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The New Methods for Assessing Soil Fertility Changes in the Apple Orchards in the North-Eastern Part of the Central Black Earth Region

Vyacheslav L. Zakharov*

Yelets State Bunin University, Yelets, Lipetsk region, Russian Federation;
monblan.pro@yandex.ru

Abstract

This study is aimed at implementing the new methods for assessing changes in soil properties in the Tambov and Lipetsk Regions occurring in time and space under the influence of the low-growing apple orchard and fallow. The paper presents data on the physicochemical and physical parameters of various types of soils in the apple orchards in the north-eastern part of the Central Black Earth area. The apple orchard impact on soils as compared to the natural lands is estimated. The approaches to assessing soil transformations in the apple orchards are suggested. Each method application is exemplified in the form of tabulated data. Contours of the decreased content of moisture, nitrogen, phosphorus, and calcium as well as the area of increased hydrolytic acidity in the apple tree rhizosphere were determined. When implementing all the recommended approaches, the most objective and complete assessment of the soil properties transformation in orchards is provided. The soil type profile demonstrates the comparative value of the removal of soil nutrients and elements of the soil compaction, acidulation, drying, and degradation, decrease in its biological activity, and, consequently, decrease in fertility. The changes in soil properties in the apple orchards occurring in space are documented through the graphical assessment, changes in time – through the individual assessment, properties deviation from the reference values – through the absolute and comparative assessment, and changes in fertility – through the bioindication. The value of the agricultural engineering impact on soil in horticulture is significantly higher than in field crop cultivation.

Keywords: Apple Tree, Bioindication, Fertility Assessment, Roots, Soil Type

1. Introduction

The soil exhaustion in an apple orchard leads to the unilateral substances circulation unbalanced by nutrients and to the reduction in the plantations productivity[1]. The paramount reason for the soil exhaustion is the unilateral orchard's impact on soil, which in turn leads to reduction in the term of this cropper usage in the production process[2]. In the north-eastern part of the Central Black Earth area, no studies were conducted that concerned the influence of an apple orchard on the fertility of various soil types. The existing approaches to the assessment of the orchard agrocenoses living activities allows us to judge on the condition of the trees themselves[3,4], on their formation and placement[5], on the location of roots[6], and on the suitability of land plots[7,8], rather than on the transformation of soils. Extending the lifetime of orchards is increasingly considered only from the perspective of influencing on plants either by cutting[9], or fertilizing[10]. Therefore, the objective of this paper was to assess the changes in soil properties in the Tambov and Lipetsk Regions occurring in space and time under the influence of a low-growing apple orchard, and to evaluate the role of fallows in the soil fertility restoration.

* Author for correspondence

2. Literature Review

For 16-20 years, an apple orchard adversely affects the soil fertility indicators. Due to the tillage, the 0-40 cm layer features decrease in the content of agronomically essential and water-stable aggregates. The 0-80 cm layer demonstrates reduction in the content of nitrogen, phosphorus, potassium, calcium, and humus as well as increase in acidity. As a result of the reducing amount of humus and major nutrient elements, the minimum moisture-holding capacity of the entire 1.5 meter soil profile is reduced, and the density increases. According to the data provided by some authors, soil grassing improves biological activity, reduces the risk of erosion and loss of nutrients[11], increases the content of organic substances[12] and at frequent mowing, does not consume much moisture[13]. In other experiments (the Krasnodar Region), the soil was dried by grass to the depth of 2 m by 4-9% compared to the weed-free fallow, but particularly strong drying occurred at the depth of 15-70 cm, i.e., in the concentrated root zone. Only in the late fall, the soil moisture level was balanced both in the turf and fallow areas[14]. Despite the experts' efforts to improve the quality of tillage[15], the problem of soil cover degradation in horticulture remains open.

3. Methodology

The studies were conducted in 2001-2010. The study objects were the most prevalent types of soils in orchards and 8-10 year-old fallows: leached chernozem, podzolized chernozem, modal chernozem, meadow chernozem-like soil, chernozem-like meadow soils, and gray forest soil as well as apple orchards represented by such varieties as Wealthy (a seedling of the Siberian crab apple tree), Lobo, Melba (seedlings of the *McIntosh* apple tree), Sinap Orlovsky (*Northern Sinap* × *Pamyat Michurina*), Pepin Shafrannyi (*Orleans Reinette* × *Pepin Litovski*), Zhigulevskoe (*Borovinka* × *Wagner-Prizovoe*), and *Mantet* (seedling of the *Grushovka Moskovskaya* apple tree) on a semi-dwarf rootstock 54-118 (*Budagovsky's Paradizka* × #13-14). The allocation pattern was 5×3 m. The row spacings were kept under the weed-free fallow. The soil properties available before the compartments establishment (data taken in the farmsteads) were compared with the soil properties discovered during the study period. The new soil and fallow areas were used as the reference checks. The "cross-sectional method" was implemented during the study of roots placement in the soil layers[16]. The soil samples for analyses were taken by a sampling pipe at the depth of 1.5 m after each 10 cm. To determine the impact of the root system on the soil properties, simultaneous sampling of roots was conducted in the same layers. The soil moisture was determined through the thermogravimetric method, the lowest moisture content – through the method of areas flooding, the soil density – through the cutting ring method, the solid phase – through the pycnometer method, the aggregate analysis – through the method by N. I. Savinov[17] and the particle-size distribution – through the pyrophosphate method modified by S. I. Dolgov and A. I. Lichmanova.[18] The agrochemical soil analyses were made according to the appropriate guideline[19]. The bioindication of the apple orchard soil fertility was carried out through a greenhouse experiment[20]. The soils allocated around the tree trunks and in the row spacings of the young and old orchards, fallows, and new soil areas were used for sowing seedlings of the Kichunov's Reinette apple tree variety. The application method was used in order to determine the cellulose decomposition intensity in soils[20]. For this purpose, linen strips of 1-x100 cm in size were embedded on 1 meter of the soil on April 15. On October 6, they were taken out. Accounting for the tree waste and ground litter was performed on 10 sites of 1x1 m size each. Accounting for the snow reserves was carried out on March 17. Determination of the common forms of nitrogen, phosphorus, and potassium was carried out through the method of wet combustion[21]. According to our data, the forestry comprised 90% of English oaks (*Quercus robur L.*), and the rest 10% of small-leaved limes (*Tilia cordata Mill.*), European hazelnuts (*Corylus avellana L.*), and Scotch elms (*Ulmus scabra Mill.*). In the forest, due to the annual tree waste (7.23 t/ha), the ground litter was maintained at the amount of 16 t/ha of absolute dry matter with the total nitrogen content of 1.86%, P_2O_5–0.84%, K_2O–0.92%, Mg_2O–0.22%, and CaO–1.73%. During the study years, 60% of the grassy cover of the 10 year-old fallow consisted of the bush grass (*Calamagrostis epigeios L.*) and Kentucky bluegrass (*Poa pretense L.*), and the rest 40% comprised the following motley grasses: common tansy (*Tanacetum vulgare L.*), common yarrow (*Achillea millefolium L.*), timothy grass (*Phleum pretense L.*), herb bennet (*Geum urbanum L.*), wild carrot (*Daucus carota L.*), common chicory (*Cichorium intybus L.*), tormentil (*Potentilla erecta L.*), silvery cinquefoil (*P. argentea L.*), brown knapweed (*Centaurea jacea L.*), prickly lettuce (*Lactuca serriola* L.), autumn hawkbit (*Leontodon autumnalis L.*), and lady's bedstraw (*Galium verum L.*). The annual apple tree waste amounted to 3.86 t/ha of the dry matter with the total nitrogen content therein of 2.6%, P_2O_5–0.19%, K_2O–1.58%, MgO–0.18%, and CaO–1.7%[22].

4. Results

4.1 Absolute Assessment of the Apple Orchard Impact on the Soil Properties

Absolute assessment is the comparison of soil properties of the apple orchards with the indicators of the nearby new soil counterparts.

As compared to the meadow, the forest water equivalent value was by 41 mm higher, and the orchard water equivalent value was by 101 mm higher. The snow level in the orchard was 2.08 times higher than in the field (Table 1).

Table 1. Snow reserves in various types of agricultural lands

Land	Snow level, cm	Snow density,g/cm^3	Water equivalent, mm
Meadow	15.73	0.83	131
Forest	24.13	0.71	172
Orchard	32.78	0.71	232

Different types of agricultural lands demonstrated significant differences in the soil properties. Thus, orchard-type of soils exploitation left a definite imprint on their morphology. The gray forest and meadow chernozem-like soils demonstrated the dispersion of the upper part of the humus horizon, and the chernozem-like meadow and leached chernozem soils were also characterized by the plow sole presence, as evidenced by the crumby-prismatic structure in the middle part of the A horizon that appeared instead of the original granular-crumby structure. The depth of the worms' penetration into the meadow chernozem-like soils reduced from 145 to 50 cm and almost disappeared in the leached chernozem and chernozem-like meadow soils. When determining the effervescence depth from 10% Hcl, it was found that the upper boundary of carbonates in the soil occupied with orchards was 20 cm lower than in the natural soils. The orchard-type soil exploitation contributed to the carbonates boundary shift 20 cm down the profile, which was apparently associated with the intensive orchard soil percolation caused by the greater water equivalent in the snow cover and lesser soil density in the 0-20 cm layer. These indicators were respectively equal to 2,320 m^3/ha and 0.9 g/cm^3 in the orchard, and 1,310 m^3/ha and 1.21 g/cm^3 in the natural composition.

It was found out that the meadow chernozem-like soil's layers with the depth down to 120 cm had a minimum content of readily hydrolysable nitrogen observed in the orchard-type soils, and the maximum – in the natural composition (in the meadow). The nitrogen content in the 0-40 cm fallow layer occupied an intermediate position. The studied types of soils did not demonstrate any further differences in the layers deeper than 120 cm (Figure 1a).

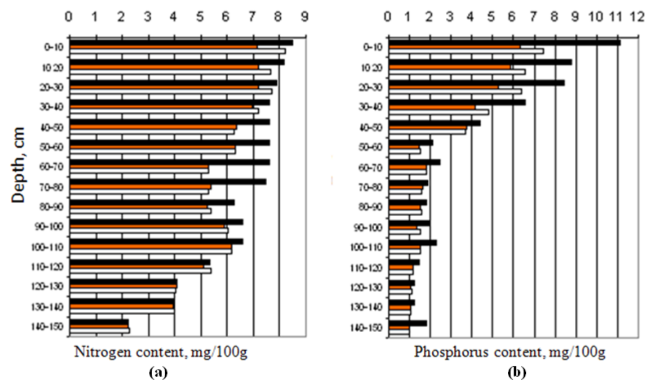

Figure 1. The content of nitrogen. **(a)** And phosphorus. **(b)** In the meadow chernozem-like soil of different phytocenoses.

A similar trend was observed in the case of mobile phosphorus and exchangeable potassium (Figure 1b and 2a). The content of these elements was maximum throughout the entire profile of the meadow chernozem-like soil in its natural condition. In the 0-40 cm layer, the level of the mobile phosphorus and magnesium forms present in the fallow soil was lower than in the meadow soil, but higher than in the cultivated soil. A somewhat different picture emerged with the exchangeable calcium (Figure 2b).

Its content in the virgin meadow chernozem-like soil was higher than in the cultivated soil throughout the entire profile, the same as with phosphorus and magnesium. The calcium content in the 0-70 cm layer of the fallow soil was lower than in the new soil, but higher than in the cultivated soil. Availability of the exchangeable potassium in the 0-30 cm layer was minimal for the orchard-type soil, but it was higher for the meadow chernozem-like soil in fallow and meadow.

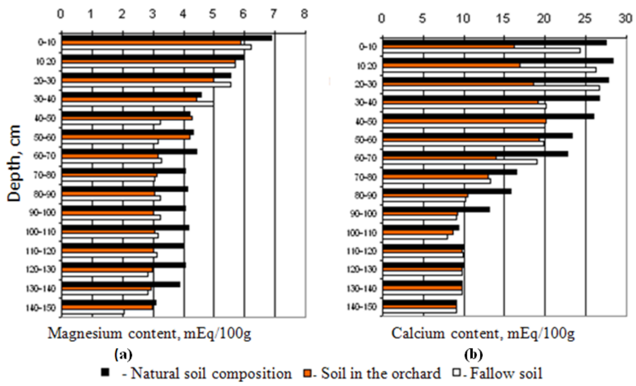

Figure 2. The content of magnesium. **(a)** And calcium. **(b)** In the meadow chernozem-like soil of different phytocenoses.

The minimum nitrogen content in the gray forest soil was observed in the 0-60 cm layer for the orchard-type soil, and the maximum nitrogen content was observed in the same layer under the natural conditions (for the forest-type soil). The nitrogen content in the 0-60 cm fallow layer occupied an intermediate position. The increase in the nitrogen content was also observed in the soil under the oak forest in the 100-120 cm layer (Figure 3a).

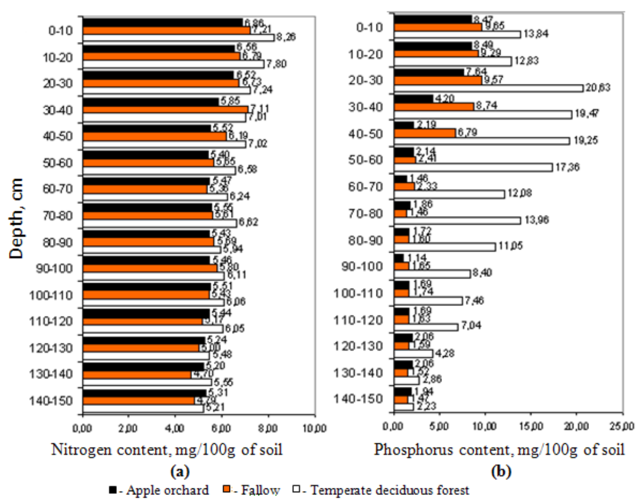

Figure 3. The content of nitrogen. **(a)** And phosphorus. **(b)** In the gray forest soil profile.

The maximum phosphorus content was observed in the entire profile of the gray forest soil in its natural composition. In the 0-50 cm layer, the predominance of the mobile phosphates amount was observed in the fallow as compared to the orchard (Figure 3b). Higher magnesium content was also observed within the entire profile of the forest soil in its natural condition. The magnesium amount predominance in the fallow soil, as compared to the orchard-type soil, was recorded in the 0-10 and 30-40 cm layers (Figure 4a). The comparative soil assessment according to its calcium content suggested the following data (Figure 4b). The 0-20 cm layer demonstrated the maximum content of this element in the forest-type soil, and the minimum content of this element in the orchard-type soil. In the naturally composed soil, the abrupt decrease in the calcium content was observed starting from the 20-30 cm layer, which continued to the depth of 1.5 m. In the 20-50 cm layer, the level of the available calcium exchangeable forms was higher in the orchard like soil, but was inferior to its content in the fallow. In this variant, the calcium content was maximal in the 20-70 and 90-100 cm layers. In terms of potassium availability in the 0-70 cm layer, the gray forest soil in its virgin condition exceeded the value of its cultivated counterpart. The fallow-type soil occupied an intermediate position.

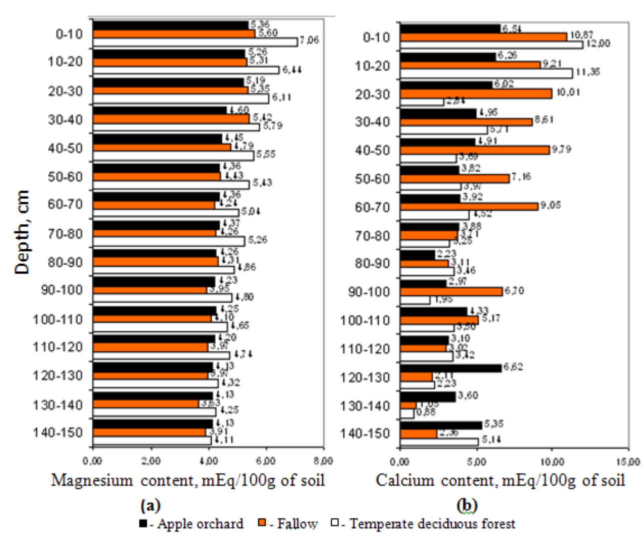

Figure 4. The content of magnesium. **(a)** and calcium. **(b)** In the gray forest soil profile.

The chernozem-like meadow soil in its virgin condition was better provided with the major nutrient elements in comparison with its cultural counterpart. The highest content of nitrogen, phosphorus, and magnesium was observed in the 0-120 cm layer of the chernozem-like meadow soil in meadows, and the content of potassium and calcium in the entire 1.5 meter profile of the soil specified was observed in its natural condition (Table 2).

The highest content of humus was observed in the 0-70 cm layer of the meadow chernozem-like, gray forest, and

Table 2. Physical and chemical properties of soils (2003)

Depth, cm	Humus, %	pH_{kcl}	N	P_2O_5	K_2O	Ca	Mg	S	Hg	T	V, %
			mg/100 g of soil			mEq/100 g of soil					
Chernozem-like meadow soil (apple orchard)											
0-30	5.11	5.15	5.6	2.56	10.92	14.95	5.06	20.01	6.5	26.5	75.48
30-70	3.6	4.86	5.65	0.6	8.13	13.44	4.17	17.61	8.46	26.07	67.56
70-120	1.5	4.69	5.91	0.01	15.89	8.04	3.83	11.87	5.8	17.67	67.0
120-150	0.59	4.56	3.54	0	17.23	2.07	3.23	7.44	3.77	11.21	66.37
Chernozem-like meadow soil (meadow)											
0-30	8.0	5.41	7.77	9.49	23.31	26.45	6.18	32.63	4.07	36.64	89.08
30-70	4.95	5.4	6.94	6.63	22.21	22.91	5.37	28.28	3.1	31.38	90.12
70-120	1.86	5.31	6.26	0.89	18.22	11.17	4.5	15.67	2.4	18.12	86.12
120-150	0.58	5.15	3.7	0	15.04	5.38	3.87	9.25	3.57	11.81	78.25

Note: pHkcl – exchangeable acidity, N – readily hydrolysable nitrogen, P2O5 – mobile phosphorus, K2O – exchangeable potassium, Ca – exchangeable calcium, Mg – exchangeable magnesium, S – total exchangeable bases, Hg – hydrolytic acidity, T – absorption capacity, V – base saturation degree.

chernozem-like meadow soils in their virgin condition, the lowest - in the same layer of soils occupied by the apple orchard. The availability of humus in this layer in the fallow soil holds an intermediate position. It was found out that the pH value of the meadow chernozem-like soil's salt extract was the closest to the optimum one within the entire 1.5 meter profile of the fallow soil and in the 30-70 cm layer of the meadow soil, and the pH value of the gray forest soil' salt extract – within the 1.5 meter formation of the fallow soil and in the 0-30 cm layer of the naturally composed soil. Within the entire 1.5 meter profile of the chernozem-like meadow soil, the pH_{kcl} value was more favorable in its virgin condition than in the orchard.

In determining the value of the hydrolytic acidity, it was established that in the meadow chernozem-like soil in its natural condition in the 0-120 cm layer, this indicator had the optimum value as compared to the soil occupied by the apple orchard. In the fallow, the hydrolytic acidity of the meadow chernozem-like soil holds an intermediate position. The same trend was noted in the 0-70 cm layer of the gray forest soil. However, acidity is the most optimal acidity in gray forest soil under fallow deeper, than 70 cm.

The hydrolytic acidity of the chernozem-like meadow soil in the 0-120 cm layer in its virgin condition was more favorable than in the orchard. Deeper than 120 cm, the differences were insignificant.

It should be noted that the sum of the exchangeable bases, absorption capacity, and base saturation degree also depended on the agricultural land type, and with the increase of these indicators, the studied soils can be arranged in the following order: Orchard < fallow < forest and meadow.

The density of the chernozem-like meadow and meadow chernozem-like soils in the 0-20 cm layer was less important in the garden as compared to its natural condition, which was caused by the frequent loosening of this layer. However, in the subsurface layer (20-40 cm), the density was higher in the orchard: by 0.13 g/cm^3 in the chernozem-like meadow soil and by 0.08 g/cm^3 in the meadow chernozem-like soil. On the gray forest soil, the entire 40 cm layer in the cultivated condition was denser by 0.07 g/cm^3 than in its natural condition. Beneath 40 cm, there were no more differences in the soil density.

The solid phase density of the cultivated chernozem-like meadow and meadow chernozem-like soils in the 0-60 cm layer was 0.13 g/cm^3 higher than that of its new soil counterparts.

The soils occupied by the apple orchards demonstrated a lower content of the agronomically essential aggregates (0.25-10 mm). Thus, in the chernozem-like meadow soil used in the orchard, the structure index in the 0-80 cm layer was 2.72 times lower as compared to its natural condition; in the 0-50 cm layer of the meadow chernozem-like soil - 3.38 times; and in the 0-40 cm layer of the gray forest soil – 4.26 times. The differences in the most frequently cultivated 0-10 cm layer are particularly high. These values for the chernozem-like meadow, meadow chernozem-like, and gray forest soils, were respectively equal to 5.76, 4.13 and 6.59 times. The deeper, the weaker differences were; and there were no differences beneath the level of 80 cm (for the chernozem-like meadow soil), 50 cm (for the meadow chernozem-like soil), and 40 cm (for the gray forest soil).

In the 0-60 cm layer, the content of the water-stable aggregates, bigger than 0.25 mm, was lower in the cultivated soils than in the virgin ones. Thus, in the 0-60 cm layer of the gray forest soil, their content was 2.3 times lower, and of the meadow chernozem-like soils – 1.9 times.

Having compared the minimum moisture-holding capacity of the soil in orchards with the moisture-holding capacity of their virgin counterparts, we can notice that the value of this indicator is lower for the soil occupied by orchards. The deeper, the fewer differences in the soil moisture-holding capacity are noticed. Thus, in the chernozem-like meadow and gray forest soils, they were present down to the depth of 80 cm, while in the meadow chernozem-like soils – down to 100 cm. The particle-size distribution of soils occupied by various phytocenoses did not show any differences.

The differences in the aeration porosity of the soils occupied by the cultural and natural lands were determined (Figure 5).

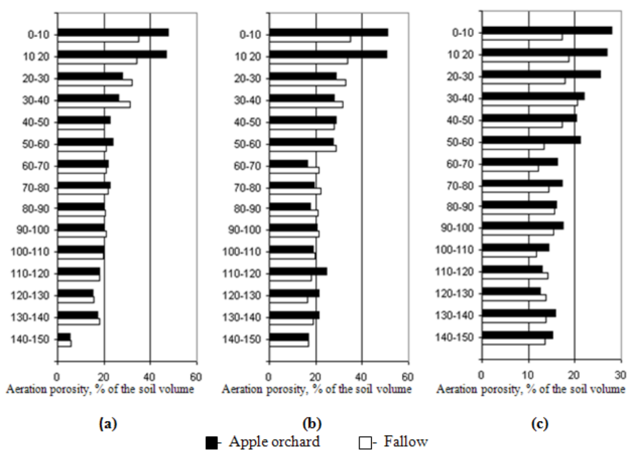

Figure 5. Aeration porosity in the chernozem-like meadow. **(a)** Meadow chernozem-like. **(b)** And gray forest. **(c)** Soils in 2002.

In the gray forest soil occupied by the apple orchard, the air exchange was higher in comparison with the unplowed soil. In 2002, aeration porosity of the gray forest soil in the forest in the 0-110 cm layer was identified at a lower level than in the orchard (Figure 5c). In the more humid year 2003, the differences increased, and the aeration porosity of the virgin forest soil in the entire 1.5 meter profile was lower than in the cultivated soil (Figure 6c). This can be explained by the higher moisture reserves in connection with mulching with intensive tree waste and forest litter stocks, which blocks water evaporation since it has no capillary porosity. The moisture conservation also occurred there due to the forest shadowing. In 2002, in the 0-20 cm layer of the meadow chernozem-like and chernozem-like meadow soils in the orchard, the aeration porosity was higher as compared to their virgin counterparts due to the periodic loosening (Figure 5a, 5b). However, the subsurface 20-40 cm layer (plow sole) featured significantly lower aeration porosity than in the virgin soil due to its compaction. In 2003, a similar trend was also observed (Figure 6a, 6b).

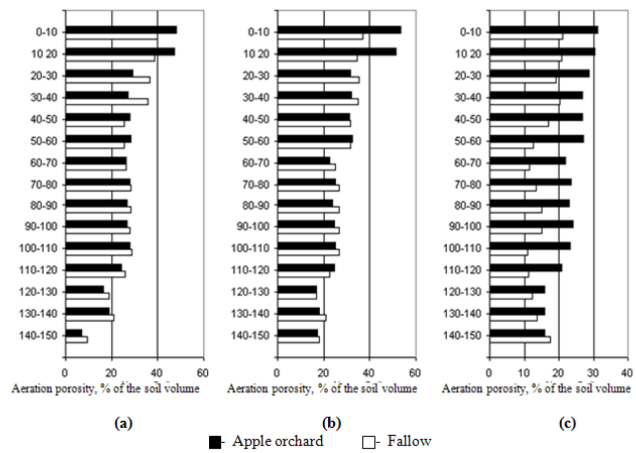

Figure 6. Aeration porosity in the chernozem-like meadow. **(a)** Meadow chernozem-like. **(b)** And gray forest. **(c)** Soils in 2003.

In 2003, the aeration degree in the 60-150 cm layer of the chernozem-like meadow soil occupied by the orchard was lower than in the soil occupied by the meadow vegetation (Figure 6a). This suggests the moisture reserves preservation in the indicated layer of the chernozem-like meadow soil of the weed-free fallow due to the capillaries destruction and absence of the grass cover with the grains varieties dominated, which contributed to the soil drying while transpiring moisture. In the virgin condition, within the entire 1.5 meter profile, the chernozem-like soils were more aerated than the gray forest soils. Such differences were caused by the mulching and shadowing in the forest and moisture suction by the grains varieties in the meadow. Having compared the porosity of the 0-20 cm layer aeration in the soils occupied by the orchard, we need to note that the meadow chernozem-like soil was the most aerated one, and the gray forest soil was the least aerated one, while the chernozem-like meadow soil held an intermediate position. This phenomenon can be explained by their density, which during the study years, amounted to 0.91, 1.38, and 1.0 g/cm^3 for the said layer in the meadow chernozem-like, gray forest, and chernozem-like meadow soils, accordingly. Beneath the depth of 20 cm, the aeration porosity of the soil in the orchard was practically the same. The periodic treatment of the 20 cm layer of the cultivated soils in the apple orchard under the weed-free fallow ensured the mulching effect. Therefore, the orchard-type soils, as opposed to the new soils, under the equal conditions acquired similar aeration porosity for the entire subsurface formation beneath the depth of 20 cm.

4.2 Graphical Assessment

Determination of the moisture, the content of humus and mineral elements, and the hydrolytic acidity of the soil profile in the immediate vicinity of the roots placement allows judging the nature of the root system impact on the soil properties.

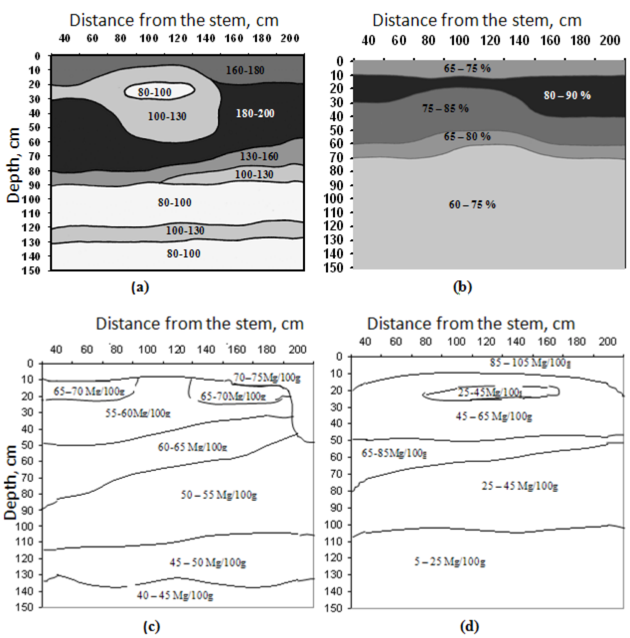

Figure 7. The distribution of calcium in mg/kg of soil. **(a)** Moisture in %. **(b)** Nitrogen in mg/100g. **(c)** And phosphorus in mg/100g. **(d)** In the soil profile of the *Pepin Shafrannyi* apple orchard in the weed-free fallow, mEq/100g (2002-2003).

In the zone of placement of the bulk of the apple tree absorbing roots, the areas of the low humidity and reduced content of the readily hydrolysable nitrogen, mobile phosphorus, and exchangeable calcium were documented (Figure 7).

Analyzing the root system placement of the *Mantet* variety apple tree in the chernozem-like meadow soil, we need to note that the amount of potentially active roots therein was considerably less than on the leached chernozem soil, and the roots were placed closer to the surface (Figure 8).

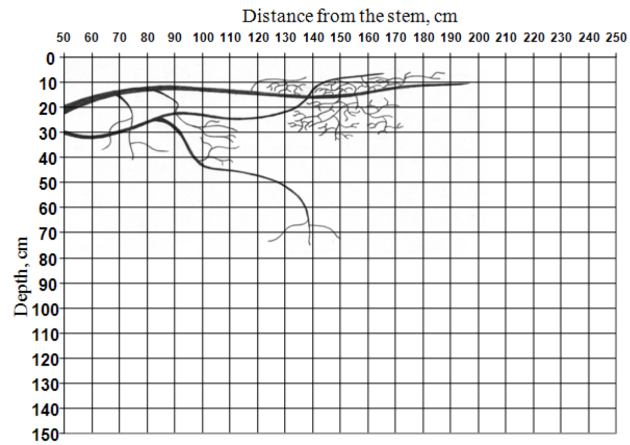

Figure 8. The skeletal roots placement in the soil profile of the *Mantet* variety apple orchard on the chernozem-like meadow soil in 2003.

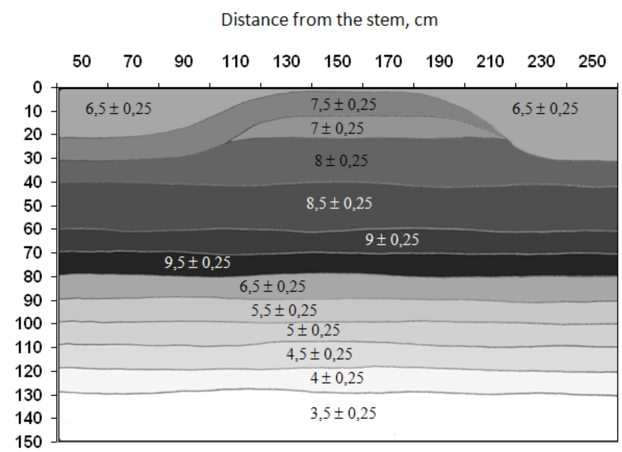

Figure 9. The hydrolytic acidity contour in the row spacing of the *Mantet* variety apple orchard on the chernozem-like meadow soil in 2003, mEq/100g.

With account of the value of the hydrolytic acidity (H_g) of the leached chernozem soil, it can be observed that at the 90-170 cm distance from the stem and in the 20-60 cm layer, the H_g value was the highest and amounted to 7.5-8.0 mEq/100g of soil. The spatial arrangement of these acidity values coincided with the area of fine roots accumulation. As the distance from the stem increases, the hydrolytic acidity increases in the chernozem-like meadow soil in the 0-10 cm layer (6.5 to 7.5 mEq/100g), and in the 20-30 cm layer (6.5 to 8.0 mEq/100g) (Figure 9).

Thus, the increase in the hydrolytic acidity in the marked layers on the both types of soils can be explained by the acidifying action of the apple tree root system.

During the study process, no differences were found in the soil humus availability as well as the exchangeable potassium and magnesium availability in the rhizosphere and in the area free from the apple tree roots.

4.3 Individual Assessment of the Apple Orchards Impact on the Soil Properties

Individual assessment is the comparison of the properties of soil before initiation with the soil properties in the fruit-bearing orchards.

During the 16 years of the low-growing apple orchard growth, the change in the physicochemical soil indicators was documented. In the leached chernozem soil of the orchard within the 1.5 meter layer, the pH_{kcl} value reduced by 0.3, the nitrogen content – by 0.7 mg/100g, the phosphorus content – by 2.5 mg/100g, and the potassium content – by 2.9 mg/100g, while the hydrolytic acidity increased by 0.6 mEq/100g. In the 0–70 cm layer of the meadow soil, the humus content reduced by 0.89%, the nitrogen – by 1 mg/100g, the phosphorus content – by 2.75 mg/100g, the potassium content – by 4.75 mg/100g, the calcium content – by 3.47 mEq/100g, and the pH_{kcl} value – by 0.2, while the hydrolytic acidity increased by 1.73 mEq/100g. Similar changes were also observed on the meadow chernozem-like and gray forest soils. The illuvial movement of phosphorus, potassium, and calcium down the profile and the weak accumulation of the gray forest soil at the depth of 1.5 m were noted, which was associated with the filtration capability of the pseudofibers deposited in the 82-150 cm layer of the said soil (Table 3).

In the 16 year-old orchard, the soil density increases faster than prior to the orchard initiation along with the depth enhancement (Table 4).

Table 4. Changes in the physical soil properties of the apple orchards during the time period of 1987 to 2007 in the experimental production farm the I.V. michurin all-Russia research institute of horticulture (- decrease, + increase)

Depth, cm	Soil types			
	Leached chernozem	Chernozem-like meadow soil	Meadow chernozem-like soil	Gray forest soil
Soil density, g/cm³				
0-70	+0.07	+0.1	+0.04	+0.17
70-150	+0.07	+0.26	+0.27	+1.23
Solid phase density, g/cm³				
0-70	0	+0.11	+0.1	+0.05
70-150	+0.05	+0.05	+0.21	+0.04
Total porosity, %				
0-70	-2.5	-2.1	0	-5.0
70-150	-1.55	-8.25	-5.9	-7.35
Structure ratio				
0-70	-1.28	-2.48	-1.65	-0.61
70-150	0	0	0	0
Content of the water-stable aggregates larger than 0.25 mm, %				
0-70	-13.44	-18.54	-25.15	-20.0
70-150	0	0	0	0
The minimum moisture-holding capacity, %				
0-70	-837	-11.9	-10.95	-6.3
70-150	-4.45	-8.15	-12.15	-10.0

Table 3. Changes in the agrochemical soil properties of the apple orchards during the period between 1987 and 2007 in the experimental production farm of the I.V. michurin all-Russia research institute of horticulture (- decrease, + increase)

Depth, cm	Humus,%	pH_{KCL}	N	P_2O_5	K_2O	Ca	Mg	H_g
			mg/100g of soil			mEq/100g		
Leached chernozem								
0-70	0	-0.37	-1.04	-3.0	-5.01	-3.76	-1.06	+1.14
70-150	0	-0.21	-0.41	-1.6	-1.37	-2.04	-0.3	+2.6
Chernozem-like meadow soil								
0-70	-0.73	-0.19	-1.0	-2.75	-4.75	-3.47	-0.32	+1.73
70-150	0	0	+0.17	0	-0.85	-0.45	-0.05	+0.4
Meadow chernozem-like soil								
0-70	-1.13	0	-0.55	-1.26	-0.45	-3.83	-0.34	+2.11
70-150	-0.15	0	-0.43	-0.56	-0.4	-1.83	-1.03	+1.01
Gray forest soil								
0-70	-1.05	-0.15	-3.26	-5.3	-7.33	-0.95	-3.08	+1.75
70-150	-0.55	+0.08	-2.25	+0.13	+1.06	+0.42	-2.8	-0.36

In the leached chernozem within the 1.5 meter formation, it increased by 0.1 g/cm^3; in the 70-150 cm layer, the solid phase density increased by 0.15 g/cm^3, and consequently, the total porosity in the 30-120 cm layer also reduced. In the 70 cm layer of the leached chernozem, the structure index reduced by 1.9 times and the content of the water-stable aggregates larger than 0.25 mm reduced by 1.2 times, while the minimum moisture-holding capacity in the 0-120 cm layer decreased by 1.4 times. Similar changes occurred in the meadow, meadow chernozem-like, and gray forest soils.

The greatest destruction of the agronomically essential aggregates was featured by the chernozem-like meadow soil. This is related to the early cultivation of soil prior to its physical maturity occurrence, as it is usually correlated with the hollows of high humidity and is characterized by the higher ground water table. The particularly strong reduction in the aggregates' water stability was recorded in the gray forest soil. The least moisture capacity of this soil decreased less than on the chernozem-like soils, as it had originally been much lower. Out of all the soil types, the leached chernozem was the least exposed to changes. Its highest buffering capacity and resistance to the orchard agrotechnics can be explained by the relatively high humus content and the cation exchange capacity, compared to other soils.

Even in the advanced farms of the Lipetsk Region, the soils have degraded for the 20 years of the orchards growth; especially the sod-podzol soils (Table 5).

Over the lifetime of the apple orchard exploitation, the reduced amount of readily hydrolysable nitrogen, mobile phosphorus, exchangeable potassium, calcium, and magnesium, moisture-holding capacity, agronomically essential and water-stable aggregates, acidulation and compaction of soils of the mentioned farmstead resulted in the decrease of the sod-podzol soil index of quality and yield from 76.75 down to 68.26 scores, and of the leached chernozem one – from 87.89 down to 84.42 scores. In comparison with the sod-podzol soil, the leached chernozem quality and yield index decreased 2.45 times less, which evidences its high buffering capacity and resistance to the orchard agrotechnics of this farmland.

4.4 Comparative Assessment of the Apple Orchards Impact on the Soil Properties

Comparative assessment is the comparison of the soil properties in the apple orchards with the indicators demonstrated by other agricultural lands.

The study determined that in the near trunk areas of the apple orchards on the meadow chernozem-like, chernozem-like meadow, gray forest, and sod-podzol chernozem-like soils, the soil structure forming capacity is similar to fallows and field crop rotations, i.e., they are better than in other types of the fruit and berry plantations. This can be explained by the stronger structure forming influence of the apple tree root system as compared to the roots of currant, chokeberry, and strawberry.

In the row spacings of the apple and chokeberry orchards, the agronomically essential aggregates content is considerably lower than in the currant and strawberry plantations, especially in the 30-60 cm layer. This is related to the stronger compaction of the subsurface layer due to the implementation of heavier machinery (Table 6).

The lower degree of the soil conditioning in the row spacings of the apple orchards as compared to the fallows and fields can be explained by the frequent cultivation of the same depth (10 cm) as well as by rarer plowing (once in 4 years instead of annual plowing in field crop cultivation). For example, the agronomically essential aggregates content in the plowing horizon (0-30 cm) of the winter wheat field turned out to be 1.3 times higher than in the same layer of the row spacings in the apple

Table 5. Changes in the agrochemical and water-physical soil properties of the apple orchards in the JSC "Agrofirma Imeny 15 let Oktyabrya" during the period between 1987 and 2007 (- decrease, + increase)

Layer, cm	Humus, %	pH_{KCL}	P_2O_5 mg/100g of soil	K_2O mg/100g of soil	H_g,mEq /100g	Content of aggregates, % air-dried 0.25-10 mm	Content of aggregates, % water-stable > 0.25 mm	Overall porosity, %
Leached chernozem								
0-30	-0.86	0	-11.44	-4.65	+0.66	-29.9	-8.2	+3.55
30-60	-1.8	0	-11.38	-6.8	0	-29.45	-5.0	-1.86
Sod-podzol soil								
0-30	-1.32	-0.24	-12.06	-4.27	+4.74	-18.92	-12.0	-1.4
30-60	-3.32	-0.11	-11.56	-9.14	+4.26	-2.4	-10.5	-3.0

Table 6. The content of the agronomically essential aggregates in the meadow chernozem-like soils according to the agricultural farmlands (average for 2003-2007)

Area	Layer, cm	Agricultural farmland					
		Apple orchard	Black currant plantations	Chokeberry plantations	Strawberry plantations	Fallows	Fields
Near trunk area	0-30	84.6	68.9	64.8	74.18		
	30-60	61.7	70.18	43.51	54.01		
Row spacing	0-30	51.2	57.91	50.1	57.55	73.46	72.3
	30-60	47.03	55.62	45.6	52.21	71.2	69.0

orchards. If the structural condition of the orchards soils is assessed as satisfactory, then the field's soil conditioning is good. As compared to the rest of the considered types of soil, the modal chernozem and leached chernozem, both in the horticulture and in the field crop cultivation, have a well-structured humus horizon. However, as a result of cultivating these soils in orchards, the subsurface layer also has a plow sole. It has also been noticed in field crop cultivation.

As compared to field crop rotations and fallow, the apple orchard soils feature lesser content of nitrogen, phosphorus, potassium, calcium, magnesium, and humus. They are characterized by the lower water permeability, water resistance, and moisture-holding capacity, as well as higher density and acidity.

4.5 Bioindication

The cellulolytic activity of the one meter layer of the soils under apple orchards has proven to be significantly lower than in the new soil state (Table 7).

This is explained by the negative physicochemical and water-physical properties of the orchard soils. In 2005, the activity of the cellulose-decomposing microorganisms of the meadow chernozem-like soil in the garden was higher than in the new soil. This is caused by the weather impact. While during the summer period of the year 2003, the total amount of precipitations was 290.8 mm, in the year 2005 it amounted to 195.5 mm, and the second decade of July had no precipitations at all. In the relatively dry year 2005, the orchard soil moisture was maintained at a level higher than in the meadow due to the periodic loosening of the 0-10 cm layer. Herein, the grass cover significantly dried out the upper soil layers through transpiration. For example, in the third decay of July, the moisture of the meadow chernozem-like soil of the orchard in the 10-40 cm layer amounted to 20.55% and in total 16.61% of absolutely dry meadow soil. In 2005, meadow clover (*Trifolium medium L.*) occupied up to 30% of the new soil grass cover. It was distinguished by the greater suction capacity than the rest of the meadow vegetation. Thus, on August 1 in the 0-10 cm layer, the soil moisture under the meadow clover and the rest of the grass and mixed herbal vegetation amounted to 15.14 and 19.98 % respectively. Therefore, the soil's cellulolytic activity in the sod layer (0-10 cm) of clover amounted to 63.17% against 85.09% under the rest vegetation free from its activity. The trend noticed in 2005, is also typical for the 0-10 and 0-30 cm layers of the more hydromorphic chernozem-like meadow soils. However, in a meter layer of this plowed soil, the fiber decomposition is 2 times lower than in the new soil. Undoubtedly, it is related to the increase in the meadow nature of the soil, since it is known that tilled soils are more hydromorphic[23]. Besides, on March 29, 2005, the water equivalent amounted to 162.38-169.4 mm in the orchard and only 84.35 mm in the meadow.

The cellulolytic activity of the gray forest soil in its natural condition is always higher than in the apple orchard. This is explained by the stability of the soil

Table 7. Intensity of the linen fabric decomposition, %

Depth, cm	Year	Soils and phytocenoses					
		Meadow chernozem-like soil		Chernozem-like meadow soil		Gray forest soil	
		Orchard	Meadow	Orchard	Meadow	Orchard	Meadow
0-10	2005	90.41	86.85	85.79	74.13	86.78	95.5
0-30	2005	94.9	64.61	81.76	64.99	77.76	94.73
0-100	2003	39.51	53.58	24.47	40.3	60.52	75.37
	2005	86.27	45.74	26.48	46.27	43.31	71.59

Table 8. The soil exhaustion impact on the vegetative productivity of the Kichunov's Reinette apple tree variety seedlings (2010)

Soil type	Agricultural farmland	Productivity indicators, g/vessel				Water retention capacity of shoots, %
		Green leaves mass	Green shoots mass	Roots mass	Total biomass	
Modal chernozem	Orchard	0.51	0.35	0.3	1.16	7.14
	Fallow	1.9	0.7	0.71	3.31	4.5
Meadow chernozem-like soil	Orchard	0.26	0.11	0.31	0.69	9.16
	Meadow	1.34	0.68	1.08	3.11	2.13
Chernozem-like meadow soil	Orchard	1.8	0.97	1.35	4.13	3.62
	Meadow	0.93	0.52	1.18	2.63	2.8

moisture level that can be achieved by means of mulching with tree waste and shadowing with trees. During the study years in forest, the ground litter reserve of 16 t/ha of dry matter was maintained due to the annual tree waste (7.23 t/ha). In order to decompose such amount of tree waste, the activity of the cellulose-decomposing microorganisms must be significantly high. The annual apple tree waste amounted only to 3.86 t/ha.

The soil exhaustion and decrease in the soil fertility can also clearly show the bioindication of the apple tree itself (Table 8).

The above ground part and roots of the apple seedlings were normally developed on the soil taken from the virgin and fallow land plots. The average height of the plants was 30-40 cm. Each shoot had 12-18 leaves with the average area of 22 cm^2. The leaves and shoots were characterized by the high water retaining capacity as compared to the plants growing on the soil from the old apple orchards. The apple seedlings growth was greatly suppressed on the soil from the 16-20 year-old apple orchards: The average plant height was 8 cm, the number of leaves on the shoots did not exceed 7 pieces, with the average lamina area of 10 cm^2, and 2/3 of the leaf area of the bottom leaves edges were dry and painted red. The water retaining capacity of the leaves and shoots of the suppressed apple trees was significantly lower than on the soils of the natural farmlands, and the total vegetative mass was 2-4 times lower.

5. Discussion

The soils of the 16-20 year-old apple orchards feature more negative properties than those of the natural farmlands: in the chernozem-like meadow soil, the 120 cm layer contains less nitrogen, phosphorus, and magnesium, the 150 cm layer contains less potassium and calcium; in the meadow chernozem-like soil, the 120 cm layer contains less nitrogen, phosphorus, and magnesium, the 150 cm layer contains less calcium, the 0-30 cm layer contains less potassium; in the gray forest soil, the 0-60 cm layer contains less nitrogen, the 150 cm layer contains less phosphorus and magnesium, the 20 cm layer contained less calcium, and the 70 cm layer contained less potassium. Due to the calcium intake and acids secretion by the roots system, the pH_{KL} of the orchard soils was lower than in the natural farmlands: in the 30-70 cm layer (meadow chernozem-like soil), in the 30 cm layer (gray forest soil), and in the 150 cm layer (chernozem-like meadow soil). The orchard soil's H_g was also less favorable: in the 0-120 cm layer (meadow chernozem-like and chernozem-like meadow soils) and in the 0-70 cm layer (gray forest soil). The 70 cm layer of all types of soils in the orchards contained less humus than that of the fallows and meadows. Due to the periodic loosening, the apple orchards were characterized by the lower density of the 20 cm layer, whereas the density of the subsurface layer (20-40 cm) was significantly higher than in the new soil and fallow. Therefore, the aeration porosity of the 20 cm layer in the orchards was higher, and the 20-40 cm layer's aeration porosity was lower than in the natural farmlands. Due to the soil cultivation, the orchard soils were characterized by the lower content of agronomically essential aggregates (0.25-10 mm): In the 0-80 cm layer (chernozem-like meadow soil), in the 0-50 cm layer (meadow chernozem-like soil), and in the 0-40 cm layer (gray forest soil). The especially strong soil dispersion was determined in the frequently cultivated 0-10 cm layer. The soil dispersion in orchards can also explain the low water stability of aggregates in the 0-60 cm layer. Removal by the apple tree of the nutrient elements and humus from the soils was the reason for their moisture-holding capacity reduction. The more negative nature of the physical and physicochemical properties of the cultivated soils was the cause of their weak cellulolytic activity.

The area of the nitrogen, phosphorus, calcium, moisture, and acidulation removal was formed within the placement zone of the bulk of the root system active part of a 16 year-old apple tree. On the initial stage of its growth, the apple tree itself was very sensitive to the deterioration of the agrochemical and physical properties of the soils in the apple orchards, which indicated the decrease in soil fertility.

The 10 year-old period of the meadow chernozem-like soil existence as a fallow contributed to the increase in the content of nitrogen, phosphorus and magnesium in the 0-40 cm layer, of potassium – in the 0-30 cm layer, of calcium – in the 0-70 cm layer, and optimized $pH_{\text{кcl}}$ in the 1.5 meter layer and H_g – in the 0-120 cm layer. The gray forest fallow soil was characterized by the increase in the content of nitrogen in the 0-60 cm layer, phosphorus – in the 0-50 cm layer, magnesium – in the 0-10 cm and 30-40 cm layers, calcium – in the 20-70 cm and 90-100 cm layers, potassium – in the 0-70 cm layer, as well as optimization of $pH_{\text{кcl}}$ in the 0-150 cm layer and of H_g - in the 0-70 cm layer. Improvement of soil properties under the fallow can be explained by the accumulation of macronutrients at the decomposition of herbaceous plants[24]. Besides, there is no biomass alienation in the fallows, which biomass completely remains in the soil enriching it with organic and conditioning it[25]. For 16-20 years, the apple orchard adversely affects the soil fertility indicators. Due to the soil cultivation, the 0-40 cm layer demonstrated reduction in the content of agronomically essential and water-stable aggregates. The 0-80 cm layer featured decline in the content of nitrogen, phosphorus, potassium, calcium, and humus as well as increase in acidity. Due to the reduction in the amount of humus and nutrient elements, the minimum moisture-holding capacity of the entire 1.5 meter soil profile declined, and the density increased.

There is the reason to believe that the cellulolytic soil activity in the apple orchard can be improved by mulching during the dry years, and by introducing a significant amount of the organic matter to the soil surface during the wet years. However, these issues require further study. In the field crop cultivation, as compared to the apple orchards and other fruit and berry plantations, the negative impact of the agrotechnics on the soils is considerably lower. The modal and leached chernozem soils should be regarded as the soils featuring the best tolerance to the orchard agrotechnics.

6. Conclusion

The soils of the 16-20 year-old apple orchards feature more negative properties than those of the natural farmlands. Due to the calcium intake and acids secretion by the roots system, the environment reaction in the orchard soils is lower than in the natural farmlands. The 70 cm layer of all types of soils in the orchards contains less humus than that of the fallows and meadows. Due to the periodic loosening, the apple orchards are characterized by the lower density of the 20 cm layer, whereas the density of the subsurface layer (20-40 cm) is significantly higher than in the new soil and fallow. The greatest soil destruction is featured by the frequently loosened 0-10 cm layers. Removal of the apple tree nutrient elements and humus from the soils is the reason for their moisture-holding capacity reduction.

Based on the implemented approaches to the assessment of changes in the fertility and other properties of soil in orchards, the following conclusions can be made: 1. The changes in soil properties in the apple orchards that occur in space are documented by the graphical assessment, the changes in time are documented by the individual assessment, the properties deviation from the reference values are documented by the absolute and comparative assessment, and the changes in fertility are documented by the bioindication; 2. The value of the agricultural engineering impact on soil in horticulture is significantly higher than in field crop cultivation.

This paper leaves unanswered the question of the content of phenolic compounds as the chemical sources of the exhaustion of various types of soils in old gardens. This research work is the basis for further studies including the determination of the chemical and microbiological methods for controlling soil exhaustion available in industrial horticulture. This will allow increasing the lifetime of orchards and reducing the waiting period for establishing young plantations in the places of the uprooted compartments.

7. References

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