Newly formed soils of the sugar industry treatment facilities and invasion of Acer Negundo (Chernozem zone of Russia)

R G GrachevaORCID 0000-0001-0042-5632, I V ZamotaevORCID 0000-0003-4587-4070, E A BelonovskayaORCID 0000-0002-8354-4606, Yu V KonovlianikovaORCID 0000-0002-9154-4070, A S DobryanskiyORCID 0000-0003-2691-3898

Institute of Geography of RAS, Moscow, Russia

E-mail: gracheva@igras.ru

Abstract. Sugar production generates a lot of wastewaters which are discharged into extensive treatment facilities. For the first time, soils and vegetation formed at the treatment facilities of the sugar industry in the Chernozem zone of Russia (Lgov sugar mill, Kursk region) were studied. Depending on the topography and activity/inactivity settling ponds Gleysols, Gleyic Cambisols, Eutric Cambisols and Technosols (Alkalic) were developed. Newly formed soils are alkaline, enriched with organic carbon and carbonates, and differ significantly from the background soils. In a wide variety of moisture conditions and soil properties, invasive Acer Negundo is widespread demonstrating a high degree of ecological plasticity.

Newly formed landscapes, which are reservoirs of organic carbon and receive a huge microbial pool from wastewater, have become an integral part of the sugar industry environment.

1. Introduction

For the first time, soils and vegetation cover formed at the treatment facilities of sugar factories in the Chernozem zone of Russia were studied. Despite the great interest in research on soils and landscapes formed on industrial waste [1, 2, 3], it is difficult to find publications on landscapes formed on the waste of the sugar industry, one of the oldest food industries in the world.

Sugar production generates more than 80% of waste, consisting of organic material and filter cake (or press mud) containing lime dust, mineral impurities and auxiliary substances. Currently, solid waste is used in agriculture and industry, or is involved in the recycling process; however, significant volumes of wastewater are discharged into extensive treatment facilities [4, 5, 6].

In Russia, sugar production began in the 16th century using imported sugar cane; the industrial production of sugar from sugar beets began at the beginning of the 19th century. Sugar factories are located in the areas of sugar beet growing, in the forest-steppe and steppe zones). They are localized in water-supplied areas, as sugar production requires a lot of water.

The purpose of our research was to study the sugar wastewater treatment areas considering them as newly formed landscapes that have been functioning under the influence of sugar mills for decades.

2. Materials and Methods

Soil-geobotanical studies of the complex of clearing constructions of the Lgov sugar plant (Kursk region), founded in 1895, have been carried out (figure 1). That is a forest-steppe zone, an area of Haplic Chernozems [7]. The sewage treatment facilities created in the 1950s, occupy 175 hectares on a gentle hill sloping into the Apoka River. It is a network of settling ponds separated by earth walls up to...
The ponds alternately operate in the mode of watering with wastewater and drying; some of them are abandoned. The earth walls are composed of a mixture of Chernozem material and carbonate loess-like loams extracted during the construction of ponds. Some of the earth walls are covered with filtration sediment (press mud) removed from the bottoms of the settling ponds. Under these conditions, a kind of "cellular" landscape arose not characteristic of the local environment. This is clearly seen in the pictures taken using the unmanned aerial vehicle (UAV) (figure 2). During the field research, UAV made it possible to reconstruct the terrain conditions and highlight key areas.

![Figure 1](image1.png)

**Figure 1.** An overview map of operating sugar mills within the chernozem zone (a) and in the Kursk region (b).

![Figure 2](image2.png)

**Figure 2.** Use of UAVs: (a) – orthophotomosaic of the study area; (b) – a fragment of orthophotomosaic; (c) – perspective aerial photo of sugar treatment facilities.

11 sites were investigated covering typical combinations of topography, soils and vegetation, taking into account the activity or inactivity of settling ponds. Soil pits were described and sampled for analytical studies and micromorphology; the samples were also examined using an electron microscope to identify newly formed soil components as traces of wastewater impact. In naming the soils, the international soil classification [8] was used. Some properties of wastewater taken from the sewer pipe were analyzed.
11 complete geobotanical plots of 10 sq. m and 20 plots of 1.0 sq. m are described with the definition of the species composition and assessment of the abundance of each species; the main characteristics of the tree layer were measured, with particular attention to Acer negundo. The plant communities are named according to floristic classification.

### 3. Results and discussion

Soils and vegetation covers formed in the bottoms of the ponds of different degrees of drainage and on the earth walls separating them were examined. All soils are enriched with organic matter, including through deep phyto-zooturbations. The soils are carbonate, which is associated with the initial carbonate of loess-like loams and the composition of wastewater in the past when the content of the calcareous component was higher. Currently, wastewaters have a pH of 7.2–7.3. Microorganisms are abundant; the content of nitrites and nitrates is minimal (table 1).

#### Table 1. Properties of wastewater from sugar production (Lgov Factory, November 2020).

| Characteristic                          | Unit of measure | SanR and N2.1.4.1074 -01 (no more) | Sample 1 | Sample 2 |
|----------------------------------------|-----------------|-----------------------------------|-----------|-----------|
| pH                                     |                 | 6-9                               | 7.2       | 7.3       |
| Ammonia and ammonium ion               | mg/dm³          | 1.5                               | 4.9       | 4.9       |
| Chemical Oxygen Demand (COD, permanganate method) | mgO₂/dm³ | 5 (drinking water) | 10.4      | 9.8       |
| Nitrite                                | mg/dm³          | 3.0                               | 0.01      | 0.01      |
| Nitrates                               | mg/dm³          | 45.0                              | 1.1       | 1.0       |
| Total microbial count 37 24 h           | CFU/ml          | 100                               | 4000      | 1600      |

Locations of the sites, soil names and vegetation are given in table 2. The soils in the bottoms of the ponds are formed on loess-like loams, which were opened during the construction of the settling ponds. Their properties are significantly different depending on the frequency of wastewater impact, the degree of drainage and the duration of non-use.

As the hydromorphism decreases, soils are successively distinguished: Gleysols (constantly waterlogged ponds), Gleyic Cambisols (periodically waterlogged), and Eutric Cambisols (wet or dry bottoms of ponds abandoned 30–45 years ago).

The soils on the filtration sediment of the pond bottom are strongly alkaline soils – Technosols (Alkalic), as well as soils on the earth wall covered with press mud. Earth walls formed on displaced Chernozem and loess loam material excavated from pond hollows are defined as Eutric Cambisols. On the periphery of the sewage treatment plant, in the abandoned garden the soils of the Hortic Chernozems series have been formed for 70 years.

Thus, under the influence of sugar wastewater, a soil cover was formed, similar to the soilscape of periodically flooded areas with separate dry elevated plots.

All soils have well-developed humus horizons, traces of biota activity and clearly defined texture and porosity. The properties of newly formed soils are shown on the example of Eutric Cambisols, site PF1-2020 (figure 3). In general, compared to conditionally background soils (Haplic (Anthric) Chernozems), the newly formed soils show high alkalinity (pH 8.86–9.13) and carbonate content (9.97–11.35%), an increase of organic carbon content (1.33–2.46) and of mobile forms of phosphorus (up to 229.0 mg/kg) and potassium (up to 648.0 mg/kg). These are the properties of highly fertile soil; high alkalinity may be the limit for some plants.

In the vegetation cover, 47 species of plants were identified (7 wooden, 6 bush, 17 annuals, 16 perennials and 1 liana). One aquatic association (Lemnetum) and five terrestrial associations were revealed (table 3). In the active settling pond on the wet bottom Phragmitetum communis is developed; as wetness decreases, on the dried bottom of the active pond Chenopodietum albi appears. On the press mud in the bottom of the pond and on the earth wall Cannabis-Atriplicetum nitentis is identified,
and the abandoned garden is distinguished as *Malus domestici*-Aceretum. The association of *Aceretum negundi* is widespread in a wide variety of moisture conditions and soil properties.

**Table 2.** Characteristics of the studied sites.

| Site index | Coordinates          | Location                                      | Soil (WRB)                                      | Vegetation                                      |
|------------|----------------------|-----------------------------------------------|------------------------------------------------|------------------------------------------------|
| PF1-2020   | N 51° 37,604′, E 35° 15,014′ | Pond, active, filled by wastewater. H=176 m | Histic Gleysol (Alcalic Clayic) | Aquatic vegetation (Lemnetum) |
| L-02-19    | N 51, 613784°; E 35,256546° | Pond, periodically active. Wet bottom. H=120 m | Histic Gleyic Cambisol (Alcalic Loamic Protocalcic) | Dense reed thicket (Phragmitetum communis) |
| PF1-2020   | N 51° 37,362′, E 35° 15,858′ | Pond abandoned 30 years ago, filled by rainwater seasonally. Wet bottom. H=180 m | Eutric Cambisol (Loamic Protocalcic Oxyaquic) | Dense box elder thickets (Aceretum negundi) |
| PF4-2020   | N 51° 36,832′, E 35° 15,251′ | Pond, active periodically. Dry bottom. H=191 m | Histic Gleysol (Alcalic Loamic) | Tallgrass (Chenopodietum albi) |
| PF7-2020   | N 51° 37,661′, E 35° 15,166′ | Pond, active periodically. Dry bottom. H=176 m | Spolic Garbic Technosol (Alkalic Calcic Silic Siltic Densic) | Tallgrass, box elder growth (Cannabio-Atriplicetum nitentis) |
| PF5-2020   | N 51° 36,902′, E 35° 14,913′ | Pond abandoned 45 years ago. Dry bottom. H=186 m | Histic Gleyic Eutric Cambisol (Loamic) | Box elder forest (Aceretum negundi) |
| PF2-2020   | N 51° 37,348′, E 35° 15,847′ | Earth wall. H=180 m | Eutric Cambisols (Loamic Huminic Transportic) | Young box elder woodland (Aceretum negundi) |
| PF3-2020   | N 51° 36,818′, E 35° 15,389′ | Earth wall. H=186 m | Eutric Cambisols (Loamic Huminic Transportic) | Box elder woodland (Aceretum negundi) |
| PF6-2020   | N 51° 36,902′, E 35° 14,913′ | Earth wall. H=176 m | Eutric Cambisols (Transportic) | Box elder woodland (Aceretum negundi) |
| PF8-2020   | N 51° 37,500′, E 35° 15,373′ | Earth wall (press mud). H=194 m | Spolic Garbic Technosol (Alkalic, Siltic, Densic, Transportic) | Dense tallgrass, reed, young box elder (Cannabio-Atriplicetum nitentis) |
| PF9-2020   | N 50° 37,368′, E 35° 14,834′ | The periphery of treatment facilities. H=168 m | Hortic Chernozem (Loamic) | 70 years old apple orchard, abandoned (Malus domestici-Aceretum) |

The invasive ash-leaved maple, or boxelder, or Manitoba elder (*Acer negundo*) turned out to be the most aggressive species, reacting negatively only to shade (table 4). Young trees form a dense monodominant cover in periodically moist habitats. Seedlings occupy vacant spaces in the *Chenopodietum albi* association. *Acer negundo* actively penetrates the dense vegetation cover (*Cannabio-Atriplicetum nitentis*) developed on Technosols (Alkalic) forming stand up to 2.5 m in height. On the earth walls and in the extensive dry bottom of abandoned settling pond it forms park forests; trees are up to 8 m height with the main stem dividing near the ground and have a large crown. *Acer negundo* loses its position in a shady abandoned garden only, where it is replaced by *Acer campestre* and *Acer platanoides*.
Box elder is a wide-ranging tree species. It can quickly colonize both cultivated and uncultivated areas, and its rapid development in the world simplifies the local flora [9]. In Russia, Acer negundo is recognized as the first in the list of unwanted alien species [10]. UAV images showed its widespread development in abandoned sewage fields, wastelands and on the periphery of vegetable gardens.

It is known that box elder, which originally occupied riverine habitats, gradually moved to well-drained positions both in the places of origin (North America) and in Europe [11, 12, 13]. Our research has shown that, under the conditions of the Chernozem zone, Acer negundo demonstrates a high degree of ecological plasticity developing in a wide range of conditions.

Figure 3. Characteristics of Eutric Cambisol (Loamic Protocalcic Oxyaquic), site PF1-2020 in the pond abandoned 30 years ago, filled by rainwater seasonally: (a) - Vegetation cover with Acer negundo, (b) – macromorphology of the soil profile and analytical properties: (c) – pH, (d) – Soil organic carbon, % (SOC), (e) – C/N ratio, (f) – CaCO₃ content (%), (g) – the content of particles less than 0,01 mm (%).

Table 3. Vegetation description (November 2019 and August 2020).

| Site index | Location | Vegetation |
|------------|----------|------------|
| PF10-2020  | Pond     | Association *Lemnetum minoris*: Alliance *Lemnion minoris* Tx. 1955; Order *Lemnetalia* Tx. 1953; Class *Lemnetea* Tx 1953 |
| L-02-19    | Pond     | Association *Phragmitetum communis* Gams 1927; Schmale 1939; Alliance *Phragmition communis* Koch 1926; Order *Phragmitetalia communis* Koch; Class *Phragmito-Magnocaricetalia* Klika in Klika et Novak 1941 |
| PF1-2020   | Ponds    | Association *Aceretum negundi*: Alliance *Chelidonio-Acerion negundi* L. Ishbirdina et A. Ishbirdin 1989; Order *Chelidonio-Robinietalia* Jurko ex Hadac |
| PF2-2020   | Earthwalls | *Rhamno-Prunetea* Rivas Goday et Borja Carbonell ex Tx. 1962 |
| PF3-2020   |          |            |
| PF4-2020   | Pond     | Association *Chenopodietum albi* Solm. In Mirk. et al. 1986; Alliance *Sisymbriion officinalis* Tx. et al. in Tx. 1950; Order *Sisymbrietalia* J. Tx. ex W. Matsz. 1962 em. Gors 1966; Class *Bidentetea tripartitae* Tx. et al. ex von Rochow 1951 |
| PF7-2020   | Pond     | Association *Cannabio-Atriplicetum nitentis* Ishbirdin in Mirkin et al. 1986; Alliance *Sisymbriion officinalis* Tx. et al. in Tx. 1950; Order *Sisymbrietalia* J. Tx. ex W. Matsz. 1962 em. Gors 1966; Class *Bidentetea tripartitae* Tx. et al. ex von Rochow 1951 |
| PF8-2020   | Earthwall (press mud) | Association *Malus domestici-Aceretum*: Alliance *Berberidion vulgaris* Br.-Bl. 1950; Order *Prunetalia spinosa* Tx. 1952; Class *Rhamno-Prunetea* Rivas Goday et Borja Carbonell ex Tx. 1962 |

Table 3. Vegetation description (November 2019 and August 2020).
Table 4. Valuation characteristics for the *Acer negundo* of studied communities (August 2020)

| Characteristic                              | PF1-2020 | PF5-2020 | PF2-2020 | PF3-2020 | PF6-2020 | PF8-2020 | PF9-2020 |
|---------------------------------------------|----------|----------|----------|----------|----------|----------|----------|
| Number of trees on the plot 1.0 sq.m        | 43       | -        | 5        | -        | -        | -        | -        |
| Average height, m                           | 2.5      | -        | 3.0      | -        | -        | -        | -        |
| Diameter (dbh), cm                          | 1.0–3.5  | -        | 3.0–5.0  | -        | -        | -        | -        |
| Number of trees on the plot 10 sq. m        | -        | 6        | -        | 4        | 4        | 15       | 6        |
| Average height, m                           | -        | 5        | -        | 8        | 7-8      | 2.5      | 10       |
| Diameter (dbh), cm                          | -        | 12-15    | -        | 15-25    | 12-15    | 2.3      | 20-40    |
| Canopy density                              | 0.9      | 0.4      | 0.5      | 0.4      | 0.6      | 0.6      | 0.8*     |

4. Conclusion

The treatment facilities of the sugar industry with their regular relief and series of settling ponds and earth walls represent specific patterns of landscapes in the Haplic Chernozem area. Newly formed soils rich in organic matter, alkaline and bioturbated are formed under the impact of sugar wastewater. Well-drained soils released from the influence of wastewater about 40-45 years ago gradually acquire the properties of natural soils such as Cambisols but not the Chernozem.

In the Chernozem zone, *Acer negundo* demonstrates a high degree of ecological plasticity, developing in the wide range of topography, wetness and soils. It uses treatment facilities as a jumping-off ground for introducing into adjacent territories.

Newly formed landscapes that store large amounts of organic carbon and are receiving a huge microbial pool from wastewater have become an integral part of the environment of the sugar industry regions.

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