The influence of the lithological factor of soil formation on the properties and composition of soils in the broad-leaved forest of the forest-steppe zone of the Volga region

O A Vasilyev¹, A O Vasiliev², R V Andreev³, N N Pushkarenko⁴ and S S Alatyrev⁵

¹Department of land management and cadastres, Chuvash State Agricultural Academy, 29 K/Marks Street, Cheboksary 428000, Russian Federation
²,³,⁴Technical Service Department, Chuvash State Agricultural Academy, 29 K/Marks Street, Cheboksary 428000, Russian Federation
⁵Department of transport and technological machines and complexes, Chuvash State Agricultural Academy, 29 K/Marks Street, Cheboksary 428000, Russian Federation

¹E-mail: vasiloleg@mail.ru
²E-mail: 3777222@bk.ru
³E-mail: rv_andreev@mail.ru
⁴E-mail: stl_mstu@mail.ru
⁵E-mail: leha.alatyrev@mail.ru

Abstract. The study of soils with the compilation of a soil map of a broad-leaved forest "Natural plantations of oak" (hereinafter referred to as the NPO) in the Komsomolsky District of the Chuvash Republic (forest-steppe zone of the Volga region) was carried out for the first time. The time of research is summer 2017. The relief is a weakly undulating watershed of the Volga Upland. The woody and shrubby vegetation of the reserve is represented mainly by an oak of different ages, linden, maple, and rarely spruce. Of the factors of soil formation, only the soil-forming rock and the relief change. Of the factors of soil formation, only the soil-forming rock and the relief change. The soil cover of NPO is represented by Glossic, Albic, Dystric Retisol on Jurassic clay eluvium and Glossic, Albic, Dystric Retisol on Jurassic clay eluvium soils, Glossic, Albic, Dystric, Stagnic Retisol on Jurassic clay eluvium, Glossic, Greyzem, Luvic Phaeozems on Cretaceous clay eluvium, and Glossic, Greyzem, Stagnic, Luvic Phaeozems on Jurassic clay eluvium. The humus horizons have a low content of humus and plant nutrients.

1. Introduction
The soils of the forest lands of the Chuvash Republic have been studied to a small extent, with the exception of certain areas [1, 2]. Various authors have emphasized that soil mapping of forests and reserves is important for revealing the patterns of their formation, changes that occurred in similar anthropogenically transformed soils, as well as their rational use and restoration of fertility. The importance of this research is given in sources [3-10]. The peculiarity of the studied soils is that the boundary between the two indigenous soil-forming rocks, the clays of the Jurassic and Cretaceous systems, lies on the studied territory, and the lithological factor of soil formation (all other factors with the same effect) influenced the process of soil formation manifested the principle of the only
difference. The lithological factor of soil formation, along with the relief of the study area, caused the formation of eight soil varieties.

The specially protected natural area "Natural plantations of oak" (hereinafter referred to as NPO) is located in the south-western part of the Komsomolsky district and covers an area of 356 hectares. It is surrounded from the west and the north by the agricultural lands of the Luch and Druzhba agricultural complexes in the Komsomolsky District, and from the south by the Urozhai Agricultural Production Complex of the Komsomolsky District and the Druzhba Joint-Stock Company in the Batyrevsky District of the Chuvash Republic (forest-steppe zone of the Volga region).

The territory of the NPO is included in the southern warm agroclimatic region, the southeastern steppe agroclimatic subarea of the Chuvash Republic, characterized by a temperate continental climate, with warm summers and moderately cold winters. The sum of positive air temperatures is 2500-2600 degrees, and the sum of active temperatures is 2200-2300 degrees. Precipitation for the year falls 605-660 mm. The maximum height of the snow cover on the fields is 35-40 cm. On the territory of the reserve winter winds prevail in the south-west, and in the summer - in the west direction.

The studied territory is located in the forest-steppe zone and enters the southern warm climatic region of Chuvashia, which is characterized by a periodically arid climate. The average annual precipitation is 500 mm. The surface is a flat watershed located on an elevated wavy plain with absolute elevations of 180-220 m. Overall, the relief of the territory is smoothed, with a depth of 75-100 m. The gully-girder ratio is only 0.2-0.3 km / km², river – 0.19 km / km².

There are no rivers and lakes on the territory of the forest under study.

The relief of the studied forest lands is represented by weakly-polished longitudinally undulating-convex and transversely-wavy-convex slopes of the watershed of the northern and eastern exposures. The slopes in the central part are rugged by gullies passing into a ravine, and by a complex microrelief - alternation of flat areas with convex and lowered ones.

Soil-forming species of the reserve are light and medium clays of the Jurassic and Cretaceous periods. Jurassic clays are widespread in the central and eastern parts of the reserve, and in the western part - Cretaceous rocks. Eluvium of Jurassic and Cretaceous deposits occurs in the form of weakly and strongly eroded gray and tobacco-brown clays.

In comparison with the chalky rocks, the eluvium of the Jurassic rocks is characterized by increased density, viscosity, weak water and air permeability, carbonate content, often with signs of gleying. The content of clay particles in Jurassic clays often exceeds 70%, and even reaches 92% (including the share of silty particles of more than 50%), which worsens its physical properties and adversely affects the soil-forming process.

The type of forest under study is oak plantation, aged 45-90 years. The woody and shrubby vegetation of the reserve is represented mainly by an oak of different ages, linden, maple, and rarely spruce. In the eastern part of the reserve, there are groups of pine and aspen. From underbrush common hazel, bird cherry. Grassy cover is typical of broad-leaved forests; 74 species of vascular plants (lat. Tracheophyta, Plantae Vasculares, Tracheobionta), among which prevail Common Aigopodium (Aegopodium podagraria), Common Bracken (Pteridium aquilinum), Rough horsetail (Equisetum hiemale), European wild ginger (Asarum europaeum), Carex hallerianna (Carex pilosa), Lamium galeobdon (Galeobdon luteum), Anemone ranunculoides, Convallaria majalis, etc. In open areas of the fringe and glades - clover (Trifolium pratense), foxtail meadow (Allopecurus pratensis), Poa pratensis, Achillea millefolium.

Pyrethrum corymbosum (L.) is found from the list of plants included in the Red Book.

The purpose of the research is to study the effect of different soil-forming rocks in similar other conditions on soil formation, morphological characteristics of the profile, and agrochemical properties.

2. Materials and methods

Soil mapping of the territory of the reserve "Natural plantations of oak" of the Komsomolsky district of the Chuvash Republic was carried out on a map of scale 1: 10000.
At the field stage of the work, 36 soil sections were carried out; in each soil profile, after description, samples were taken for analyzes with a mass of 300-400 g in canvas bags, which were supplied with accompanying labels indicating the area, section number, horizon, depth of selection and date of selection. Sacks with soil samples were opened on the evening of the selection day to dry the soil.

At the cameral stage, the dried soil samples were ground in a porcelain mortar, sieved through a 1 mm sieve.

Laboratory analyzes were carried out according to generally accepted methods: humus - according to Tyurin, mobile phosphorus and exchange potassium - according to Kirsanov, exchange acidity - potentiometrically, on ionomer "EV-74".

3. Results and discussion

The soil cover of NPO is represented by Glossic, Albic, Dystric Retisol on Jurassic clay eluvium and Glossic, Albic, Dystric Retisol on Jurassic clay eluvium soils, Glossic, Albic, Dystric, Stagnic Retisol on Jurassic clay eluvium, Glossic, Greyzemic, Luvic Phaeozems on Cretaceous clay eluvium, and Glossic, Greyzemic, Stagnic, Luvic Phaeozems on Jurassic clay eluvium.

In connection with the heavy granulometric composition of the soil-forming rocks, the studied soils have a shortened profile (the lower boundary of the horizon $A_{2}$B as a rule does not fall deeper than 22 cm), in soddy-podzolic soils the thickness of horizons AU is within the range of 6-9 cm, AEL within 4-6 cm; in light gray forest soils the thickness of horizon AU is 10-22 cm. Soil-forming rocks (a shortened soil profile is observed due to the heavy particle size distribution) lie at a depth of 105-115 cm. A distinguishing feature of sod-podzolic from light gray forest soils is the presence of a whitish, with a light gray shade and a layered podzolic horizon $EL$. The sod-podzolic soils of the reserve belong to the genus of residual-carbonate, the species of finely podzolic horizons $EL$ horizon to 20 cm deep and medium podzolic horizons - horizon $EL$ of a continuous, slab-cloddy structure.

Table 1. Description of soil profile number 9 (18.08.17).

| Horizon | Depth, cm | Description |
|---------|-----------|-------------|
| O       | 0-2       | Fresh, brown, friable, the remains of leaves of various degrees of decomposition, permeated by the roots of plants. The transition is clear. |
| AU      | 2-5       | Fresh, slightly moistened, dark gray, heavy loamy, small-cloddy, friable. With the roots of herbaceous plants, earthworms. Does not effervesce. |
| AEL     | 5-7       | Fresh, slightly moistened, gray, with whitish spots, heavy loamy, small-lumpy, loose. There are roots. |
| EL      | 7-16      | Fresh, ashy-light gray, with rusty specks (smeared), silty, lamellar-laminated, dense. There are plant roots. Does not effervesce. |
| BEL     | 16-26     | Fresh, light-clayey, brownish-gray, dusty-nutty, dense, with excretions of powdery powder of silica, with plant roots. Does not effervesce. |
| BI₁     | 26-33     | Fresh, light-clayey, brownish-gray, dusty-nutty, dense, with excretions of powdery powder of silica, with plant roots. Does not effervesce. |
| BI₂     | 33-47     | Wet, spotted: brown with gray spots, coarse-grained, with plant roots. Does not effervesce. |
| BI₃     | 47-64     | Wet, brown, with dark spots, light-clayey, dense, structureless, with plant roots. |
| BIC     | 64-103    | Wet, brown, light-clayey, structureless, with sparse spots of humus, effervesces from 70 cm. |
| C       | 103-120   | Wet, bluish-brown (eluvium of Jurassic rocks), medium-clayey, with dark dense lumps, structureless, with white spots of carbonates. Burns violently. |
The profile of sod-podzolic heavy loamy soil on eluvium of Jurassic clays is shown on the example of profile description of section 9 (Table 1). The surrounding vegetation is a forest with young oaks, maples, limes, hazel. The grass cover in the area of the soil cut is thinned: pale, fern.

Light-gray forest soils of the reserve "Natural plantations of oak" are common in areas among trees with well-developed grassy cover. Their granulometric composition is light-clayey.

In light gray forest soils, in contrast to sod-podzolic soils, a greater thickness of the humus horizon is observed and a lesser degree of podzolization - in place of horizon EL there is a horizon AEL, more humified and less podzolized. The light gray forest soils of the reserve belong to the genus of residual-carbonate, high-boiling species - effervescence from carbonates begins at a depth of 60-90 cm and low-power - the thickness of the humus horizon (AU + AEL) is less than 20 cm.

As an example of the structure of the profile of light gray forest soils, a description of the section No. 26 is given (Table 2).

### Table 2. Description of soil profile No. 26 (28.08.17).

| Horizon | Depth, cm | Description |
|---------|-----------|-------------|
| O       | 0-2       | Brown, loose, the remains of leaves, permeated by the roots of plants. The transition is clear. |
| AY      | 2-8       | Dry, gray, light-clayey, powdery-granular, interwoven with plant roots, contains many organic residues. |
| AU      | 8-15      | Dry, slightly moistened, gray, light-clayey, small-cloddy, friable. Roots of herbaceous plants. |
| AEL     | 15-22     | Humidified, light-clayey, brownish-grayish-ashy, dusty-nutty, dense, with excreta of powdery powdered silica, with plant roots. |
| BEL     | 22-27     | Moist, brown, light-clayey, nutty, dense, with spots of silica, with plant roots. |
| BI₁     | 76-33     | Wet, spotted: brown with gray and brown spots, coarse-grained, with plant roots. |
| BI₂     | 33-59     | Wet, brown, with dark spots, light-clay, dense, structureless, with plant roots. |
| BI₃     | 59-87     | Weak effervescence from 75 cm, strong - from 79 cm. |
| BIC     | 87-106    | Wet, brown, light-clayey, structureless, with rare spots of humus, effervesces. Nests of carbonates - from 87 cm. |
| C       | 106-130   | Wet, brown, medium-clay, with dark dense lumps, structureless, with nests of carbonates. |

In the sod-podzolic and light gray forest surface-gley soils, rusty specks and iron pellets are clearly seen from the surface in the humus horizon, in the horizon BEL - gley and rusty stains of iron oxides.

Sod-podzolic gleyed soils stretch a wide stripe of 150-200 m into the depth of the forest and 1500-1600 m in length in the southern central part of the forest under study. They are characterized by meadow vegetation (fox-tail, fire, bluegrass, grasses, etc.), far apart oaks, including dead ones.

Often, the surface of the soil is waterlogged, wet, and reminiscent of marsh. Such soils were formed on native Jurassic rocks, which have unsatisfactory water-physical properties.

As an example of the description of sod-podzolic superficial-gleyed soils, a description of the soil profile No. 13 is given below (Table 3).

Soil incision No. 13 was laid on a flat top of the watershed, 100 m to the north of the southwestern edge of the oak grove.

Vegetation - oaks standing sparse - 30-50 m from each other, meadow grasses: bluegrass, foxtail, boneless beet, etc.
Table 3. Description of the profile of Glossic, Albic, Dystric, Stagnic Retisol (Abruptic, Clayic, Cutanic, Differentic, Humic) on Jurassic clay eluvium soil (profile 13).

| Horizon | Depth, cm | Description |
|---------|-----------|-------------|
| O       | 0-2       | Brownish-dark gray, loose, the remains of stems and leaves. The transition is clear. |
| AY      | 2-5       | Wet, brownish-dark gray, light-clayey, granular-lumpy, interwoven with plant roots, contains many organic residues. |
| AEL<sup>g</sup> | 5-10 | Wet, light-rusty, with whitish spots, light-clayey, small cloddy-nutty, loose. With the roots of herbaceous plants, there are iron-manganese pellets of rusty and black color. |
| E<sup>g</sup> | 10-20 | Wet, light-gray-whitish, light-clayey, finely ore-laminar, dense, with rusty spots. |
| BEL<sup>g</sup> | 20-35 | Very moist, dark-gray, with rusty glandular spots, nutty, light-clayey, dense, with discharge of gray and rusty iron spots, with plant roots. |
| BI<sup>fe</sup> | 27-60 | Wet, brown, with rusty spots lightly clayey, nutty, dense, with plant roots. |

Light-gray forest soils gleyed in profile structure are similar to sod-podzolic gleyed, but they lack the horizon BEL<sup>g</sup>. It is noted that the herbaceous vegetation in the region of the soil profile is somewhat different - no foxtail occurs (Table 4).

Table 4. Description of the profile of Glossic, Greyzemic, Luvic Phaeozems (Abruptic, Clayic, Albic) on Jurassic clay eluvium soils (profile 3).

| Horizon | Depth, cm | Description |
|---------|-----------|-------------|
| O       | 0-1       | Brownish-dark gray, loose, the remains of stems and leaves. The transition is clear. |
| AY      | 2-8       | Humidified, brownish-dark gray, light-clayey, granular-lumpy, interwoven with plant roots, contains many organic residues. |
| AEL<sup>g</sup> | 8-16 | Wet, light-rusty, with whitish spots, light-clayey, small cloddy-nutty, loose. Intertwined by the roots of herbaceous plants. |
| BEL<sup>g</sup> | 16-23 | Very moist, bluish-rusty, fine-grained, light-clayey, dense, with spots of iron spots, with plant roots. |
| BI<sup>fe</sup> | 23-63 | Wet, brown, with rusty spots lightly clayey, nutty, dense, with plant roots. |

In the gleyed soils, the sod horizon AY, the transition horizon AEL<sup>g</sup> and the podzolic horizon BI<sup>fe</sup> with rusty-ocherous glandular spots are clearly visible.

The results of agrochemical analyzes indicate a very low content of humus (less than 3%), very low availability of soils of the reserve with mobile phosphorus according to Kirsanov and an average supply of exchangeable potassium, a very strong acidic and highly acidic medium of humus horizons (pH of exchange acidity less than 4 and 4.0-4, 5 respectively).

In Figure 1, the regressive-accumulative profile and humus content are recognized.
Figure 1. Agrochemical properties of Glossic, Albic, Dystric, Stagnic Retisol (Abruptic, Clayic, Cutanic, Differentic, Humic) on Jurassic clay eluvium soil: **K2O** - The content of exchangeable potassium, mg / kg, **P2O5** - The content of mobile phosphorus, mg / kg, **Humus**, % - Humus content, %, **pH exchange** - Exchange acidity of soil horizons, pH.

The minimum value in the humus horizon is observed in horizon EL - 0.39%. Such a graph of humus content in the profile is characteristic of sod-podzolic soils.

The content of mobile phosphorus has two maxima - in horizons AU and AEL. Its minimum is observed in the horizon AU and in the soil-forming rock.

In the profile there are two maxima of the content of exchangeable potassium in the horizon AEL and in the illuvial horizon Bl2. Its minimum content is in the podzolic horizon A2.

The minimum value of the exchange acidity is in the podzolic horizon EL - pH 3.24 - a very strong acid medium.

The data of the chemical analysis of soil-forming rocks - Jurassic clays - attest to their rich mineralogical and chemical composition, which is transmitted to the soil and affects agrochemical properties.

Thus, the agrochemical characteristic of the soil profile further characterizes its belonging to the sod-podzolic type.

For the agrochemical characteristics of light gray forest soils of NPO, we give data from analyzes of the soil profile 26.

The change in the content of humus, mobile plant nutrients and pH of exchange acidity in the soil profile corresponds to the type of gray forest soils, a subtype of light gray forest soil (Figure 2).
According to the results of the conducted studies, 137 hectares occupy the total area of the natural monument, equal to 356 hectares, the type of sod-podzolic soils of the genus residual-carbonate, the medium podzolic, fine podzolic, high-boiling, heavy-loamy and light-clayey varieties on the eluvium of the indigenous Jurassic rocks.

On an area of 6 hectares of soil, NPO consist of sod-podzolic gleyed heavy loamy and light-clay soils on eluvium of Jurassic rocks.

On an area of 195 hectares in the northern part of the forest "Natural plantations of oak" a broad stripe from east to west spreads the type of gray forest, subtype light gray forest, a kind of residual carbonate, a species of low-power, high-boiling, light loamy and heavy loamy eluvial native Jurassic and Cretaceous rocks with a strong acid reaction and low and medium content of humus and plant nutrients in the upper part of the profile.

In the central part on the southern boundary of the oak grove on the area of 29 hectares of the reserve's grounds there are light-gray forest gleyed light-clayey, eluvium-based cretaceous rocks.

As an exception, in the extreme southeastern part of the NPO there are typical gray forest soils, light-clayey, on the eluvium of the Cretaceous rocks (section No. 11), occupying an insignificant area of 2 hectares and adjoining the arable land of the “Druzhba” collective farm of the Batyrevsky District of the Chuvash Republic (Table 5).
Table 5. Soil areas of NPO.

| Soil name                                                                 | Area, hectares | In % of total area |
|---------------------------------------------------------------------------|----------------|-------------------|
| Glossic, Albic, Dystric Retisol (Abruptic, Loamic, Cutanic, Differentic, Humic) on Jurassic clay eluvium | 9              | 2.0               |
| Glossic, Albic, Dystric Retisol (Abruptic, Clayic, Cutanic, Differentic, Humic) on Jurassic clay eluvium | 130            | 36.5              |
| Glossic, Albic, Dystric, Stagnic Retisol (Abruptic, Clayic, Cutanic, Differentic, Humic) on Jurassic clay eluvium | 4              | 1.7               |
| Glossic, Greyzemic, Luvic Phaeozem (Abruptic, Loamic, Albic) on Jurassic clay eluvium | 20             | 5.6               |
| Glossic, Greyzemic, Luvic Phaeozem (Abruptic, Clayic, Albic) on Jurassic clay eluvium | 144            | 40.4              |
| Glossic, Greyzemic, Luvic Phaeozem (Abruptic, Clayic, Albic) on Cretaceous clay eluvium | 23             | 6.5               |
| Glossic, Greyzemic, Stagnic, Luvic Phaeozems (Abruptic, Clayic, Albic) on Cretaceous clay eluvium | 24             | 6.7               |
| Chernic, Greyzemic Luvic Phaeozem (Abruptic, Clayic) on Cretaceous clay eluvium | 2              | 0.6               |
| Total area                                                               | 356            | 100%              |

4. Conclusions

As a result of the first work on soil mapping of the territory of specially protected natural areas "Natural plantations of oak" with an area of 356 hectares, a soil map was created on a scale of 1:10000.

For the first time, the studied soils of a specially protected natural area "Natural plantations of oak" of the Komsomolsky district of the Chuvash Republic have a shortened profile (the lower boundary of the horizon BEL as a rule does not fall deeper than 22 cm), in the sod-podzolic soils the thickness of horizons AU is in the range of 6-9 cm, AEL in the limits of 4-6 cm; in light gray forest soils the thickness of the horizon AU is 10-22 cm. Soil-forming rocks lie at a depth of 105-115 cm.

A distinctive feature of sod-podzolic from light gray forest soils is the presence of a whitish, with a light gray tinge and a lumpy-platy structure of the podzolic horizon EL. The sod-podzolic soils of the reserve belong to the genus of residual-carbonate, the species of finely podzolic and medium podzolic soils-horizon EL of a continuous, cloddy structure.

On an area of 145 hectares, the soils of forest are of the type of sod-podzolic soils, the genus of residual carbonate, the type of medium podzolic, finely podzolic, high-boiling, heavy-loamy and light-clayey varieties, on eluvium of native Jurassic rocks, with very acidic reaction and low humus content and mobile plant nutrients in the soil horizons.

On an area of 9 hectares, the reserve's grounds consist of Glossic, Albic, Dystric Retisol (Abruptic, Loamic, Cutanic, Differentic, Humic) on Jurassic clay eluvium with a low content of humus and mobile plant nutrients.

On the area of 189 hectares, soils of the gray forest type, light gray forest type subtype, the genus of residual carbonate, the type of low-power, high-boiling, light loamy and light loamy eluvium species of the indigenous Jurassic and Cretaceous rocks with a strong acid reaction and low and medium humus content and plant nutrients in the soil horizons.

On the area of 24 hectares of the reserve's grounds - Glossic, Greyzemic, Stagnic, Luvic Phaeozems (Abruptic, Clayic, Albic) on Cretaceous clay eluvium with a low and medium content of humus and mobile plant nutrients.

Typically gray forest soils found in the extreme south-eastern part of forest - Glossic, Greyzemic, Luvic Phaeozems (Abruptic, Clayic, Albic) on Cretaceous clay eluvium, occupy an insignificant area of 2 hectares.
References

[1] Vasiliev O A, Egorov V G, Ilyin A N and Nikitin K P 2017 Restoration of fertility of degraded gray forest soils in the southern part of the Non-chernozem zone of the Russian Federation Land management, cadastre and land monitoring [Zemleustrojstvo, kadastr i monitoring zemel' - in Russian] 1 29-35

[2] Vasiliev O A, Semenov V G, Yulbashayev Y A, Baimukanov D A and Aubakirov K A 2018 Soil cover of the "Zaovrazhny" micro-district, Cheboksary, and its ecological state News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences 3 (430) 74-78

[3] Alexis S, García-Montero L G, Hernández A J, García-Abril A and Pastor J 2009 Soil fertility and GIS raster models for tropical agroforestry planning in economically depressed and contaminated Caribbean areas (coffee and kidney bean plantations) Agroforestry Systems 79(3) 381-391

[4] Bourgault R R, Ross D S and Bailey S W 2015 Chemical and morphological distinctions between vertical and lateral podzolization at Hubbard Brook Soil Science Society of America Journal 79(2) 428-439

[5] Guimarães R M L, Lamandé M, Munkholm L J, Ball B C and Keller T 2017 Opportunities and future directions for visual soil evaluation methods in soil structure research Soil and Tillage Research 173 2017 104-113

[6] Ingle S T, Patil S N, Kolhe P M, Marathe N P and Kachate N R 2018 Evaluation of agricultural soil quality in Khandesh region of Maharashtra, India Nature Environment and Pollution Technology 17(4) 1147-1160

[7] Li W, Fan W Y, Mao X G and Zhao L 2013 Soil erosion research based on RS and USLE in Great Khinggan Advanced Materials Research. 3rd International Conference on Energy, Environment and Sustainable Development EESD 2013, Shanghai, China, 12 November 2013 864 2799-2803

[8] Petrovský E, Remeš J, Kapička A, Podrázský V, Grison H and Borůvka L 2018 Magnetic mapping of distribution of wood ash used for fertilization of forest soil Science of the Total Environment 626 228-234

[9] Qu J-L and Zhao D-X 2016 Comparative research on tillable properties of diatomite-improved soils in the Yangtze River Delta region, China Science of the Total Environment 568 480-488

[10] Wieczorek J, Baran A, Urbański K, Mazurek R and Klimowicz-Pawlas 2018 A Assessment of the pollution and ecological risk of lead and cadmium in soils Environmental Geochemistry and Health 40(6) 2325-2342