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Topsoil bulk density of abandoned rural settlements of the Russian boreal zone

I A Martynenko[1*], J L Meshalkina [1,2], N Yu Goncharuk[3], M A Butylkina[1] and G S Bykova[1]

[1] Faculty of Soil Science, Lomonosov Moscow State University, GSP-1, Leninskie Gory, Moscow 119991, Russian Federation
[2] Department of Ecology, Russian Timiryazev State Agrarian University, Timiryazevskaya Str. 49, Moscow, 127550, Russian Federation
[3] FBI the Russian Federal Center of Forensic Expertise under Ministry of Justice of Russia, Khokhlovsky lane 13, bld. 2, Moscow, 109028, Russian Federation

[*]E-mail: martynenko.irina@gmail.com

Abstract. The topsoil bulk density of two abandoned small rural settlements situated at Tver and Yaroslavl regions of Russia was studied. The key sites had light grain soil texture. They had a long history of rural land use, and they were abandoned simultaneously. There were no stone buildings. The values of the abandoned rural settlements' topsoil bulk density are correlated with the land use type and the time of reforestation. The topsoil bulk density of the former buildings and the dirt roads was significantly higher than the one of the plough horizons of the former gardens, orchards and arable lands (1.7 and 1.4 g/cm^3, respectively). Soil horizons of former buildings' territory are characterized by coarser granulometric composition of fine-grained fraction; however, they do not differ from plough horizons in bulk density that may be related to 2-3 times higher organic carbon content.

1. Introduction
According to the Russian Census 2010, 12.7% of rural settlements are abandoned [1]. Nowadays, there is no population approximately in the quarter of rural settlements in Tver and Yaroslavl regions [1]. The soil cover in such areas is heterogeneous. Urbic horizons are common for the soils of former buildings and curtilages territories. They are characterized by anthropogenic artifacts` availability. Horticultural soils were formed on the premises of former gardens and orchards. Plough soils were common for former hayfields and arable lands.

As human impact on the taiga agricultural soils was ceased, gradual natural soil genetic profile recovery has been observed. Biocenosis progressively changes in the agro-ecosystem row (agrocenosis - meadow - forest). The upper part of the plough horizon is transformed at the lea land stage that causes two sub-horizons formation: sod horizon (humus horizon largely interwoven with roots of herbaceous plants) and lower horizon (the former plough horizon). The further forest renovation leads to the sod layer replacement with a humus-accumulative one; forest litter is being formed on the surface. The lower part of the former plough horizon obtains the textural differentiation features. However, the agricultural development signs had been preserved under the forest for 100-200 years and more [2]. The marks caused by human impact remain in the most modified places as long as possible (parcel boundaries, former dirt roads and buildings areas). Meanwhile, a sod horizon is also

formed in the upper part of urban soil in the settlement zone, while the lower part remains unchangeable [3]. This transformation concerns morphological as well as physical properties of the antropogenically-modified horizons, particularly the bulk density.

The objective of the paper was to research the influence of various aspects (reforestation time, the type of horizon, previous land use, etc.) on the humus horizon differentiation of abandoned rural settlement zones according to the bulk density.

2. Objects and methods

The research covers two key sites representing the areas of the former rural settlements including the settlement zone itself, orchards, gardens, ploughs and dirt roads located on the taiga kame hills. The key sites had light grain soil texture. They had a long history of rural land use, and they were abandoned more or less simultaneously.

According to the General Survey of the Lands of the Russian Empire of 1765-1836 and archival records, both areas had been settled by the 17th century and extensively used for gardens, ploughs and hey fields up to the 1970s and 1980s [2, 3]. The abandoning time was identified by the topographical maps tiles with a scale of 1:10 000 dated back to the 1955s-1990s.

The first key site is situated at the watershed of the Mezha River and Staroselskiy stream (N 56.4844°, E 32.9856°) inside the array of the indigenous intact spruce forests of the Central Forest Nature Reserve (Tver region). The vegetation cover was changing from the top to the foothill. The motley grass-grasses associations of hill upper parts were gradually replaced with forest ranges of different age and structure: from 20-years-old birch forests to 60-years-old birch woods with spruce young growth and then to 100-200-years-old spruce forests.

The second key site (N 57.7070°, E 38.0732°) is located at the watershed of the rivers Sutka and Katja (Yaroslavl region) inside the array of secondary small-leaved forests formed instead of lime and spruce forests existing before the settlement process. Humus layers of natural soil under the indigenous 120-130-years-old forests were selected as a natural background. There were no traces of anthropogenic impact in these soils.

Totally, 115 humus-accumulative layers samples have been selected from 73 places of the first key site, while 28 examples have been chosen from 11 places of the second key point. The sampling was conducted only from the middle part of the genetic horizons. The morphological description of the soil profile upper part was made for all points. The particle-size distribution was determined by the Kaczynski-Robinson-Kehl Pipette method [4]. Soil samples were grinded in the porcelain mortar with a rubber-tipped pestle and then passed through a 1 mm sieve. Dispersion of the particles less than 1 mm was conducted by grinding in the mortar with the addition of 4% sodium pyrophosphate. The fraction composition sizing 1 – 0.25 mm was detected by the sieve method. The fraction composition sizing less than 0.25 mm was determined by a pipette method [4]. For textural types detection the USDA classification has been applied [5].

For soil bulk density identifying in three replications, the samples having an undisturbed structure were selected with an auger, h=3.2 cm, d=3 cm. The samples' weight was determined after oven drying for six hours at 105° temperature. The names of soils and horizons indices (except for sod one) were given by World Reference Base for Soil Resources 2015 [6].

The research included a multivariate analysis of variance without interaction (MANOVA) [7], where the bulk density was regarded as a response, while the factors were represented by location, key site (region), land use type before abandoning (buildings, roads, gardens, orchards, ploughs, forests), current vegetation type (woody, motley grass-grasses), woody vegetation age (absent, 20, 40, 60, 80, 110 years), genetic horizon type (A(sod), Ap, Au, A), horizon depth (surficial, underlying).

3. Results and discussion

The humus-accumulative soil profile part of both key sites is represented by four horizon types. Two topsoil horizons were observed: sod (A (sod)) under the meadow vegetation of overgrown ploughs, and humus (A) under the forest vegetation. Two detected subsurface horizons were humus ones:

plough horizon (Ap) on the premises of the former ploughs, gardens and orchards and urban layers (Au) on the premises of the former buildings. The plough horizon on the premises of dirt roads lies under the sod one or from the surface.

Upper soil horizons in Tver region are characterized by a high concentration of stony fractions (grus, crushed stone, pebble) amounting sometimes up to 50% of total soil weight. According to the particle-size composition of a fine soil, natural and plough horizons come to the slit loam and sandy loam texture classes, urban soils horizons in Tver region – to the loamy fine sand class while in Yaroslavl region – to the sandy loam one, i.e. urban soil can be characterized by a coarser particle-size composition of a fine soil. Thereby urban horizons are characterized by coarser granulometric composition of fine-grained fraction.

On average, key sites did not differ according to all the humus horizons bulk density; therefore, the data were combined into one array.

As analysis shows, the bulk density of a sod horizon (A(sod)) is higher than A one. The average bulk density values of subsurface (plough and urban) horizons is higher and significantly different from the surface ones (table 1).

Table 1. Statistical characteristics of bulk density values distributions for different topsoil horizons.

Horizons	C, %[a]	Bulk density			
		SN[b]	Mean, g/cm^3	St.dev. , g/cm^3	CV, %[c]
A(sod)	2.96	49	1.34	0.25	19
A	4.13	35	1.12	0.30	26
Ap	1.88	54	1.61	0.27	17
Au	5.02	5	1.65	0.32	19

[a] C - organic carbon content.
[b] SN – sample number.
[c] CV - coefficient of variation.

The average bulk density values of urban layers accounts 1.68 g/cm^3 for Tver region and 1.61 g/cm^3 for Yaroslavl region. The average bulk density values of urban soils usually range from 1.2-1.6 g/cm^3 [8-10].

In fact, the material reaching the rural surfaces does not contain stony building waste. However, the depth of these horizons is more than 40 cm that, according to the Urbic horizon definition in Russian classification [11], indicates the human impact intensity compared with urban conditions. The mean organic carbon content in the urban horizons of researched areas is almost twice higher in comparison with urban Moscow soils (5.0 % and 2.7 %, respectively) [12]. The density increase can be explained by the synlitogenic character of urban horizons as well as sandy particle-size soil composition of the researched areas.

The statistical analysis of land use type influence has shown that the soils of former ploughs, gardens and orchards do not differ according to the bulk density. The lowest mean bulk density value was typical for horizons under forests. It was significantly different from the others. The maximum density values are naturally associated with buildings and roads, and do not have statistically considerable distinctions (figure 1). There are no statistically significant differences between them.
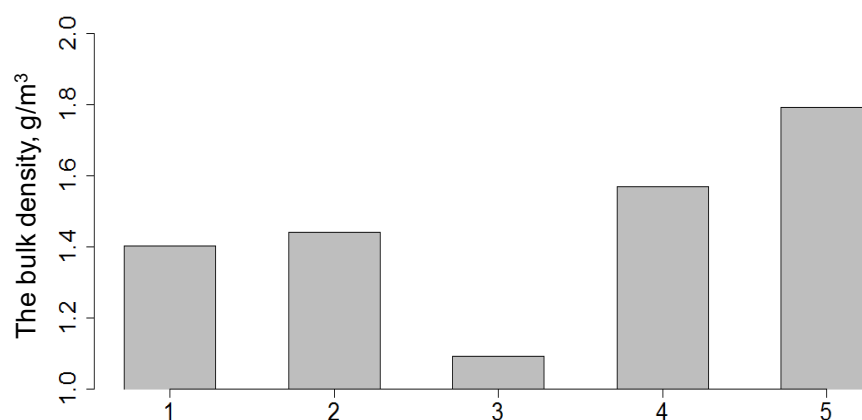
Figure 1. The average bulk density values for areas with different types of former land use: 1 – arable land, 2 - gardens and orchards, 3 - forest, 4 - buildings, 5 – roads.

The analysis of the reforestation time impact on the topsoil bulk density has shown three rather different groups: meadow areas and young birch forests, 60-years-old birch woods with young spruce growth, and 100-120-years-old forests. The topsoil density is regularly decreasing in this line from 1.51 g/cm^3 to 1.26 g/cm^3 and 1.06 g/cm^3, respectively.

4. Conclusions

Over the last 50 years since abandonment has started, the spatial heterogeneity can be observed in the bulk density distribution of humus horizon topsoil on the premises of abandoned rural areas: edge regions being under forest renovation over 40 years can be characterized by lower bulk density values. Bulk density of sod horizon is identical regardless of the former land use type.

Land usage character determines the average humus horizon bulk density dividing the rural region into two parts: the area of the former buildings and dirt roads with density values exceeding the preferable ones and areas of the former gardens, orchards and ploughs with almost ideal values.

The urban horizons of the rural settlement zone located on sandy loams can be characterized by the rise of a physical sand concentration approximately by 10% compared with plough ones. However, this does not lead to their bulk density increase that can be related to a higher organic carbon concentration (two or three time higher compared with plough ones).

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