Microbiology, Vol. 72, No. 1, 2003, pp. 103–109. Translated from Mikrobiologiya, Vol. 72, No. 1, 2003, pp. 117–125.
Original Russian Text Copyright © 2003 by Rusakov, Novikov.

EXPERIMENTAL ARTICLES

Biological Activity in Modern and Buried Soils of the Historical Center of St. Petersburg

A. V. Rusakov* and V. V. Novikov**

**Department of Soil Ecology and Soil Science, Faculty of Biology and Soil Science, St. Petersburg State University, St. Petersburg, Russia*

***Department of Soil Biology, Faculty of Soil Science, Moscow State University, Vorob'evy gory, Moscow, 119899 Russia*

Received April 29, 2002; in final form, August 26, 2002

Abstract—Biological activity in the urban modern and medieval soils of St. Petersburg was determined using soil samples taken from sections located at the historical center of this city nearby the Kazan Cathedral and the Twelve Colleges building (now the main building of St. Petersburg State University) and on the site where the Swedish fortress Nienshants formerly existed. The studied parameters of biological activity included the rate of microbial transformation of organic matter under aerobic and anaerobic conditions, the intensity of denitrification and nitrogen fixation, and the amount of microbial biomass. This investigation is the first attempt to comparatively study modern urban anthropogenically impacted soils and buried soils that had formed the soil cover of this region before St. Petersburg was founded. The major microbiological and physicochemical parameters of the soils were subjected to correlation analysis.

Key words: urbanozem, urban soils, buried soils, biomass, respiration rate, methane formation, denitrification, nitrogen fixation.

Urban environments are usually severely impacted due to intense human activities. Ever-increasing urbanization results in the formation of urban ecosystems, which include fragments of natural ecosystems surrounded by buildings, industrial zones, roads, etc. [1]. Urban ecosystems are characterized by altered biogeochemical cycles, limited biodiversity, and an elevated content of pathogenic microorganisms. The microbiota of urban soils is low in diversity, abundance, and total biomass, which results in a considerable decline of soil fertility [2].

At the end of the 19th century, the pioneer Russian soil scientist Dokuchaev suggested a research program for a complex investigation of all natural elements (including soils) of St. Petersburg and its environs [3]. Unfortunately, this program, which considered the natural elements "in their genetic relationship," was not fulfilled.

Nowadays, in spite of the extensive investigation of urban ecosystems, the role of microorganisms in their formation receives little attention. Suffice it to say that, at the first international conference on the soils of urban, industrial, traffic, and mining areas, held at the University of Essen, Germany, July 2000, none of the reports dealt with the biological activity of soils [4]. Recent publications describing the morphological structure and the main properties of St. Petersburg's urban soils do not present the parameters of their biological activity either [5–11].

To fill this gap, the aim of this work was to comparatively study the microbial biomass, the rate of the microbial transformation of organic matter under aerobic and anaerobic conditions, and the intensity of denitrification and nitrogen fixation in the modern and buried soils of St. Petersburg.

MATERIALS AND METHODS

Experiments were carried out with soil samples taken in 1999 and 2000 from soil sections located at the historical center of St. Petersburg (Fig. 1) during engineering earthworks (a replacement of communication mains) and archeological excavations. The samples were taken from depths of 1.5–2.5 m from cultural horizons of urban soils, whose bottom layers represented sod gley soils (umbric gley soils according to the WRB international standard soil classification). Before St. Petersburg was founded at the mouth of the Neva River, the latter soils formed the soil cover of this region. All the soil horizons under study were either humic or humus-accumulating: Uh (upper man-made (allochthonous) soil horizon; DUh, [UA] (lower allochthonous soil horizon and early cultural layers of the 18th century); [Pg] (buried tilled soil horizon); and [Ag], [AG] (buried virgin soil horizon).

Sections 1H/99 and 2H/00 were located in the Bol'shaya Okhta district (near the confluence of the Okhta River and the Neva) on the site where, since 1611 up to the foundation of St. Petersburg, the Swed-

0026-2617/03/7201-0103$25.00 © 2003 MAIK "Nauka / Interperiodica"

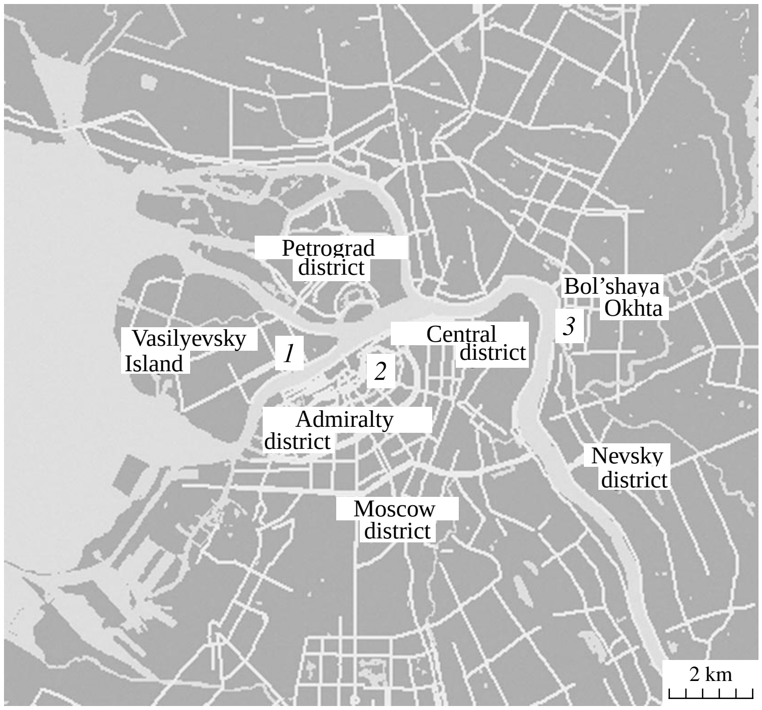

Fig. 1. Location of soil sections on the St. Petersburg map: (*1*) sections GP 4/00 and GP 6/00, in the square near the main building of St. Petersburg State University; (*2*) section GR 3/00, in the lawn in front of the Kazan Cathedral at a distance of 15 m from Nevsky Prospect; (*3*) sections 1H/99 and 2H/00, in the Bol'shaya Okhta region (the site of the ruined Swedish fortress Nienshants).

ish fortress Nienshants had existed. Section 1H/99 represented an engineering trench, about 2 m in depth, which was situated on ul. Kontorskaya and crossed the asphalt-paved internal yard of a local communication center. Section 2H/00 represented an archeological excavation situated on a playground with growing poplar and linden trees.

Section GP 3/00 also represented an archeological excavation, which was situated on a lawn in front of the Kazan Cathedral at a distance of 70 m from the Barclay de Tolly monument and at a distance of 15 m from Nevsky Prospect. The excavation was made on the site of the foundation of the Birth of Our Lady Church, the first church on Nevsky Prospect, built in the 1730s and then ruined. The soil profile at this site is characterized by the presence of a 66-cm-thick man-made humic Uh horizon, whose physicochemical and hydrophysical properties are favorable for the growth of the lawn [10].

Section GP 4/00 represented a deep trench in the park square along the front of the Twelve Colleges building (now home of the main building of St. Petersburg State University) on the side of Sakharov Square. In this section, at a depth of 127–160 cm, we found a lens of medieval tilled soil about 2.5 m in width and 15–30 cm in thickness. Section GP 6/00 represented an archeological excavation in the park square near the Twelve Colleges building wall on the side of the Neva River. In this section, at a depth of 62 cm, we found a well-preserved stone pavement built in the first part of the 18th century, beneath which, at a depth of 2.5 m, there is virgin sod gley soil. Above the pavement, there is a man-made layer of fertile humic soil carried from the environs of St. Petersburg. The park's trees are linden and maple.

All of the soils under study were highly anthropogenically impacted urbanozems [16]. According to the classification system of Russian soils [17], these urbanozems refer to the group of surface technogenic quasizems (Table 1).

Research Methods

The microbial biomass in soil was determined by the substrate-induced respiration method, with minor modifications of West and Sparling [12]. Aliquots (1 g) of soil samples with the natural moisture content were placed in 15-ml serum vials and supplemented with 2 ml of 0.1% glucose solution (i.e., glucose was added in a proportion of 2 mg per g soil). After preliminary incubation for 30 min, the vials were sealed with rubber stoppers and incubated at 25°C for 1 h, after which the increase in the CO_2 concentration in the gas phase was determined by gas chromatography. These measurements were performed in ten replicates. The mean values of increase in the CO_2 concentration were recalculated into the microbial biomass by the formula $C = 433\ln A + 40.3$,

Table 1. Classification of the soils under study

Section	Soil name according to	
	Stroganova *et al*. [16]	classification of Russian soils [17]
1H/99	Ekranozem on thick urbanozem with a cultural layer	Lithostrat on cultural layer
2H/00	Thick urbanozem on buried sod gley soil	Urbiquasizem on buried sod gley soil
GP3/00, GP6/00	Thick agrourbanozem (culturozem) on buried sod gley soil	Urbiquasizem on buried sod gley soil
GP4/00	Thick agrourbanozem (culturozem) on buried tilled sod gley soil	Urbiquasizem on buried tilled sod gley soil

where C is the microbial biomass expressed as the amount of microbial carbon (in μg per g soil) and A is the CO_2 emission rate expressed as μl CO_2/(g soil h).

The potential activity of denitrification in soil was determined as follows: Soil aliquots (5 g) placed in 15-ml serum vials were supplemented with 1 ml of a solution containing 1.2 g glucose and 0.4 g KNO_3 per 100 ml of the solution. The gas phase in the headspace of the vials was replaced with argon, followed by the injection of 1 ml acetylene. The flasks were incubated at 28°C for 1 day [13]. The intensity of denitrification was calculated from the amount of N_2O accumulated in the headspace of the vials.

To determine respiration rate, soil aliquots (5 g) with a moisture content of 20 wt % were placed in 15-ml serum vials and incubated at 28°C for 1 day. The intensity of respiration was calculated from the amount of CO_2 accumulated in the gas phase [14].

The amount of N_2O and CO_2 in the gas phase was evaluated using a model 3700/4 gas chromatograph (Chromatograph, Moscow, Russia) equipped with a thermal conductivity detector and a stainless steel column (3.2 m × 2 mm ID) packed with Polysorb-1. The detector temperature was 100°C. The current through the detector was 148 mA. The column and injector were kept at 30 and 40°C, respectively. The carrier gas was helium at a flow rate of 30 ml/min. The gas probe (0.5 ml) was injected into the column with the aid of a gas-tight syringe.

To determine the rate of methane (CH_4) formation, soil aliquots (5 g) with a moisture content of 20 wt % were placed in 15-ml serum vials and supplemented with 2 wt % glucose (with respect to the mass of absolutely dry soil). To create the anaerobic conditions necessary to methanogens [15], the gas phase in the headspace of the flasks was replaced with nitrogen. The flasks were incubated at 28°C for 3 days. The activity of methanogenesis was evaluated from the amount of NH_4 accumulated in the headspace of the vials.

Nitrogen-fixing activity in soils was determined with acetylene [13]. This method is based on the ability of diazotrophic bacteria to reduce not only molecular nitrogen but also some other compounds whose molecules have a triple bond, acetylene in particular. The reduction of three molecules of acetylene (C_2H_2) to ethylene (C_2H_4) is equivalent to the reduction of one nitrogen molecule. Accordingly, the rates of C_2H_2 and N_2 reduction differ by a factor of 3. To determine the nitrogen fixation rate, soil aliquots (5 g) with a moisture content of 20 wt % were placed in 15-ml serum vials and supplemented with 2 wt % glucose (with respect to the mass of absolutely dry soil). Acetylene was injected into the gas phase of the vials in a volume of 1 ml. The vials were incubated at 28°C for 2 h [13]. The intensity of nitrogen fixation was calculated from the amount of ethylene accumulated in the gas phase.

The content of methane and ethylene in the gas phase was determined using a Chrom-41 gas chromatograph equipped with a flame ionization detector and 2.2-m column packed with Spherosil. The column was kept at 30°C. The carrier gas was argon at a flow rate of 30 ml/min. Hydrogen and oxygen were supplied to the flame ionization detector at flow rates of 20 and 10 ml/min, respectively. The gas probe (0.5 ml) was injected into the column with the aid of a gas-tight syringe.

RESULTS AND DISCUSSION

The full-profile sections under study included both man-made layers of urban soils and buried natural and tilled soils. The soil types included urbanozem, agrourbanozem (culturozem), impermeable soil (ekranozem), and agrourbanozem with a stone pavement in its allochthonous layer.

The soils (with the exception of those in section 2H/00) were either slightly acidic, neutral, or slightly alkaline (Table 2), which is typical of urban soils [7–10, 16]. The alkaline reaction of allochthonous soils was due to the presence of detrital constructional materials (bricks and lime), whereas that of buried soils was due to the migration of hard ground waters and alkaline solutions from the overlying allochthonous soils. The $CaCO_3$ content widely varied in both allochthonous and buried soil horizons.

Allochthonous soil horizons, including early cultural layers and especially the humic layers of culturozems, were rich (up to 5%) in organic carbon (Table 2). In spite of the dark gray and gray color of the organogenic horizons of buried soils, their humus content was either low (3.2%) or very low (0.2–1.9%), especially in the buried tilled soil horizon. The cultural

Table 2. Inclusions and the chemical and granulometric characterization of the urban soils under study

Section location	Section	Horizon	Depth, cm	Aqueous pH	*C*, %	$CaCO_3$, %	Soil name according to granulometry	Inclusions
Fortress Nienshants	1H/99	DUh	150–170	8.4	3.44	6.9	Sandy loam	Constructional lime, fragments of ceramics and bricks, nails
	2H/00	DUh1	172–181	6.0	0.91	11.8	Medium loam	Granite gruss, glass fragments, charcoal pieces
		DUh2	181–193	6.1	0.93	10.8	Light loam	Fragments of ceramics, charcoal pieces
		[AG]	193–208	6.1	0.65	13.5	Light loam	–
Square in front of the Kazan Cathedral	GP3/00	Uh1	6–20	6.5	4.89	13.9	Sandy loam	Fragments of bricks and glass, charcoal pieces, carbonate and granite gruss
			40–60	7.0	5.15	9.8		
			60–66	7.3	3.77	35.7		
		[UA]	183–190	7.6	5.37	43.1	Light loam	Small charcoal pieces; fragments of bricks, bones, ceramics, and wood
		[AG]	190–202	7.6	1.87	18.1	Medium loam	–
Square near the main building of St. Petersburg State University	GP4/00	Uh1	0–19	7.6	1.39	8.4	Light loam	Constructional lime, fragments of glass and bricks
		[Pg]	127–147	7.7	0.14	1.0	Sandy loam	Granite gruss
			147–160	7.2	0.26	1.1		Charcoal pieces
	GP6/00	Uh1	0–11	7.6	4.02	0.6	Light loam	Constructional lime; fragments of bricks, ceramics, and wood; small boulders
			21–42	6.6	1.29	3.0		
			42–62	7.5	4.21	2.4		
		[Ag]	251–272	7.2	1.09	0.4	Light loam	Quartz grains; remains of medieval roots, bark, and branches

layers and the buried humic horizon of urbiquasizem (section 2H/00) were also low in organic carbon (Table 2).

At the same time, biological activity in St. Petersburg's urban soils was high, especially in urbic humic soil horizons (an urbic horizon represents a layer of allochthonous mixed soil and part of the cultural layer containing anthropogenic inclusions, such as constructional, household, and industrial garbage more than 5 cm in size) [1]. The biological activity in humus-accumulating horizons of buried soils, which had formed the natural soil cover of this region before the city was founded, was relatively low.

Microbial biomass was relatively high in all soils under study, tending to decrease downward along the soil profile (Fig. 2). In other words, medieval cultural layers and buried humic horizons contain less biomass than younger allochthonous soils do. The only exception was the buried [Ag] horizon of section GP 6/00, which contained two times as much biomass as the overlying Uh5 horizon and the paleohorizons of other soil sections did. The buried [Ag] horizon also exhibited a high content of organic matter (Table 2). This can be accounted for by the conservation of the [Ag] horizon beneath the 2.7-m-thick cultural layer containing the tight stone pavement, which favored the formation of reducing conditions in this horizon (this suggestion is confirmed by the severe hydrogen sulfide odor sensed during the unearthing of this horizon). In turn, reducing conditions promote anaerobic microbial processes, such as methanogenesis (Fig. 4) and denitrification (Fig. 6), in this soil horizon.

The content of microbial biomass in the upper layer of the buried tilled horizon of section GP 4/00 was higher than it was in the lower layers of this horizon and in the upper urbic humic horizon. This was likely due to active anthropogenic processes.

The greatest amounts of microbial biomass were detected in the Uh1 horizon (0–11 cm in depth) of section GP 6/00, which was formed by the humic tilled soils carried from the environs of St. Petersburg in order to establish the square park nearby the main building of the St. Petersburg State University. The high humus content of this horizon (6.9%) could be due to degressive processes and high annual leaf debris from the park's trees.

The calculation of correlation coefficients between the content of organic carbon and the microbial bio-

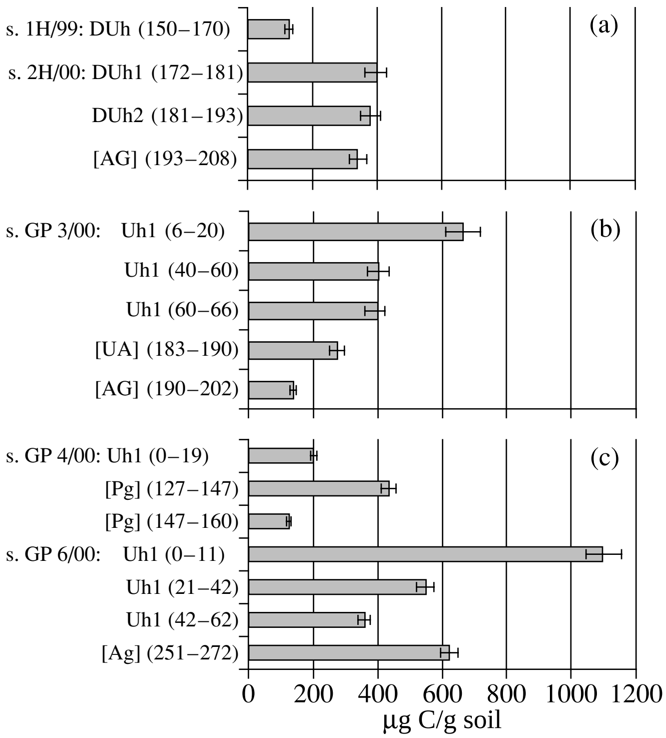

Fig. 2. Microbial biomass in soil samples taken from (a) sections 1H/99 and 2H/00 (the ruined fortress Nienshants), (b) section GP 3/00 (the Kazan Cathedral), and (c) sections GP 4/00 and GP 6/00 (St. Petersburg State University). The designations of soil horizons and their depths (in cm) are given in the figure.

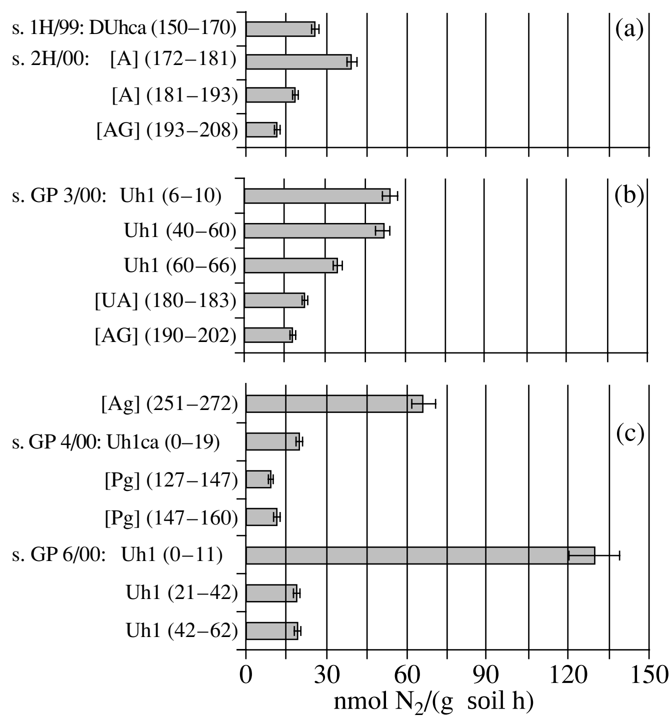

Fig. 3. Respiration rate in soil samples taken from (a) sections 1H/99 and 2H/00 (the ruined fortress Nienshants), (b) section GP 3/00 (the Kazan Cathedral), and (c) sections GP 4/00 and GP 6/00 (St. Petersburg State University). The designations of soil horizons and their depths (in cm) are given in the figure.

mass (or the respiration rate) in different soil horizons for all soil sections studies showed a high degree of correlation between these parameters for soil horizons of section 2H/00, situated on the site of the ruined fortress Nienshants (the value of the correlation coefficient is as high as 0.92) (Table 3).

The activity of the aerobic processes of microbial degradation of organic matter (the major product of such degradation is CO_2) was high in the upper horizons of the man-made soils (Fig. 3), being maximum in the Uh1 horizon of the GP 6/00 section. A strong correlation between the respiration rate and the organic matter content was observed for the soil horizon of section 2H/00 (the ruined fortress Nienshants) and section GP 4/00 (the square park near St. Petersburg University) (Table 3).

Figure 4 presents the results of the measurements of methanogenesis in the soils under study. In section GP 6/00, the activity of methanogenesis tended to increase downward along the soil profile. This confirms the above supposition that horizon [Ag] is dominated by reducing conditions. The general inference that follows from the above estimations is that the aerobic transformation of organic matter prevails in the soils of section 2H/00 (the ruined fortress Nienshants), whereas anaerobic degradation processes prevail in the soils of section GP 6/00 (the square park near St. Petersburg University).

The proportion between nitrogen fixation and denitrification processes characterizes the total nitrogen balance of soil. Measurements showed that the potential activity of nitrogen fixation was high in the soil horizons of section GP 6/00 near St. Petersburg University (Fig. 5), being maximum in the horizon Uh1

Table 3. The coefficients of correlation between some parameters of biological activity in urban soils

Coefficient of correlation between	2H/00	GP3/00	GP4/00	GP6/00
Organic carbon content (C, %) and microbial biomass (μg C/g soil)	0.92	0.58	–0.37	0.21
Organic carbon content (C, %) and respiration rate (nmol CO_2/(g soil h))	0.94	0.57	0.98	0.32

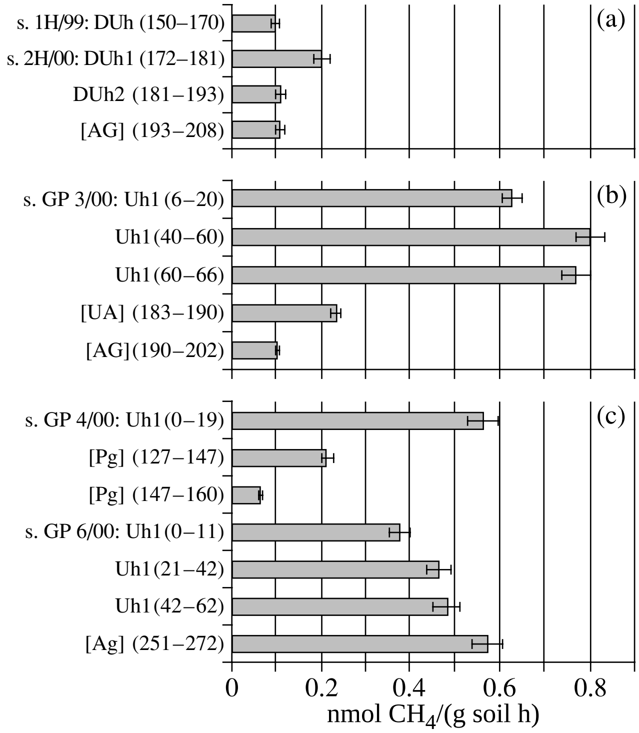

Fig. 4. Activity of methanogenesis in soil samples taken from (a) sections 1H/99 and 2H/00 (the ruined fortress Nienshants), (b) section GP 3/00 (the Kazan Cathedral), and (c) sections GP 4/00 and GP 6/00 (St. Petersburg State University). The designations of soil horizons and their depths (in cm) are given in the figure.

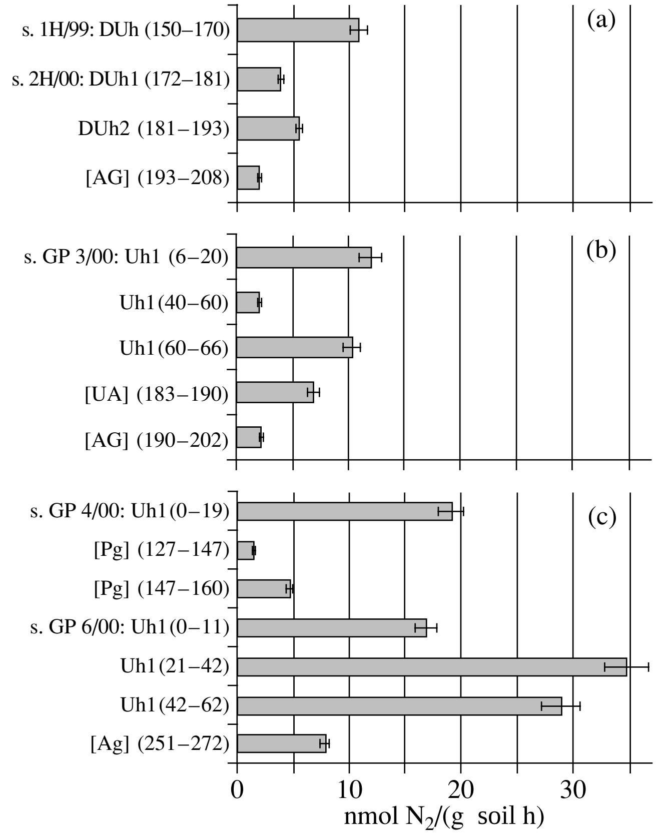

Fig. 5. Activity of nitrogen fixation in soil samples taken from (a) sections 1H/99 and 2H/00 (the ruined fortress Nienshants), (b) section GP 3/00 (the Kazan Cathedral), and (c) sections GP 4/00 and GP 6/00 (St. Petersburg State University). The designations of soil horizons and their depths (in cm) are given in the figure.

(21–42 cm in depth) of this section. This is in agreement with the high microbial biomass of this horizon (Fig. 2).

The activity of denitrification tended to increase downward along the soil profiles (Fig. 6), being maximum in the lower horizons [UA] (183–190 cm) and [AG] (190–202 cm) of section GP 3/00 and in the buried humic horizon [Ag] (251–272 cm) of section GP 6/00.

Based on all the parameters of biological activity in soils, we calculated the coefficient of biological activity change (CBAC) according to the formula

$$CBAC = [(A - B)/A] \times 100,$$

where A is the mean biological activity of the urbic horizons of allochthonous soils and B is the mean biological activity of buried soil horizons. CBAC is expressed as a percent and can be either positive or negative. Positive values of CBAC indicate that the biological activity of the anthropogenically impacted soil horizons is higher than that of the underlying buried soil horizons, and vice versa.

As can be seen from Table 4, the potential biological activity of the anthropogenically impacted soil horizons is on the average 30% higher than that of the natural buried soil horizons. This inference is in agreement with the results of the investigation of natural buried and anthropogenically impacted soils on the territory of the Iverskii Monastery (17th century) [18].

Thus, the comparative study of the modern and buried soil horizons of St. Petersburg showed that urban soils with their anthropogenically impacted cultural horizons and natural buried horizons function as an integral system formed in the course of centuries. Like allochthonous soils, buried soils possess high potential biological activity and, hence, must be considered as

Table 4. Coefficients of change in biological activity in the cultural horizons of allochthonous urban soils and buried soils, expressed as a percent

Parameter of biological activity	2H/00	GP3/00	GP4/00	GP6/00
Microbial biomass	12.6	58.0	–37.5	7.2
Respiration rate	77.8	65.4	57.4	–7.9
Methanogenesis	22.4	77.1	75.1	–29.8
Denitrification	–10.5	–16.8	–30.5	–13.5
Nitrogen fixation	60.7	43.6	83.9	71.0

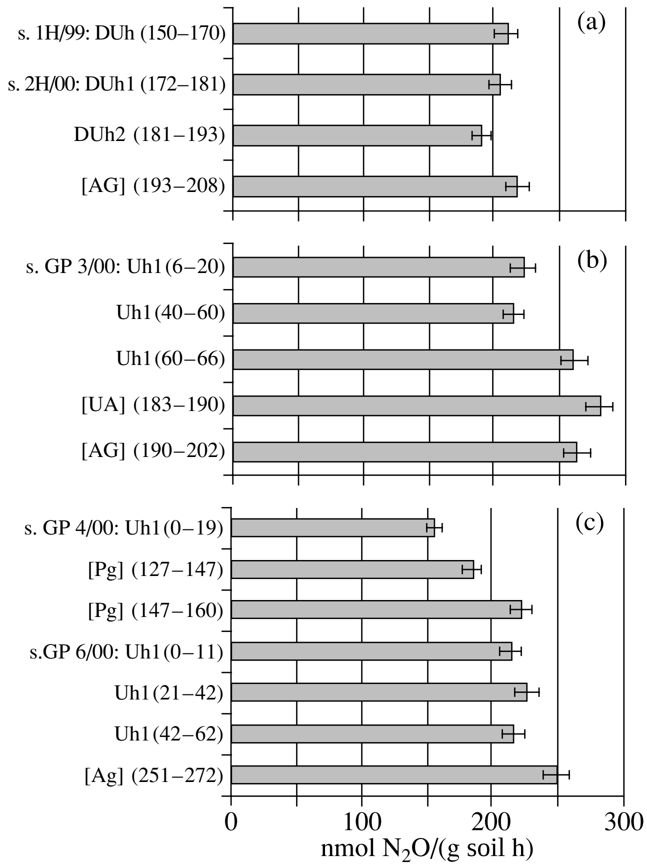

Fig. 6. Activity of denitrification in soil samples taken from (a) sections 1H/99 and 2H/00 (the ruined fortress Nienshants), (b) section GP 3/00 (the Kazan Cathedral), and (c) sections GP 4/00 and GP 6/00 (St. Petersburg State University). The designations of soil horizons and their depths (in cm) are given in the figure.

integral parts of the urban ecosystem. The data presented in this paper show the necessity of expanding investigations along this line.

ACKNOWLEDGMENT

This work was supported by grant no. 02-04-49188 from the Russian Foundation for Basic Research.

REFERENCES

1. *Pochva, gorod, ekologiya* (Soil, City, and Ecology), Moscow: Fond Ekonom. Gramotn., 1997.
2. Myagkova, A.D. and Stroganova, M.N., Detrimental Processes and Their Effects on the Soil Cover of the City, in *Pochva, gorod, ekologiya* (Soil, City, and Ecology), Moscow: Fond Ekonom. Gramotn., 1997, pp. 266–289.
3. Dokuchaev, V.V., Comprehensive Investigation of St. Petersburg and Its Environs), *Izv. Ross. Geogr. Obshch.*, 1890, vol. 26, supplement, pp. 53–61.
4. *First International Conference on Soils of Urban, Industrial, Traffic, and Mining Areas*, University of Essen, Germany, July 12–18, 2000, vol. 1.
5. Dolotov, V.A. and Ponomareva, V.V., Some Characteristics of Soils in the St. Petersburg Summer Garden, *Pochvovedenie*, 1982, no. 9, pp. 134–138.
6. Ivanova, K.A., Some Physicochemical and Hydrophysical Properties of Agrourbanozem in the Central Part of St. Petersburg, *Tez. dokl. Dokuchaevskikh molodezhnykh chtenii "Metodologicheskie problemy sovremennogo pochvovedeniya"* (Proc. Dokuchayev Conf. of Young Scientists "Methodological Problems in Modern Soil Science"), St. Petersburg, 2001, pp. 2–43.
7. Nadporozhskaya, M.A., Slepyan, E.I., and Kovsh, N.V., Soils of the Historical Center of St. Petersburg, *Vestn. St.-Peterb. Univ., Ser. 3*, 2000, no. 3, pp. 116–126.
8. Nadporozhskaya, M.A. and Sheinerman, N.A., Soils of the St. Petersburg Historical Center with Special Reference to Ecological Problems of Urban Areas, *First Int. Conf. on Soils of Urban, Industrial, Traffic, and Mining Areas*, University of Essen, Germany, July 12–18, 2000, vol. 1, pp. 71–74.
9. Prokof'eva, T.V., Sedov, S.N., Stroganova, M.N., and Kazdym, A.A., Experience on the Micromorphological Diagnosis of Urban Soils, *Pochvovedenie*, 2001, no. 7, pp. 879–890.
10. Rusakov, A.V. and Ivanova, K.A., Morphological Structure and Some Properties of Soils at the St. Petersburg Historical Center (the Square in Front of the Kazan Cathedral), *Materialy po izucheniyu russkikh pochv* (Some Data on Russian Soils), Aparin, B.F. and Chukov, S.N., Eds., St. Petersburg: Izd. St. Petersb. Univ., 2002.
11. Rusakov, A.V. and Ivanova, K.A., Urban Soils, Paleosols, and Cultural Layers of the Central Historic Parts of St. Petersburg, *Proc. First Int. Conf. on Soils and Archaeology*, Szahalombatta, Hungary, May 30–June 3, 2001, pp. 181–184.
12. West, A.W. and Sparling, G.P., Modifications to the Substrate-induced Respiration Method to Permit Measurement of Microbial Biomass in Soils of Different Water Contents, *J. Microbiol. Methods*, 1986, no. 5, pp. 177–189.
13. *Metody pochvennoi mikrobiologii i biokhimii* (Methods of Soil Microbiology and Biochemistry), Zvyagintsev, D.G., Ed., Moscow: Mosk. Gos. Univ., 1991.
14. Novikov, V.V. and Stepanov, A.L., The Effect of Mineral Nitrogen on the Microbial Transformation of Methane in Soil, *Pochvovedenie*, 1999, vol. 32, no. 10, pp. 1255–1258.
15. Nozhevnikova, A.N., Nekrasova, V.K., and Lebedev, V.S., Low-Temperature Production and Oxidation of Methane by the Microflora of Sludge Checks, *Mikrobiologiya*, 1999, vol. 68, no. 2, pp. 267–272.
16. Stroganova, M.N., Myagkova, A.D., and Prokof'eva, T.V., Urban Soils: Genesis, Classification, and Functions, *Pochva, gorod, ekologiya* (Soil, City, and Ecology), Moscow: Fond Ekonom. Gramotn., 1997, pp. 15–88.
17. *Klassifikatsiya pochv Rossii* (Classification of Russian Soils), Moscow: Dokuchayev Pochv. Inst., 1997.
18. Novikov, V.V. and Stepanov, A.L., Biological Activity of Ancient Cultivated Soil with Buried Horizons (the Iverskii Monastery, XVII Century), *Mikrobiologiya*, 2000, vol. 69, no. 3, pp. 441–446.