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Abstract

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Keywords

Alfisols, agricultural soils, arable soils, burrowing, chronosequences, forest soils, humus climate, deciduous forests, exchangeable cations, land use change, mesic conditions, organic horizons, prairies, rodents, soil aggregates, soil depth, soil profiles, Iowa

Disciplines

Agriculture | Forest Sciences | Soil Science

Comments

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Transformation of Forest Soils in Iowa (United States) under the Impact of Long-Term Agricultural Development

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Abstract—The evolution of automorphic cultivated soils of the Fayette series (the order of Alfisols)—close analogues of gray forest soils in the European part of Russia—was studied by the method of agrosoil chronosequences in the lower reaches of the Iowa River. It was found that the old-arable soils are characterized by an increase in the thickness of humus horizons and better aggregation; they are subjected to active biogenic turbation by rodents; some alkalization of the soil reaction and an increase in the sum of exchangeable bases also take place. These features are developed against the background of active eluvial–illuvial differentiation and gleyzation of the soil profiles under conditions of a relatively wet climate typical of the ecotone between the zones of prairies and broadleaved forests in the northeast Central Plains of the United States.

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INTRODUCTION

One of the priority directions of modern soil science is the study of anthropogenic impacts on soils and soil cover with investigation of the trends, stages, and intensity of temporal changes in the soil morphology and properties and the soil cover patterns. These problems are actively discussed at Russian and international conferences and workshops; many works devoted to them have been published [1, 3, 8–10, 22–24, 27].

International exchange of experience and methods applied by scientists to study these problems is of particular importance. The authors of this paper participated in the experimental study of the agrotechnogenic evolution of soils in the United States with the use of the method of agrosoil chronosequences developed by Russian scientists [2, 4, 7, 11–13].

Our study was aimed at the analysis of the direction and intensity of temporal changes in the automorphic forest soils of Iowa under the impact of long-term rainfed farming. The following particular tasks had to be solved: (a) to trace the history of the agricultural development of lands in the northeast Central Plains, (b) to characterize the spatiotemporal dynamics of arable fields in place of the former forest areas and to identify a key site for a detailed study of the agrotechnogenic evolution of soils, (c) to study soil agrochronosequence at the key site in the field, (d) to perform laboratory analyses of the soils, and (e) to reveal tendencies of agrotechnogenic changes in the morphology and properties of studied soils.

OBJECTIVES AND METHODS

The major method applied in our study can be referred to as the method of soil agrochronosequences; it represents a modification of the widely applied method of soil chronosequences [5, 7]. In essence, it implies a comparative analysis of the morphology and properties of soil profiles studied under virgin vegetation (the 0-moment of the agrotechnogenic transformation) and on arable fields that appeared in place of the analogous former virgin vegetation in different periods in the past. The analysis of published materials and maps, the genetic analyses of the soil profiles, laboratory soil studies, the methods of mathematical statistics, and the general comparative geographic method of soil studies were also applied in our work. Laboratory analyses of soil samples were performed in the National Laboratory for Agriculture and the Environment of the United State Department of Agriculture and in the Soil Laboratory of the Department of Agronomy at Iowa State University.

The choice of the appropriate key site for this study was dictated by the degree of completeness and detail of cartographic information and the availability of remote sensing materials obtained in different times for the studied territory. The preference was given to Johnson County in the eastern part of Iowa, for which the oldest and detailed cartographic information was available. In particular, the maps on a scale of 1 : 50000 with indication of forest areas in 1870 were used [17]. It was also important that the maps on a close scale were developed and published for this territory in the 1910ths [15]. Detailed information on changes in the forested areas in later periods was obtained from the

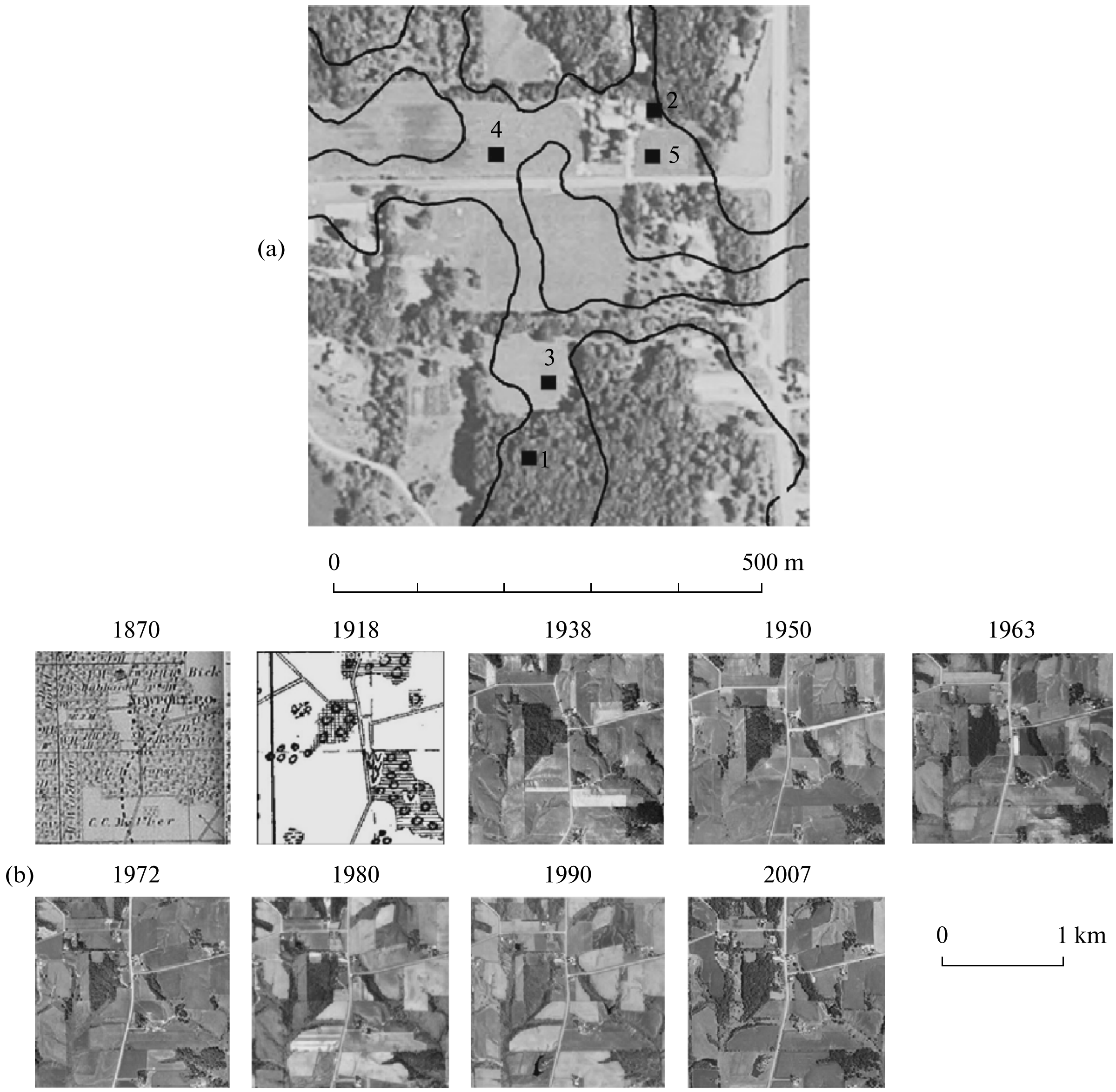

Fig. 1. (a) Studied soil plots and (b) maps of different periods, on the basis of which the history of changes in the percentage of forested areas and the conversion of forest land into cropland were reconstructed. Soils: (1, 2) background forest soils, (3) arable soils cultivated for 50 years, (4) arable soils cultivated for 110 years, and (5) arable soils cultivated for 150 years. The black line delineates the area of the Fayette soil series.

analysis of high-resolution aerial imagery of 1938, 1950, 1963, 1972, 1980, 1990, and 2007 [19].

As judged from the maps of 1870, vast forest areas existed in that period on the left-bank part of the Iowa River valley and on the adjacent interfluves at a distance of 12–20 km from the river. The historical analysis of cartographic materials indicates that the dynamics of forest vegetation within the studied territory in the past 138 years have been uneven. In general, deforestation predominated from 1870 to 1938; later, a tendency for an increase in the forested area owing to the environmental conservation policy in the United States has been observed. A unidirectional tendency for deforestation during the entire studied period, i.e., a staged conversion of former forested areas into croplands has been observed in a few cases. One of such sites (near Newport township) has been selected as a key site for our study (Fig. 1). Within this site, under similar topographic (a flat interfluve) and soil (the Fayette series developing from heavy leached loesslike loam) conditions, different land uses—the virgin forest and the adjacent croplands of 50, 110, and 150 years in age—were identified [30]. The field survey was performed in October–November 2008. Each of the land plots was characterized by one major soil pit and ten additional boreholes made with an auger along the perimeter of a 10-m square around the major pit. At the second forest plot (near the oldest cropland), only four core soil samples were taken with an auger. Core soil samples were necessary to ensure the sufficient number of statistical data on the soil morphology, and their number was limited by the time of fieldwork with due account for weather conditions. The identification of morphogenetic features of the soils was performed according to standard methods of soil description accepted in Russia and in the United States. The major conclusions of our study are based on the comparative analysis of soil data obtained from these plots.

The Fayette soil series was established in 1919. According to *Soil Taxonomy*, it belongs to fine-silty, mixed, superactive, mesic Typic Hapludalfs. The Ochric epipedon and the Albic and Argillic horizons are considered to be diagnostic of the Fayette soil series. These soils are formed in well-drained sites under broadleaved (predominantly, hickory–oak) forests. Their profile consists of a thin humus horizon underlain by a relatively thick eluvial horizon and a system of illuvial Bt horizons. The presence of iron–manganic concentrations in the eluvial and illuvial parts of the profile attests to the seasonal overmoistening of these soils [28, 30]. The soils of this series correspond to the subtypes of gray and light gray soils in the European territory of Russia (according to [6]), though direct analogies are impossible because of certain differences in the climates, the intensities of the biological turnover, and the rates of humification and mineralization of organic residues between these soils.

PHYSIOGRAPHIC CHARACTERIZATION AND HISTORY OF THE ECONOMIC DEVELOPMENT OF THE TERRITORY

Johnson county lies within the Southern Iowa Drift Plain composed of the Early Pleistocene glacial and glaciofluvial sediments overlying the Devonian limestone. From the top, they are covered by a layer of loesslike loams and clays that serve as parent materials on the watersheds [25]. The territory has a gently hilly topography. Local divides are relatively narrow and elongated. The erosional dissection by the ravine network is strong, especially within the elevated left-bank part of the Iowa River valley and reaches 4–5 km per 1 km^2. The absolute height of the divide in the area of our studies is 260 m a.s.l., and the water level in the river is at about 209 m a.s.l. The amplitude of heights between the bottoms of the ravines and the local divides is 15–20 m. Despite the southern position (42° N), the territory has a moderately continental climate with the mean July temperature of 23.6°C, the mean January temperature of –8°C, and the mean annual temperature of 10°C. The high solar radiation is partly compensated for by the great heat expenses for evaporation because of the high (850–900 mm per year) precipitation. According to Collins [16], the hydrothermal coefficient in Johnson county is about 1.5–1.6. In terms of natural vegetation, this area corresponds to the wet forest-steppe zone. Hickory–oak forests alternating with tall-grass prairies predominated here in the preagricultural period. The soil cover consists of the texturally differentiated soils developing under the broadleaved forests (the Clinton, Fayette, Lindley, Ladoga, Down, and other series) and of the soils resembling leached chernozems (the Muscatine, Tama, Waukee, and other series) under the prairie vegetation [18, 23].

The first European colonists appeared in Johnson county in 1836. In that time [26], the natural landscape represented a vast prairie with oak groves and broadleaved forests along the Iowa River. Thus, it was a typical forest-steppe landscape. During the colonization of this territory, preferences were given to forested parts and to the forest-prairie ecotone as the places favorable from the strategic military and economic considerations [14, 26]. In the first 10–15 years (from 1836 to 1850), the population growth was very slow. A significant growth of the number of permanent residents took place after 1850 [21]. This year can be considered the year of the beginning of the active land development and the growth of cropland area. By 1870, a considerable part of the forests was converted into arable fields, though the percent of forested areas remained high. The practice of the creation of rectangular-shaped arable fields upon the development of forested areas should be noted [17]. Steel plows were used for soil tillage in prairie areas and in the former forests from the very beginning [26]. Before 1870, wheat crops predominated on the cultivated fields. During the past 130 years, the portion of wheat, oats, barley, and vegetable crops in the cropland structure has been decreasing at the expense of a corresponding increased in the portion of corn and, in the last 70 years, soybean [14, 20, 21, 29, 30]. In the first 70 years (1850–1920) of the active agricultural development, no considerable increase in the crop yields was observed [14, 21, 26], which points to the insufficient level of agrotechnologies and small rates of fertilizer application. The depletion of arable soils and the necessity of annual application of at least 20–25 t of manure per hectare were noted in the report of the first soil survey of the county [29]. The application of phosphorus fertilizers and regular soil liming to decrease the high soil acidity were also recommended. At present, the yields of corn and oats exceed the yields of 1880–1921 by two–three times. This positive tendency was achieved at the expense of the high rates of application fertilizers (predominantly, mineral fertilizers). However, the problem of further improvement of arable soils is still preserved because of the unsettled questions related to tax policy and high prices of the agricultural machinery and fertilizers. Under these conditions, the traditional practice of using lucerne, clover, and their mixtures with grasses in the crop rotation system deserves special attention. Their application as green manure partly compensates for the deficit of carbon, nitrogen, and other nutrients in the cultivated soils. The use of green manure crops on the fields in Johnson county has been advocated for more than a century [21, 29, 30].

RESULTS AND DISCUSSION

The background virgin soil was studied on a flat interfluve under the hickory–oak forest (hickory (*Shagbark*, 5; white oak, 4; and red oak, 1). The height of the trees reached 25–28 m, the average distance between them was about 7–8 m, and the breath-height diameter of the trees was about 50 cm). Maple, white ash, and hackberry were present in the understory. The shrub layer consisted of sparse wild gooseberry bushes. The projective cover of herbs reached 30–35%. The upper soil layer was very loose owing to the activity of earthworms. Coprolites were present in significant amounts immediately under the leaf litter. The description of the soil pit studied at this plot is given below. The determination of the soil cover according to the Munsell color charts was performed in the field for the samples with natural moisture.

AO, 0–1 cm. Yellow-brown leaf litter with twigs.

A1, 1–14 cm. Gray (10YR 2/2); moist; fine granular–crumb silty medium loam; slightly compact; coprogenic; densely penetrated by fine herb roots and by fine and medium tree roots.

A2A1, 14–32 cm. Light gray, with yellowish tint (10YR 3/3); becomes lighter upon drying because of the abundance of skeletans; moist; granular–crumb, with elements of platy structure; silty medium loam (close to light loam); moderately compact; coprogenic in some places; with fine and medium tree roots and with few fine herb roots.

A2Btg, 32–47 cm. Yellowish light brown with bluish and whitish mottles (10YR 4/4); moist; angular blocky parting to crumb; very compact; the faces of blocky peds are covered by thin brownish glossy colloidal coatings; grayish skeletans are abundant along fissure zones; fine iron–manganic concentrations are evenly scattered in the soil mass; inclusions of tree roots.

Btg1, 47–65 cm. Light brown, with bluish and yellowish mottles (10YR 4/4–4/6); moist; angular blocky heavy loam; very compact; with thin glossy pale brown colloidal coating on ped faces; gleyed zones are marked by bluish streaks along vertical and horizontal fissures; the size and number of iron–manganic concentrations are higher than those in the A2Btg horizon; vertically oriented earthworm paths are partly filled with gray coprolites, and their walls are covered by gray humus-enriched coatings; few tree roots.

Btg2, 65–88 cm. Yellowish brown with bluish and ocherous mottles; darker than the above-lying horizon (10YR 4/6); moist; angular blocky; compact to very compact; slightly porous; with fissures; aggregate faces are covered by glossy and dull yellowish-brown films; gleyed zones are seen along the major fissures; from the depth of 75 cm, gleyed mottles (3–6 cm) appear in the soil mass; abundant iron–manganic concentrations; gray coprolites; few fine tree roots.

Btg3, 88–107 cm. Yellowish brown with bluish and ocherous tints (less homogeneous than the Btg2 horizon) (10YR 4/6); moist; coarse angular blocky heavy loam to clay; very compact; with thin bluish light brown glossy films on ped faces; gleyed mottles; iron–manganic concentrations are unevenly distributed and tend to accumulate in places with “warmer” colors (brown or ocherous), where their abundance reaches 10 concentrations/cm^2, and their size is from 0.3 to 1 mm; in the gleyed zones, the number of iron–manganic concentrations decreases to 5 concentrations/cm^2, and their size is about 0.1–0.3 mm; few earthworm paths are filled with gray coprolites; few tree roots.

Btg4, 107–124 cm. Bluish to light brown with yellowish mottles (10YR 6/8–2.5Y 6/5); moist; coarse angular blocky to blocky prismatic in the lower part; clayey; very compact; with gleyed mottles; ped faces are covered by thin glossy and dull bluish brown and brownish blue colloidal films; iron–manganic concentrations are unevenly distributed with their maximum amounts in the oxidized (brown) zones and minimum amounts in the gleyed zones; few tree roots.

BtCg, 124–149 cm. Heterogeneous, pale yellow with bluish tint and small ocherous mottles (10YR 4/6–2.5Y 4/4–5/6); moist; coarse blocky prismatic; clayey to heavy loamy; very compact; slightly porous; with few bluish gleyed mottles of 3–5 cm in size and numerous small (1–1.5 cm) bluish and ocherous mottles; peds are yellowish brown inside and are covered by bluish brown glossy and dull colloidal films; the sizes, amounts, and distribution of iron–manganic concentrations are similar to those in the overlying horizon; few fine tree roots.

BCg, 149–186 cm (and deeper). Heterogeneous, bluish pale yellow with greenish and ocherous tints (2.5Y 5/4–10YR 6/6–6/8); moist; very coarse blocky prismatic; silty heavy loam; faces of prismatic aggregates are partly covered by bluish light brown dull colloidal coatings; numerous fine bluish and ocherous mottles; considerable amount of iron–manganic concentrations; few tree roots.

The results of deep drilling showed that the soil does not contain carbonates to the depth of 270 cm, which is typical of the strongly leached forest soils of Iowa forming under conditions of the increased atmospheric moistening [25, 30].

According to the soil profile morphology, this soil is relatively close to the light gray surface-gleyed forest soils distinguished in the Russian soil classification system [6] near their boundary with gray forest soils.

At about 100 m to the north of this soil pit, the soil of an arable field cultivated for 50 years was studied. In the first 30 years after forest cutting, this soil was used for growing traditional corn and soybean crops. In the past two decades, it has been used as a periodically tilled hayfield and pasture. A mixture of clover and grasses is grown on this plot; the seeding is performed each three years after soil plowing. In the past two decades, this plot has been characterized by relatively favorable conditions for a positive humus budget; the annual input of organic matter is estimated at 12 t/ha, including 6 t/ha with the root litter of herbs and 6 t/ha with the aboveground litter and excrements of feeding animals. The soil profile consists of the following horizons: Asod, 0–3 cm; Ap, 3–23 cm; A2A1, 23–29 cm; A2A1Btg, 29–40 cm; BtA2g, 40–55 cm; Btg1, 55–72 cm; Btg2, 72–98 cm; Btg3, 98–122 cm; Btg4, 122–147 cm; BtCg, 147–164 cm; and BCg, >164 cm. Effervescence has not been observed in the upper three meters. This soil can be classified as a plowed surface-gleyic gray forest soil. In 50 years of its cultivation, the following changes have taken place (in comparison with the background forest soil): the plow horizon has appeared in place of the former humus horizon and a part of the humus-eluvial horizon; the thickness of the layer colored with humus and with elements of granular structure has increased; the upper part of the profile has been strongly transformed by earthworms and gophers (the burrowing activity of gophers was absent in the forest soil); the zone of eluvial bleaching (horizons with A2 indices) has shifted down into the soil profile; the thickness of the illuvial layer has increased (at the expense of the coarse angular blocky subhorizon Btg4 in place of the BtCg horizon of the background soil); and the degree of gleyzation in the lower part of the profile has increased (as judged from the abundance and size of iron–manganic concentrations).

The third soil was studied on a leveled watershed under an arable field cultivated for about 110 years. According to the reports of local farmers and the analysis of aerial survey materials, in the past 60 years, this plot has been used for corn growing. Earlier, it was growing corn, oats, barley, and vegetables. Farmer A. Tailor (the owner of this field) has been practicing the application of high corn residues during spring tillage to compensate for the loss of soil organic matter. Mineral fertilizers have been applied rarely and in small amounts. Thus, this is an extensively managed plot.

We studied it after the harvest. Postharvest residues were left on the field in high amounts. In some places, weeds with a thin layer of green moss under them were preserved. The soil had the following morphology.

Ap, 0–23 cm. Gray (2.5Y 3/3); moist, crumb structure with elements of granular and coarse blocky structure; silty medium loam; moderately compact; coprogenic; with few grass roots.

A1A2, 23–30 cm. Fragmentary (lens-shaped) whitish gray horizon (2.5Y 4/2); moist; granular–crumb (curdled); silty medium loam; compact; coprogenic; few fine roots.

A2A1, 30–40 cm. Grayish yellow with whitish tint (2.5Y 4/4); upon drying, the horizon becomes lighter; moist; curdled structure with elements of platy structure; silty medium loam; iron–manganic concentrations; compact; many coprolites; gray mole tunnels; few roots.

A2A1Btg, 40–57 cm. Yellowish light brown with bluish and whitish tints and with gray mottles (2.5Y 4/3); moist; angular blocky parting to crumb; silty medium loam; ped faces covered by thin brownish colloidal films; iron–manganic concentrations; coprolites; few gray mole tunnels; few herb roots.

Btg1, 57–82 cm. Grayish brown with bluish, yellowish, and ocherous tints in some places (2.5Y 5/4); moist; angular blocky; silty heavy loam; with thin glossy brownish films on ped faces; rounded grayish blue gleyed mottles (3–5 cm) are present from the depth of 65 cm; brown zones enriched in iron hydroxides are seen along the fissures; iron–manganic concentrations are more distinct than in the overlying horizon; brownish gray coprolites; few herb roots.

Btg2, 82–107 cm. Yellowish brown with bluish tints (10YR 5/4); moist; angular blocky; heavy loam to clay; glossy bluish brown films on ped faces; gleyed features are more evenly distributed; the size of iron–manganic concentrations (nodules) varies from 0.1 to 2 mm, and their abundance is from 4 nodules/cm^2 in strongly gleyed zones to 9–11 nodules/cm^2 in the main soil mass; few gray coprolites; few herb roots.

Btg3, 107–138 cm. Heterogeneous, rusty brown with yellowish and bluish mottles (10YR 5/4); moist; coarse angular blocky; clayey; compact; with glossy brown and bluish brown films on ped faces; the intensity of gleyzation is higher than that in the overlying horizon; the size and abundance of iron–manganic concentrations are also higher; brownish gray and yellowish gray coprolites can be found in the soil mass.

BtCg, 138–167 cm. Heterogeneous, rusty bluish with brownish and yellowish mottles (2.5Y 5/6); moist to wet; prismatic structure; ped faces are covered by grayish and bluish light brown glossy and dull colloidal films; zones near interaggregate fissures are oxidized and have a brown rusty color; their thickness is up to 1–1.5 cm; the abundance and size of iron–manganic concentrations increase in these zones and near them; bluish gray coprolites are present in the soil mass.

BCg, 167–185 cm. Rusty colored with bluish tint; lighter than the above-lying horizon (2.5Y 5/6–10YR 5/8); moist to wet; coarse prismatic; clayey; porous; grayish brown and bluish brown dull colloidal films cover less than 50% of the surface of ped faces; coprolites are only present along single vertical paths of earthworms.

No effervescence was observed in the upper 250 cm of the drilled soil. The soil was classified as a surface-gleyed plowed gray forest soil.

In comparison with the recently (50 years) developed soil, the thickness of the humus layer in this soil is larger; the features of zoogenic turbation in the upper horizons are better pronounced; and gley features in the lower part of the soil profile are more distinct.

The fourth soil was studied in the field cultivated for 150 years. Up to the 1960s, this plot was a part of a larger field in crop rotation together with the 110-year-old cultivated field. Then, these plots were separated by a road and buildings. Since 1963, the plot has been used for growing the mixtures of lucerne, clover, and perennial grasses for two–three years alternating with corn (for three years). The rates of application of organic and mineral fertilizers in the last 45 years have been small. The mean annual input of fresh plant residues into the soil is estimated at about 9–11 t/ha, and the removal of the phytomass with the yield is of approximately the same value (11–13 t/ha). Thus, the humus budget has been more or less balanced in the past several decades. At the time of our study, the plot was used for growing a mixture of lucerne and grasses. The soil profile has the following morphology.

Asod, 0–3 cm. Sod layer; brownish gray with yellowish tint.

Ap, 3–23 cm. Gray (2.5Y 3/2); moist; from granular–crumb to crumb–granular, powdery; silty medium loam; slightly compact; coprogenic; with abundant herb roots.

A1A2, 23–39 cm. Gray (2.5Y 3/3) (whitish gray in the dry state); moist; granular–crumb structure with a tendency for platy structure; slightly compact; with iron–manganic concentrations; coprogenic; moderate amount of herb roots.

A2A1, 39–51 cm. Grayish yellow with whitish tint (2.5Y 4/4–4/3); moist; granular–crumb with elements of curdled structure; silty medium loam; compact; with whitish skeletans on dried ped faces; iron–manganic concentrations; coprolites; mole tunnels (4–6 cm); few herb roots.

BtA2A1g, 51–67 cm. Grayish yellow with brown tint and with bluish and whitish mottles (2.5Y 5/4); moist; angular blocky parting to crumb; heavy loam; compact; gleyed mottles (4–6 cm); numerous iron–manganic concentrations; gray coprolites filling paths of earthworms; few mole tunnels filled with gray material; few herb roots.

BtA2g, 67–81 cm. Heterogeneous; yellowish light brown with grayish, bluish, and rusty mottles (10YR 5/4–2.5Y 4/4); moist; angular blocky; heavy loam; with bluish brown glossy colloidal films on ped faces; oval-shaped strongly gleyed mottles; iron–manganic concentrations have typical sizes of 0.2–0.5 mm (up to 2 mm) and are present in amounts of up to 10–12 nodules/cm^2; in the gleyed zones, these values decrease to 0.1–0.4 mm and 2–3 nodules/cm^2, respectively; on the dried wall, whitish skeletans of up to 1–2 cm in diameter become pronounced; vertical paths of earthworms are partly filled with gray coprolites, and their walls are covered by gray humified films; few herb roots.

Btg1, 81–98 cm. Heterogeneous, yellowish brown with bluish and rusty mottles (10YR 4/6–2.5Y 5/4); moist; heavy loam to clay; coarse angular blocky parting to smaller angular blocky aggregates; ped faces are covered by bluish-brown glossy and dull colloidal films; the intraped mass displays mottled color pattern with alternation of small (0.3–0.5 cm) bluish yellow and rusty brown mottles; the zones with more pronounced gley features have the same distribution as in the overlying horizon; abundant iron–manganic concentrations; gray coprolites; vertically oriented paths of earthworms; few herb roots.

Btg2, 98–115 cm. Heterogeneous, bluish light brown with rusty and yellowish mottles (2.5Y 4/3–10YR 4/4); moist; coarse angular blocky; clayey; compact; with thin brownish dull and glossy colloidal films on ped faces; alternation of bluish yellow and rusty brown microzones in the intraped mass (similar to that in the overlying horizon); bluish gray mottles with stronger gleyzation; gray coprolites; vertically oriented paths and chambers of earthworms; few herb roots.

Btg3, 115–144 cm. Heterogeneous, brownish yellow with bluish, greenish, and rusty mottles (2.5Y 5/4); moist; coarse angular blocky, with elements of prismatic structure in the lower part; thin bluish brown dull colloidal films on ped faces; mottles of strongly gleyed grayish blue material (3–5 cm); abundant iron–manganic concentrations; bluish gray coprolites; earthworm chambers; few herb roots.

BtCg, 144–165 cm. Heterogeneous, bluish yellow with brown and rusty mottles (2.5Y 4/4–10YR 5/6); moist; prismatic; clayey; with thin bluish brown and grayish dull colloidal films on ped faces; grayish blue and yellowish blue strongly gleyed mottles; abundant iron–manganic concentrations; coprolites; paths of earthworms.

BCg, 165–205 cm. Heterogeneous, bluish yellow with greenish and rusty mottles (2.5Y 5/4–5/6–5YR 4/4); coarse prismatic; compact; slightly porous; the intraped mass is bluish light brown; thin brownish yellow colloidal films cover less than 50% of the surface of peds; the abundance and sizes of iron–manganic concentrations are the same as in the above-lying horizon.

Cg, >205 cm. Pale yellow with olive tint (2.5Y 5/4); structureless gleyed heavy loam; very compact; slightly porous; with fine (3–5 mm) rusty brown (5YR 4/4) and relatively loose segregations of iron hydroxides.

No carbonates were found in the soil to the depth of 270 cm. This soil can be classified as a surface-gleyed dark gray forest soil.

The morphogenetic features of this old-arable soil suggest that its agrogenic transformation was accompanied by the more pronounced humus-accumulative process manifested by the intense gray color of the humus horizons, considerable zoogenic transformation of the soil mass, and the increased portion of granular aggregates. The thickness of the zone of eluviation (all the horizons with A2 index) increased, and

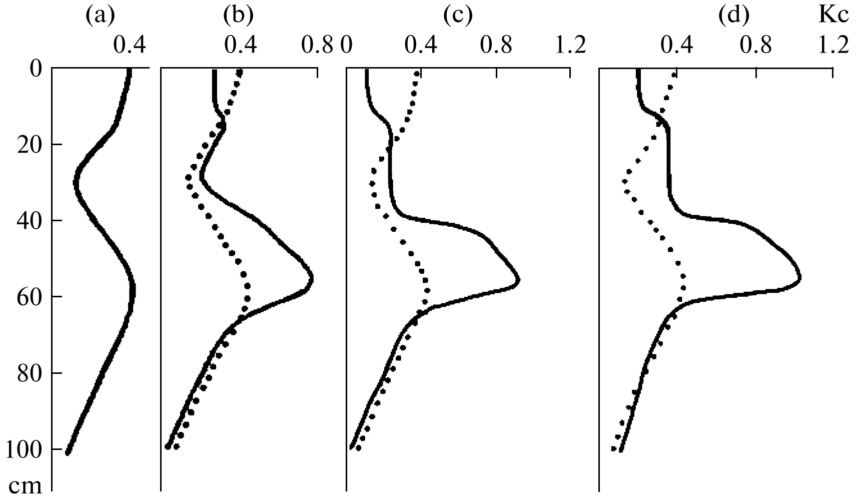

Fig. 2. Distribution of aggregation coefficients (averaged data from two determinations for the samples from opposite walls of the pits) in (a) background forest soil, (b) arable soils cultivated for 50 years, (c) arable soils cultivated for 110 years, and (d) arable soils cultivated for 150 years. Dotted lines on plots (b–d) indicate the distribution of aggregation coefficients in the background forest soil.

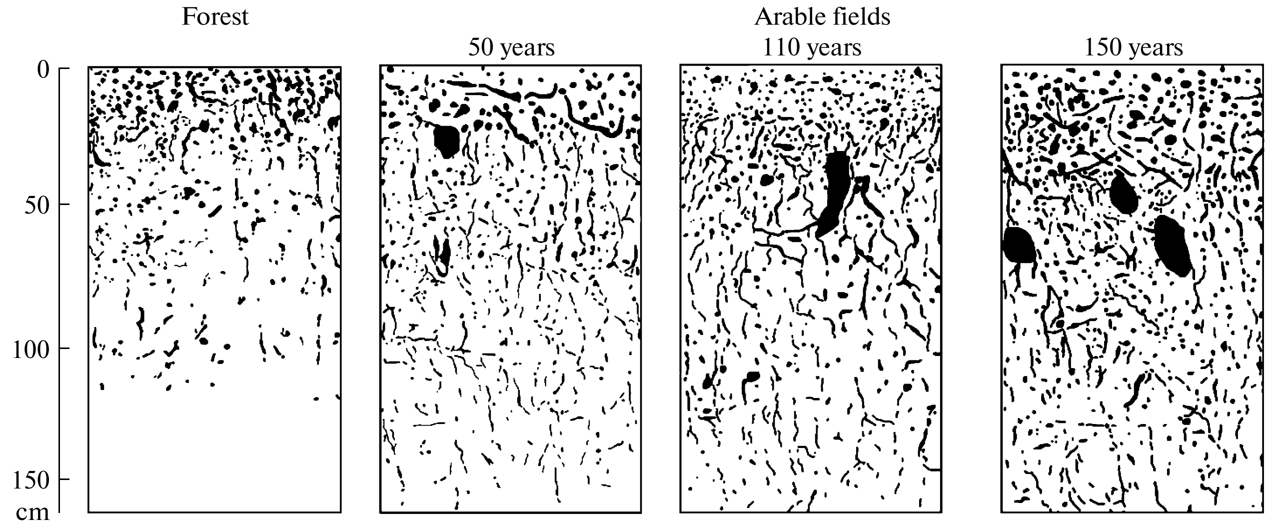

Fig. 3. The features of zoogenic activity (earthworm paths, coprolites, mole tunnels) in the profiles of studied soils (front walls of the pits).

the gley features in the lower part of the profile became more pronounced.

The aggregate-size distribution analysis performed according to N.I. Savvinov's method (dry sifting) showed that the aggregation coefficient in the layer of 20–65 cm of the studied soil chronosequence has a tendency for an increase from the zero moment of the agrotechnogenic transformation (in the soil under the forest) to the old-arable (150 years) soil (Fig. 2).

Regular changes are also observed in the degree of the zoogenic transformation of the soil profiles (Fig. 3) and in the sizes and abundance of iron–manganic concentrations (Fig. 4). The morphogenetic characteristics of the soil agrochronosequence, for which definite trends of changes were noted during the field survey, are listed in Table 1. In addition, definite trends of changes were noted for the soil reaction (some alkalization of the soils in the course of their agricultural use took place) and for the sum of exchangeable bases that increased with an increase in the duration of soil cultivation (Table 2).

The results of determination of the total humus content point to the staged character of the agrotechnogenic changes in the soil properties: during the first

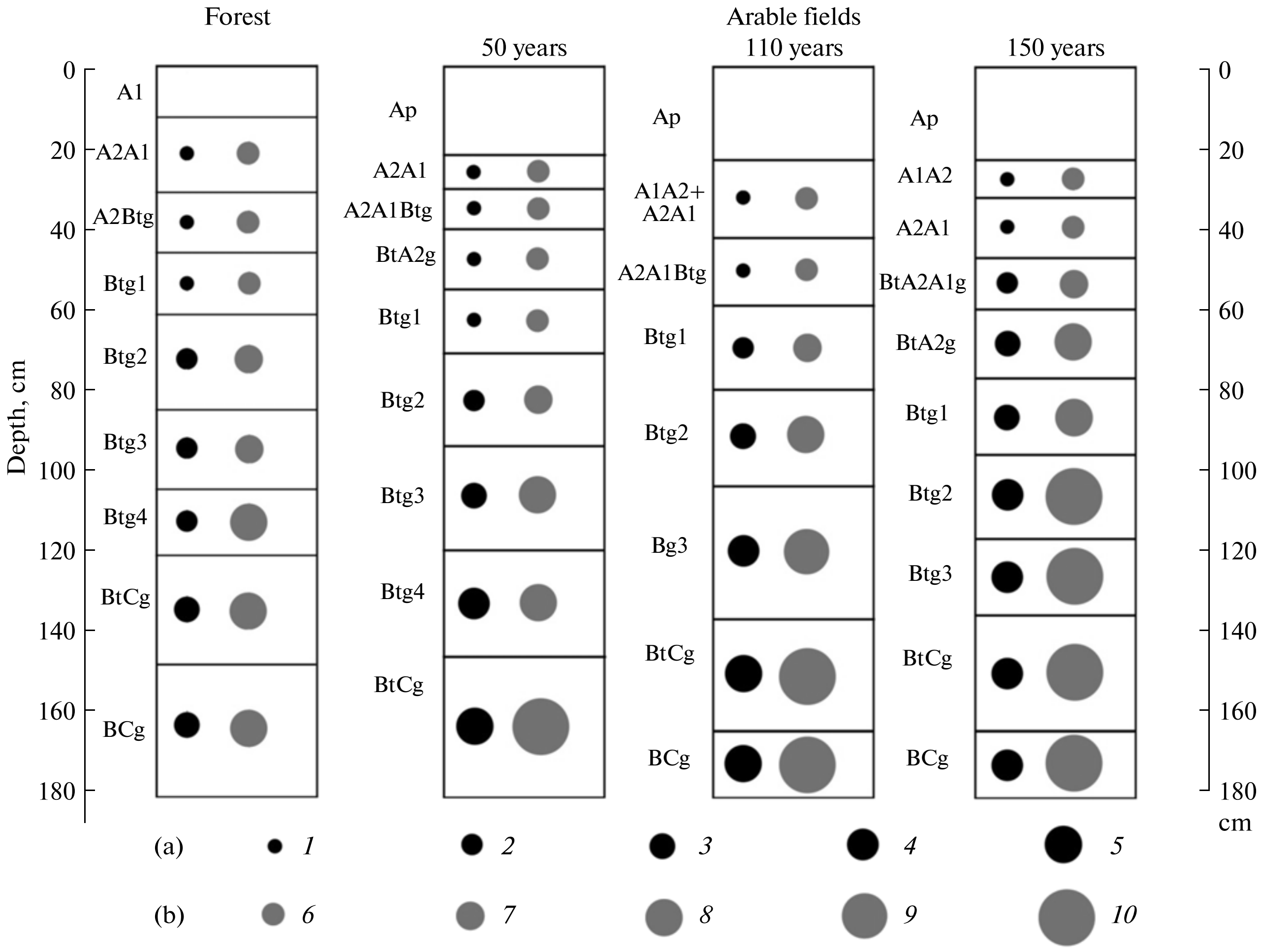

Fig. 4. Size (a) and area (b) of iron–manganic concentrations (according to the computer-aided analysis of photographs of the soil profiles). Size, mm: (*1*) <0.5, (*2*) 0.5–0.7, (*3*) 0.8–1.0, (*4*) 1.1–1.3, (*5*) >1.3. Area, % of the section of the horizon: (*6*) <1, (*7*) 1.0–4.0, (*8*) 4.1–7.0, (*9*) 7.1–10.0, and (*10*) 10.1–13.0.

110 years of the agricultural development, some decrease in the humus content was observed in the entire profile; later, this tendency was replaced by the tendency for humus accumulation (Table 2). Calculations of the total reserves of humus (with account for the soil bulk density values) showed the following changes: in the initial soil under the forest, the humus pool in the layer of 0–50 cm reached 94 t/ha; in the soil of the 50-year-old cropland, 89 t/ha; in the soil of the 110-year-old cropland, 69 t/ha; and in the soil of the 150-year-old cropland, 98 t/ha. The corresponding figures calculated for the 1-m-deep soil layer comprised 117, 106, 85, and 120 t/ha, respectively.

These changes may be explained by the significant transformation of vegetation and by the alteration of the soil water and temperature regimes upon the conversion of the plots from forests to croplands.

Special studies aimed to reveal the role of root systems of trees and shrubs in the accumulation of humus in the forest soils have not been performed. Taking into account the perennial character of these plants, their contribution to the accumulation of humus might be very small. A different situation takes place in the arable soils. Regular soil tillage favors the death of plant roots, so that root residues replenish the reserves of soil organic matter in the entire layer penetrated by the roots (not only in the plow layer proper). This process manifests itself in about 100 years of the soil cultivation. During the initial period of the soil cultivation, the removal of the soil organic matter with the harvest, the mineralization of the organic materials, and their leaching into the lower soil horizons predominate over the humus accumulation. The development of humus accumulation is one of the reasons for the increase in the thickness of the humus layer in the cultivated soils. Another reason is related to the increased mobility of humus in the arable soils with its illuviation into the lower horizons. The third, but no less important reason, is the creation of more favorable conditions for the soil mesofauna (including earthworms) in the arable soils. They favor the soil aggregation, and the prod-

Table 1. Trends of changes in some morphometric indices in the studied soil agrochronosequence

Feature		Soil under forest	Cropland, years		
			50	110	150
Thickness of the humus (A1 horizons) profile, cm		30.5 ± 1.0	40.4 ± 0.9	59.4 ± 1.0	59.8 ± 1.2
Area of zooturbation, % of the total section area	Layer 0–50 cm	20	20	21	27
	Layer 50–100 cm	8	13	14	24
	Layer 100–150 cm	2	7	10	13
	Layer 0–150 cm	10	13	15	21
Aggregation coefficient	Layer 20–40 cm	0.17	0.31	0.23	0.36
	Layer 40–60 cm	0.39	0.69	0.82	0.96
Depth of the central point, cm	Eluviation layer (A2 horizons)	30.0 ± 0.7	38.2 ± 0.7	41.5 ± 0.7	49.9 ± 0.8
	Btg1	53.6 ± 1.0	63.1 ± 0.8	69.8 ± 0.8	86.6 ± 1.4
	Btg2	72.6 ± 1.3	82.4 ± 0.8	91.9 ± 1.0	106.5 ± 1.4
	Btg3	93.2 ± 1.4	106.9 ± 0.9	120.3 ± 0.9	126.9 ± 1.3
Size (above the line, mm) and area (under the line, % of the total section area) of iron–manganic concentrations	Mean weighted index in the Btg horizon	$\frac{0.5}{2.0}$	$\frac{0.7}{3.5}$	$\frac{1.0}{6.4}$	$\frac{1.2}{10.5}$
	Mean weighted index in the BtCg and BCg horizons	$\frac{0.8}{4.3}$	$\frac{1.4}{11.7}$	$\frac{1.4}{12.0}$	$\frac{1.3}{12.3}$

Note: Statistical characteristics of morphometric indices were calculated for $n = 11$ for each of cropland plots and for $n = 15$ for the examined forest plots.

ucts of their metabolism also contribute to the humus pool of the soils.

We suppose that one of the important factors favoring the higher activity of mesofauna in the arable soils is the "warming" of the soil climate. Additional studies are required to verify this assumption.

The absence of water uptake from the arable soil by tree roots could favor the activation of gleyzation in the soil profiles; it could also contribute to the further development of the textural differentiation of the soils. The latter is confirmed by the deepening of the central points of the illuvial subhorizons (Btg1–Btg3) and an increase in the thickness of the eluvial layer in the long-cultivated soils. Judging from these trends, we can expect further development of gleyzation upon the agricultural use of the studied soils in the future. The development of gleyzation above the contact with the dense illuvial layer (>60–80 cm), along with the zoogenic activity of the soil mesofauna, could favor the improvement of the soil structure in the layer of 40–60 cm. The mechanism of the positive effect of gleyzation on the soil structure may be related to the destruction of illuviation coating in the reducing medium and comminution of the large and very large angular blocky aggregates into smaller agronomically valuable aggregates. A similar process was noted during the micromorphological study of an agrochronosequence of dark gray forest soils in the Central forest-steppe region of European Russia [11].

CONCLUSIONS

The conclusions that can be drawn from this study are in agreement with the results obtained during the study of the agrotechnogenic evolution of gray forest soils in the Central Russian Upland [1, 2, 11–13]. The long-term agricultural development of noneroded automorphic forest soils on leveled surfaces in the forest-steppe zone of European Russia and in the Mid-West region of the United States is accompanied by the accumulation of humus in the soil profiles (i.e., by the chernozemic trend of the soil development) despite some differences in the history of the agricultural development of these territories, the structure of croplands, and the modern agrotechnologies.

The particular processes are specified by the bioclimatic conditions of the studied region (the wet forest-steppe of Iowa at the boundary with the zone of broadleaved forests). Two opposite trends can be identified in the arable soils of the region. On the one hand, the accumulation of humus (the chernozemic trend) takes place in them; on the other hand, the further development of the textural differentiation of the soils is observed. The first trend reflects the conditions typical of the drier and warmer soils of the prairie zone, whereas the second trend is typical of the colder and wetter soils of the forest zone. Both sets of processes are combined in the profiles of arable soils, and the predominance of one of them is specified by the climatic conditions of the particular region. For example, the long-term cultivation of gray forest soils in the south, center, and north of the forest-steppe zone in

Table 2. Some physical, physicochemical, and chemical properties of the studied soils

Horizon; Depth, cm	Bulk density, g/cm^3	pH H_2O	Porosity	Clay	Total humus	Total nitrogen	$\frac{C}{N}$	Exchangeable bases, meq/100 g soil			
			%					Ca^{2+}	Mg^{2+}	K^+	sum
Background soil under the hickory–oak forest											
A1, 1–14	0.99	6.30	62	15.4	3.72	0.19	11.26	10.4	1.7	0.38	12.5
A2A1, 14–32	1.37	6.41	48	17.1	1.05	0.07	8.57	6.8	1.7	0.32	8.9
A2Btg, 32–47	1.57	5.67	41	23.5	0.45	0.06	4.00	7.3	2.8	0.41	10.5
Btg1, 47–65	1.57	5.31	41	33.2	0.40	0.06	3.50	11.1	5.3	0.54	17.0
Btg2, 65–88	1.55	5.02	42	34.7	0.26	0.06	2.17	12.9	6.6	0.51	20.1
Btg3, 88–107	1.54	5.03	42	34.2	0.24	0.05	2.40	13.6	6.9	0.48	21.0
Btg4, 107–124	1.54	5.15	43	32.5	0.19	0.05	2.00	12.4	6.2	0.43	19.1
BtCg, 124–149	Not det.	5.28	Not det.	29.8	0.14	0.05	1.40	11.8	5.8	0.39	18.0
BCg, 149–186	″	5.49	″	28.4	0.12	0.05	1.00	13.7	6.6	0.45	20.8
Arable soil cultivated for 50 years											
Ap, 3–23	1.41	7.08	37	17.1	2.24	0.14	9.21	10.4	1.2	0.12	11.7
A2A1, 23–29	1.48	7.44	43	21.0	0.47	0.07	3.71	9.2	1.6	0.17	10.9
A2A1Btg, 29–40	1.51	7.23	41	26.5	0.41	0.07	3.29	10.9	2.9	0.28	14.1
BtA2g, 40–55	1.51	6.16	43	37.4	0.34	0.06	3.33	12.5	5.3	0.27	18.0
Btg1, 55–74	1.50	5.89	41	37.8	0.24	0.06	3.23	12.5	6.0	0.30	18.9
Btg2, 74–98	1.49	5.78	44	37.0	0.19	0.06	1.67	12.2	6.1	0.37	18.6
Btg3, 98–122	1.49	5.76	43	34.0	0.14	0.05	1.40	12.5	6.2	0.25	19.0
Btg4, 122–147	Not det.	5.76	Not det.	30.4	0.10	0.05	1.20	10.9	5.5	0.22	16.6
BtCg, 147–160	″	5.92	″	29.0	0.12	0.04	1.75	10.7	5.4	0.24	16.3
Arable soil cultivated for 110 years											
Ap, 0–23	1.26	7.39	51	16.0	1.86	0.12	8.08	12.4	1.1	0.17	13.6
A1A2 + A2A1, 23–40	1.49	7.48	43	23.7	0.40	0.06	3.50	11.2	1.9	0.24	13.3
A2A1Btg, 40–57	1.41	6.55	44	38.3	0.34	0.06	3.0	17.6	5.3	0.50	23.4
Btg1, 57–82	1.46	5.28	43	39.0	0.28	0.06	2.67	14.9	6.3	0.47	21.7
Btg2, 82–107	1.49	5.23	40	36.3	0.14	0.06	1.00	13.3	6.3	0.49	20.1
Btg3, 107–138	1.49	5.36	41	31.8	0.12	0.05	1.20	12.4	6.2	0.46	19.1
BtCg, 138–167	Not det.	5.97	Not det.	30.7	0.12	0.06	0.83	11.5	6.1	0.43	18.0
BtCg, 167–185	″	6.39	″	27.7	0.10	0.04	1.00	12.5	6.7	0.41	19.6
Arable soil cultivated for 150 years											
Ap, 0–23	1.16	7.14	53	15.3	2.22	0.14	8.93	12.4	1.5	0.11	14.1
A1A2, 23–39	1.42	7.60	45	16.7	1.43	0.10	7.90	10.9	0.9	0.09	11.9
A2A,1 39–51	1.49	7.70	44	26.0	0.33	0.06	3.00	14.5	2.1	0.18	16.8
BtA2A1, 51–67	1.51	7.42	42	35.6	0.38	0.07	3.00	19.7	4.2	0.36	24.3
BtA2g, 67–81	1.48	7.09	43	39.7	0.29	0.07	2.14	21.1	6.3	0.37	27.8
Btg1, 81–98	1.46	6.36	46	37.0	0.21	0.05	2.20	14.6	5.9	0.21	20.8
Btg2, 98–115	1.43	5.96	46	34.4	0.19	0.05	1.80	15.2	6.7	0.41	22.3
Btg3, 115–144	Not det.	6.15	Not det.	31.0	0.17	0.05	1.80	13.6	6.2	0.35	20.2
BtCg, 144–165	″	6.33	″	27.1	0.19	0.05	1.80	12.9	6.0	0.39	19.3
BCg, 165–185	″	6.55	″	25.8	0.17	0.07	1.14	12.6	6.0	0.41	19.0

the European part of Russia is accompanied by the progradation of these soils into chernozems [1, 2, 4, 13]. In the southern taiga zone and in the zone of broadleaved forests with somewhat wetter climatic conditions, the long-term cultivation of gray forest soils (interrupted with temporary restoration of forest vegetation) has led to the progressive development of podzolization and the transformation of these soils into the soddy-podzolic soils [3, 8].

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