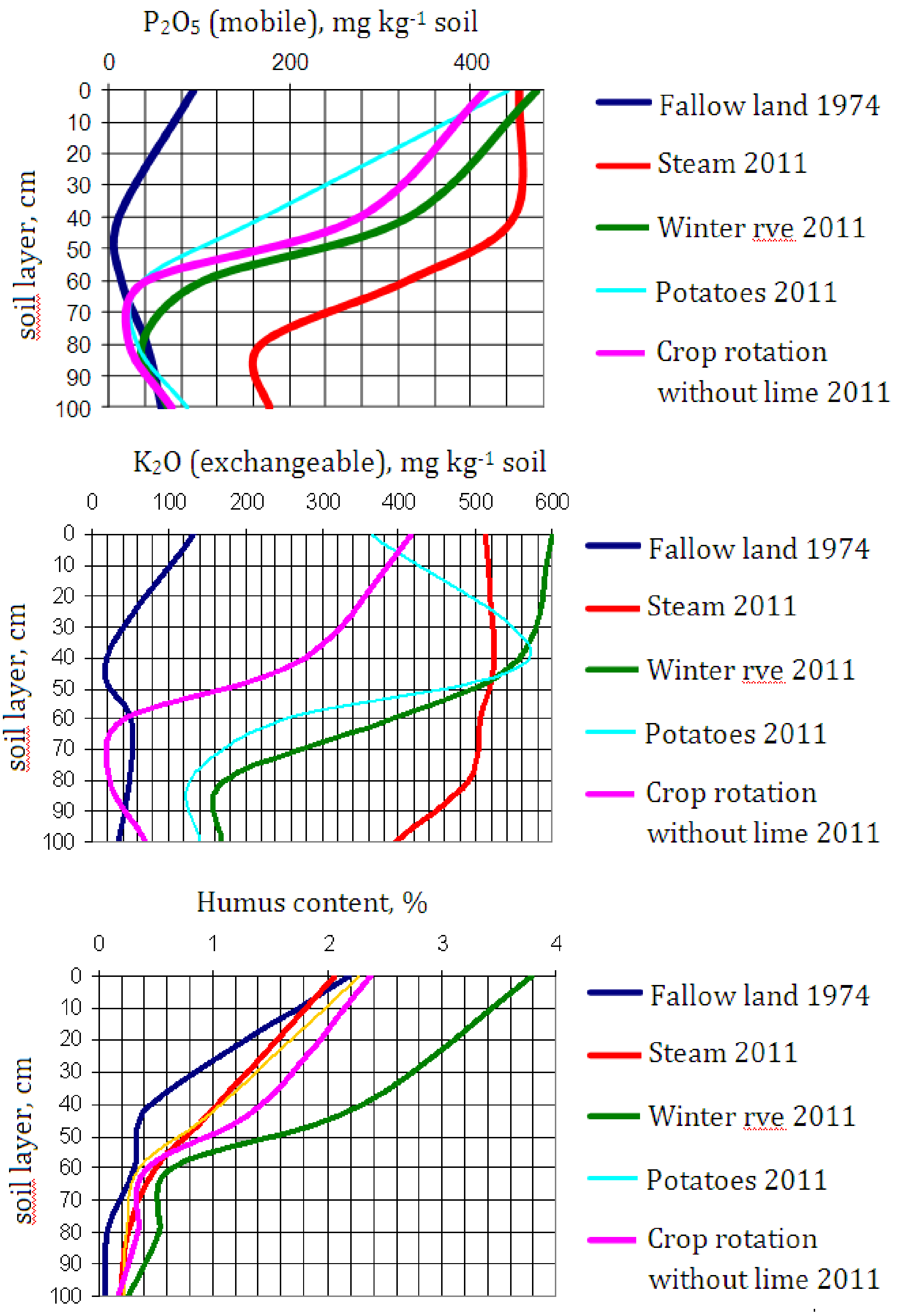

Figure 2. Dissemination of humus, mobile phosphorus and exchange potassium in the profile of sod-podzolic soil ($N_{100}P_{150}K_{120}$ + $manure_{17,7}$)

The layer of 0-50 cm characterizes, in general, accumulative and elluvial depth, but the layer of 0-100 cm characterizes the most stable humus content and nutrients content that maintain the plants vegetation in extreme conditions (Table 4).

Table 4. Changes in humus content (t ^{ha}) along the profile of sod-podzolic soil , 2011

Variants	**Humus content (t ha^{-1})**					
	soil profile, cm			**percentage from the humus content in fallow land**		
	0-30	**0-50**	**0-100**	**0-30**	**0-50**	**0-100**
Fallow land	76,5	96,2	108,0	-	-	-
Permanently: Steam	47,7	70,8	91,5	62	74	85
Winter rye	148,3	192,6	225,6	194	200	209
Potatoes	84,4	105,8	125,1	110	110	112
Crops rotation	92,9	120,6	142,2	121	125	132

In arable sod-podzolic loam soils humus content and nutrients content are tightly connected with the intensity level of arable treatment and dozes of mineral and organic fertilizers. During the 100-year steam implementation along with applying of high dozes of mineral ($N_{100}P_{150}K_{120}$) and organic (17,7 t ha^{-1}) fertilizers humus content in the layer of 0-30 cm decreases at 38%, in the layer of 0-50 cm - at 26%, and in the layer of 0-100 cm – only at 15% in comparison with fallow land.

The other tendencies in humus content are indicated in connection with the cultivation of the crops on the same level of the nutrition both permanently or in crops rotation.

Permanent winter rye caused significant positive balance of the organic matter in all the soil layers, but potatoes caused only maintenance of the positive balance. Rotation of the crops on the same level of the nutrition caused the decrease of humus content level in comparison with permanent winter rye, but caused the higher level of humus content in all the soil layers in comparison with potatoes.

Lasting mineral fertilizers implementation changes soil acidity. Application of ammonia saltpetre and potassium chloride causes significant increasing of exchange and hydraulic acidity (Figure 3). Periodical lime implementation (once in each six years since 1949) halted increasing the soil acidity along entire soil profile on the plots without fertilizing, and on the plots with lasting implementation of mineral fertilizers – up to the depth of 40-60 cm.

Conditions and intensity of arable treatment cause the significant influence on the changes of ion-exchange soil characteristics. On the plots with 100-year steam implementation without lime applying even along with NPK + manure implementation the high level of hydrolytic acidity, especially in the layer of 0-40 cm, and low level of content of exchange bases are indicated.

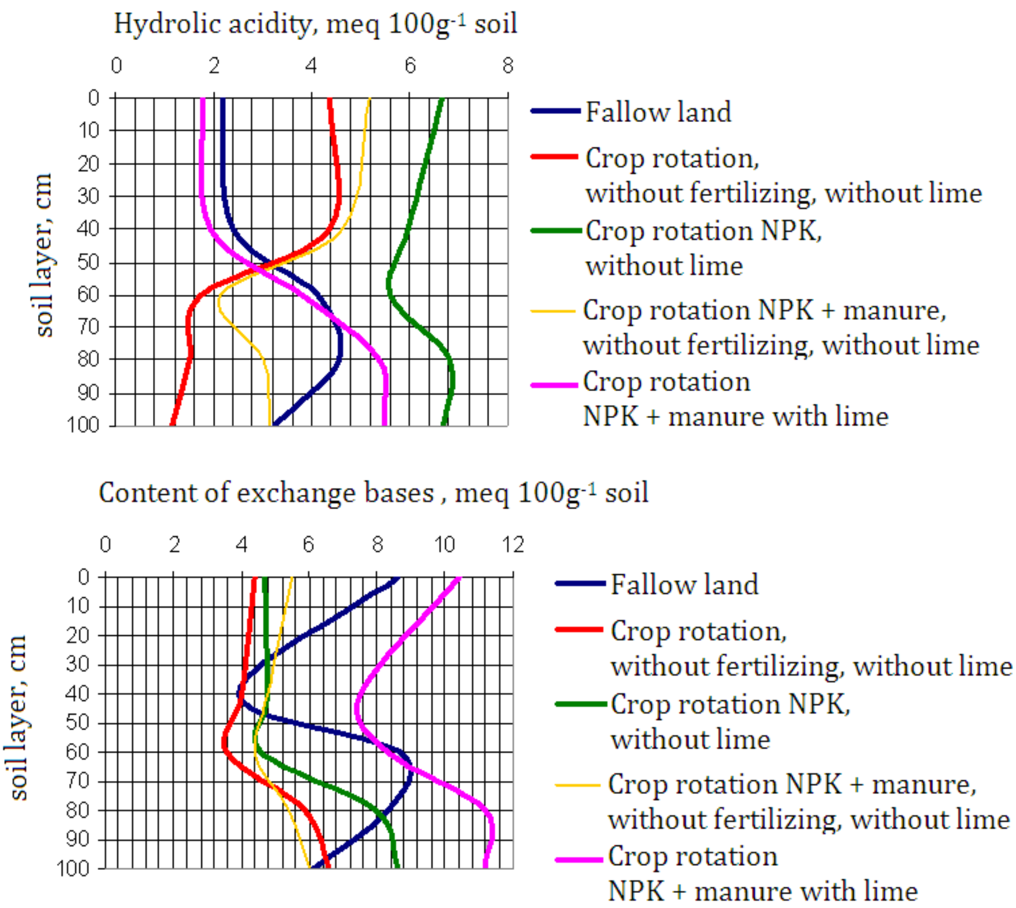

Figure 3. Changes of physics and chemical soil characteristics under the influence of fertilizing and lime implementation

Cultivation of winter rye as the crop with the high quantity of the rests, stabilizes the level of hydraulic acidity in the layer up to 0-60 cm, and cultivation of potatoes – only in the roots growing layer (Figure 4).

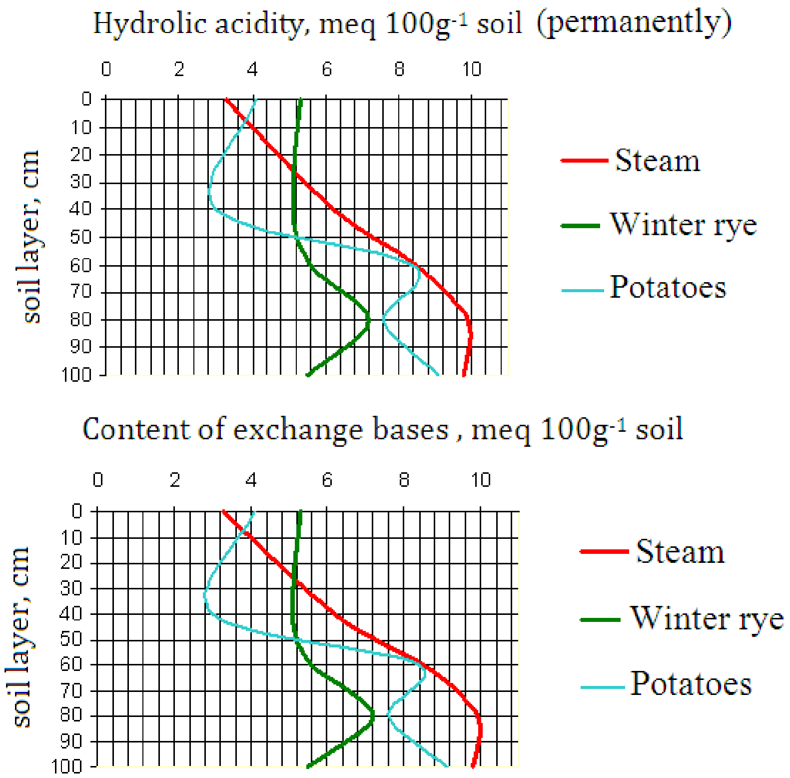

Figure 4. Changes in ion-exchange soil characteristics under the different levels of arable treatment

The negative effect of systematic NPK implementation and crops cultivation on changing the acidity in the layer of 60-100 cm is indicated at the present time and proved by the high content of mobile aliminium that cases the toxic environment for the crops (Table 5).

Table 5. Comparable content of mobile aluminium in arable land and fallow land, meq 100g^{-1} soil

Variants	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

Effects of crops rotations and monocrops cultivation on soil acidity in the upper part of soil profile (0-100 cm) don’t differ significantly. Content of absorbed bases in the soil of the plots without lime implementation decreases up to the depth of 60-80 cm, but, the typical for podzolic layer of fallow land “gap”, is not indicated. Improvement of soil characteristics in roots growing layer (0-40 cm) under the effect of crops cultivation, fertilizing and lime application in the 100-year period was indicated by increasing the agrocenosis productivity.

Mean yield of winter rye on the plots without fertilizing increased in 3 times during the 100-year period due to introducing the new varieties and improvement of agrotechnical treatment; on the plots with complete dozes of mineral fertilizers mean yield of winter rye increased from 0,9 t ha^{-1} in the period of two first crops rotations (1912-1924) up to 2,5 t ha^{-1} in the recent years.

Mean yield of potatoes not significantly varied within the crops rotations: from 6,0-12,0 4 t ha^{-1} on the plots without fertilizing up to 10,0-12,0 t ha^{-1} during the first 36-year period of conducting the researches and to 20,0-25,0 t ha^{-1} in subsequent years.

Conclusion

As the results of 100-year arable treatment, effect of soil treatment, fertilizing and crops cultivation the significant changing of agrochemical characteristics in one-meter profile of sod-podzolic loamy soil was indicated in upper part of under arable layer that coincide with the podzolic layer which is not favorable for crops cultivation. Scales and directions of changing the agrochemical characteristics in soil are tightly connected with intensive level and type of soil treatment and mainly determined by implementation and systematical implementation of organic and mineral fertilizers.

Principal differences in formation of agrochemical characteristics in the soil of one-meter profiles from the plots of comparable variants with crops rotation and monocrops are not indicated. Specific effect of various crops cultivation and agrotechnical treatments mainly indicated in humus content, content of total and exchange nutritious elements in roots growing layer of 0-40 cm.

Lasting ammonia saltpetre and potassium chloride implementation produces negative effect on absorb characteristics and acidity of entire soil profile without lime implementation.

All types of acidity increases, the content of mobile aluminium significantly increases, total content of absorbed bases decreases at the phone of NPK implementation. Periodical lime implementation halts increasing acidity along entire soil profile on the plots without fertilizing and causes creating the favorable conditions for crops cultivation up to the depth of 4-60 cm on the plots with lasting lime implementation before NPK fertilizing. Negative effect of physiologically acid mineral fertilizers on soil acidity in the layer of 60-100 cm is not completely eliminated by periodical (once in each six years) lime implementation. Improvement of soil characteristics causes increasing of the crops yield: potatoes – 2,0-2,5 times, winter cereals – in 3,0-4,0 times.

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