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# DECOMPOSITION OF ORGANIC WASTE IN CAVES*

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## Abstract

This study considers the problem of organic matter decomposition in alpine-type caves. The aim of this study was to evaluate the decomposition of food waste and fecal sludge in the cave conditions by using the clay sediments of the Snezhnaya cave. The model experiment was conducted, where the cave conditions were simulated. In the experiments, we used the following products: mashed potatoes, buckwheat and rice porridge, and fresh fecal sludge. Three types of standard waste management were modeled: they were placed on the soil, buried in the soil and scattered with carbide sludge. The waste decomposition was evaluated by two methods: by the amount of carbon remaining in the soil and by the amount of carbon dioxide emitted from the system. As a result, it was revealed that the decomposition of waste that was buried in the substrate occurs faster. Buckwheat porridge and mashed potatoes decompose slower. In all variants of the experiment, decomposition of fecal sludge in the soil revealed bacteria of the *Escherichia coli* group and *Clostridium perfringens*. It was revealed that when waste was filled with mined carbide sludge, the decomposition of organic matter slows down and the number of sanitary-indicative microorganisms grows.

*Keywords:* cave system, contamination, fecal sludge, organic waste

## 1. Introduction

Karst caves are unique natural objects, where unique ecosystems develop without sunlight. Many caves are equipped for visitors to access and used as museums; some caves are used as medical treatment centers and for industrial purposes (Spate and Hamilton-Smith, 1991). Deep karst systems, originating in the midlands and highlands, are the accumulators of groundwater, some powerful streams flow in, and natural processes of water purification are implemented (Vesper et al., 2000). Groundwater outflows from karst caves are of high

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quality in terms of sanitary-indicative microbiota and often used as drinking water. Many caves give rise to rivers, so it is especially important to keep caves clean (Pramaningsih et al., 2019; Pronk et al., 2009; Spate and Hamilton-Smith, 1991).

In recent years, the active development of technology has made it easier to visit the caves of a high category of difficulty such as caves with vertical sections, narrow sections, water-filled and flooded galleries. The depths of the largest caves exceed 2,000 m (Krubera-Voronya cave, named after Veryovkin). Technically complex caves even today require long lasting and sometimes autonomous expeditions in order to pass through and study them. An example is the Snezhnaya cave system which requires at least 5 days to reach its bottom from the upper entrance, and its water flows and soils are contaminated (Mazina et al., 2015). It has been noted that a presence of people in subterranean cavities and organization of tourist camps in caves leads to the contamination of caves, including an increase in the sanitary-indicative microorganisms (Hunter et al., 2005; Mazina et al., 2009). Nowadays, there is an equipment of caves with stationary speleological roping and the presence of permanent camping areas. Thus, the number of visits in deep caves is increasing and the problem of waste disposal in subterranean cavities is becoming increasingly important (Buecher, 1995; Mazina et al., 2009). While the most correct way to dispose of inorganic waste is its removal and disposal on the surface or outside the massif, organic waste and especially feces, require proper rules for disposal that are safe for cave ecosystems and for humans to be developed. There is very little data on the activity of decomposition of organic waste in caves, and this information provides the basis for developing recommendations for the disposal of organic waste in caves.

The aim of this study was to evaluate the decomposition of food waste and fecal sludge in the cave conditions by using the clay sediments of the Snezhnaya cave system.

The main objective of this study was to evaluate the decomposition of food waste and fecal sludge in the cave conditions by using the clay sediments of the Snezhnaya cave system.

This work is divided into three main parts.

- The model experiment was conducted, where the conditions of the cave was simulated: the humidity of the substrate corresponded to the Snezhnaya cave, the temperature was 5ºC, and the air humidity was 86-96%. In the experiments, we used products prepared according to the speleologist recipe: mashed potatoes, buckwheat and rice porridge, as well as fresh fecal sludge. Three types of standard waste management were modeled: they were placed on the soil, buried in the soil and scattered with calcium carbide from an acetylene burner.
- The waste decomposition was evaluated by two methods: by the amount of carbon remaining in the soil (Tyurin's method) and by the amount of carbon dioxide emitted from the system. Sanitary-indicative microorganisms were evaluated after decomposition of fecal sludge.
- Was conduct analysis of results, drawing conclusions and formulation of recommendations.

## 2. Material and methods

Laboratory experiments were conducted to determine the rate of decomposition of various types of organic waste in the karst caves.

Soil samples for the experiment were collected in the Snezhnaya cave system, located on the southern slope of the spur of the Bzyb Range, in the Hipstinskiy Karst Massif (Western Caucasus). Soil was placed into sealed sterile containers and transported at the temperature of the cave; before the experiment, the soil was stored at the temperature of the cave (4–5°C). The soil had a moisture content close to the maximum water capacity. Eluvial clays (residual deposits, product of disintegration of host rocks), the most common type of deposits in the cave, were used (Bazarova et al., 2013).

The decomposition of organic waste, fresh fecal sludge, and various food products most often used in speleological expeditions were evaluated (Mazina et al., 2016). Buckwheat porridge, rice porridge, and mashed potatoes were selected for the experiments. Products were prepared in accordance with the recipes used by speleologists during expeditions. Freeze-dried meat and broth cubes were added to the porridge. Mashed potatoes were prepared from a dry product (Mazina et al., 2016).

Three types of the experiment and a control one were carried out. In the first type, the waste was placed on the surface of the substrate; in the second type of the experiment, the waste was buried in the substrate using a sterile spatula; in the third type, the waste was placed on the ground and scattered with calcium carbide mining.

Calcium carbide mining is a typical waste resulting from the use of acetylene burners, which is often used by speleologists to illuminate caves. The carbide reacts with water in the burner when there is a lack of water, as a result, lime forms with the remains of unreacted calcium carbide. There is a widespread practice of filling waste with carbide mining, despite the fact that the negative impact of mining on the cave ecosystem has been proved (Mazina and Kontsevova, 2015). Air-dry, pre-sieved mining weighing 2 g was used to remove residual carbide.

The ratio of the mass of waste and clay was 1:6 or 6:36 g. The total mass was 42 g, in the control experiment only soil with a mass of 36 g was used. The soil humidity was 40% and corresponded to the soil humidity in the cave, the samples were incubated at the cave temperature 5°C and air humidity 86-96%. Thus, cave conditions were recreated.

Each sample was incubated in a sealed container that exceeded the sample volume by more than 10 times (500 ml); the container was equipped with a gas outlet. Gas was vented into a 500 ml vessel with a NaCl shutter. Once every 1-3 days, gas was measured in a gas outlet tank with gas analyzers Testo 316-1 (methane) and Testo 330-1 (carbon dioxide), after which the vessel with the sample was opened to provide aeration. The studies were carried out in triplicate for each type of waste, the duration of the experiment was 176 days.

An analysis of the amount of organic matter in the soil and in the waste before the start of the experiment, and also in experimental mixtures after the end of the experiment according to the method of Tyurin were carried out (Arinushkina, 1970). The moisture content of the soil and waste samples was determined by drying 100 g of samples at a temperature of 105°C to a constant weight; the percentage of moisture in the sample was determined by weight loss.

Since no methane emission was detected, we calculated the $CO_2$ released during the exposure using the Mendeleev – Clapeyron equation.

$$m_c = \frac{12 \times 10^{-6} \times D_c \times P \times V}{8.314 \times (t + 273)} \tag{1}$$

where

$m_c$ – change in carbon mass in the chamber, g C;
12 – carbon’s molar mass, g C•mol$^{-1}$;
$10^{-6}$ – ppm to volume fractions conversion, ppm$^{-1}$;
$D_C$ – change in $CO_2$ concentration in the chamber, ppm;
$P$ – atmospheric pressure, Pa;
$V$ – volume of the chamber, m$^3$;
8.314– ideal gas constant m$^3$·Pa·K$^{-1}$·mol$^{-1}$;
$t$ – air temperature, °C;
273 – Celsius to Kelvin conversion (Yuzbekov and Zamolodchikov, 2017).

At the end of the experiment, the obtained values were summarized to calculate the total amount of carbon released.

The duration of the experiment was chosen in accordance with the frequency of expeditions conducted in complex cave systems, it usually takes six months.

The bacteria of the *Escherichia coli* group (*E. coli* bacterial group) and the content of *Clostridium perfringens* were determined by standard methods in the soil before the experiment and after the experiment with the decomposition of fecal sludge. *E. coli* bacterial group was determined on Endo medium at a temperature of 37°C using a lactose test and a fermentation sample. The content of *Clostridium perfringens* was determined using Wilson-Blair iron-sulfite medium at a temperature of 43°C (Netrusov et al., 2005).

The average values and standard deviations were calculated, the reliability of the obtained values was evaluated using Student's t-test with a significance level of 0.05 in Microsoft Excel.

## 3. Results and discussion

The content of organic matter in the clay deposits of the cave was determined, which amounted to 0.2% of the dry mass of the soil. The initial parameters of humidity and the organic matter in different wastes and soils are represented in Table 1.

**Table 1.** The weight of organic material and moisture of the waste and soil that were used for the experiments

| ***Material*** | ***Percentage of moisture (%)*** | ***Weight of organic material (g)*** |
|---|---|---|
| Rice porridge | 56 ± 2.1* | 2.701 ± 0.059 |
| Buckwheat porridge | 54 ± 1.9 | 2.145 ± 0.064 |
| Mashed potatoes | 65 ± 1.7 | 1.761 ± 0.093 |
| Fecal matter | 78 ± 2.2 | 1.086 ± 0.035 |
| Soil | 40 ± 1.7 | 0.0504 ± 0.003 |

* - the standard deviation

**Table 2.** The weight of the organic carbon in the experimental table at the beginning of the experiment and at the end (minus C of the soil)

| ***$C_{org}$, g*** | ***Initial experimental system*** | ***After the experiment*** | | |
|---|---|---|---|---|
| | | ***Waste was on the surface of the soil*** | ***Waste was in the soil*** | ***Waste was filled up with mining*** |
| Rice porridge | 0.060 ± 0.002 | 0.035 ± 0.004 | 0.010 ± 0.004 | 0.042 ± 0.001 |
| Buckwheat porridge | 0.060 ± 0.002 | 0.011 ± 0.002 | 0.005 ± 0.004 | 0.037 ± 0.004 |
| Mashed potatoes | 0.049 ± 0.003 | 0.007 ± 0.003 | 0.002 ± 0.001 | 0.035 ± 0.011 |
| Fecal sludge | 0.030 ± 0.001 | 0.011 ± 0.007 | 0.005 ± 0.003 | 0.022 ± 0.005 |

Given the humidity of waste and soil, the ratio of the mass of dry matter and organic matter, the total amount of organic carbon in each experimental system was calculated (Table 2). All values are significantly differ from the original sample, $p < 0.05$. The mass of the organic matter in the soil was considered constant during the whole experiment.

Assuming that the mass of soil organic substance is constant, it was subtracted from the total mass of the organic substance, which was determined experimentally in the system after the experiment. Thus, when calculating the percentage of organic carbon at the beginning and at the end of the experiment, soil organic carbon was not taken into account.

The comparison of the decomposition efficiency of different types of waste revealed that the waste decomposes most quickly when it's mixed with the substrate, the smallest decomposition was detected in the experiment, when the waste was scattered with carbide mining. The comparison of waste decomposition efficiency showed that mashed potatoes and buckwheat decompose faster (Fig. 1).

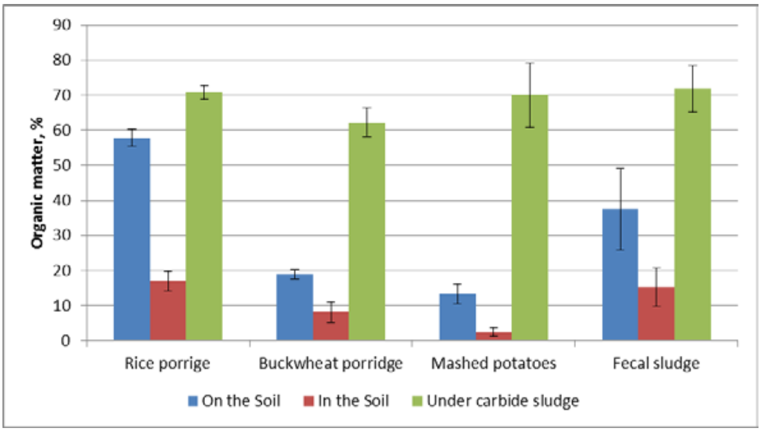


**Fig. 1.** Organic matter remaining in the system after the end of the experiment with various experimental options

An analysis of the amount of $CO_2$ released during the experiment characterizes the amount of decomposed organic matter. Comparison of the results of calculating the amount of carbon remaining in the system from the total carbon dioxide emissions during the experiment with the data obtained by the Tyurin method, revealed that the first method gives slightly lower estimates of the content of carbon remaining in the system (Fig. 2). At the same time, the spread of data in a series of experiments was higher, which reduces the reliability of the results.

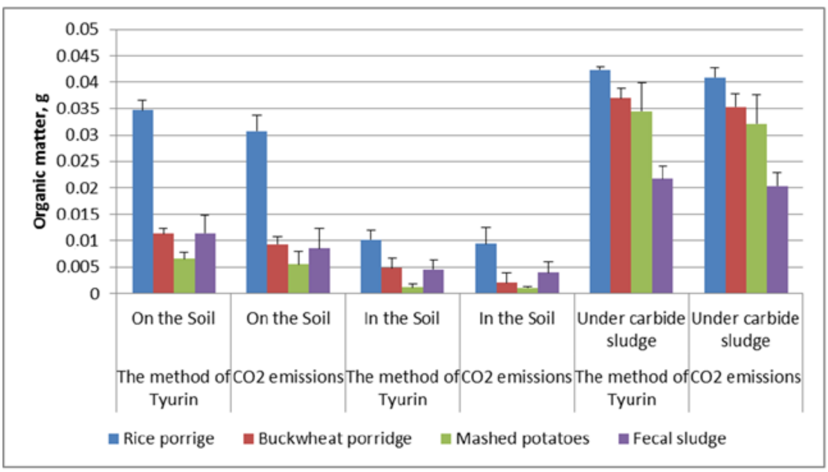


**Fig. 2.** Comparison of the mass of organic carbon was obtained by the Tyurin's method measurement and by estimating CO2 emissions

Analysis of the contents of bacteria of the *Escherichia coli* group and the bacteria *Clostridium perfringens* in the native soil of the cave showed negative results. After the experiment with the decomposition of fecal matter, the greatest bacterial contamination of *Clostridium perfringens* was found when waste was found in the soil or on its surface. The number of colony forming units (CFU) of *E. coli* bacterial group was the greatest in the case when the waste was filled up with carbide mining (Table 3).

**Table 3.** The number of microorganisms in the soil during the decomposition of fecal matter

| ***CFU of the dry soil*** | ***Waste was on the surface of the soil*** | ***Waste was in the soil*** | ***Waste was filled up with mining*** |
|---|---|---|---|
| Bacteria of the *Escherichia coli* group | 40 ± 12 | 14 ± 8 | 68 ± 10 |
| *Clostridium perfringens* | 35 ± 16 | 42 ± 19 | 12 ± 6 |

It is known that during the decomposition of organic substance only 10% of the carbon goes into the mass of microorganisms, the rest of the carbon is released in the form of $CO_2$. Thus, it is possible to estimate the theoretical mass of carbon, which should remain in the soil during the complete decomposition of the waste.

The study showed that in two experiments with the decomposition of buckwheat porridge and mashed potatoes mixed with the soil a complete decomposition of the waste revealed. Values close to the calculated ones were obtained in four other types of the experiments: mashed potatoes and buckwheat porridge placed on the ground and rice porridge and fecal masses mixed with soil.

In the experiment with scattering carbide mining into waste, the decomposition rate was slower, this could be due to the negative effect of carbide mining on bacterial activity (Mazina and Kontsevova, 2015). This effect can also be explained by the features of cave soils in which there is a low number of microorganisms that primarily use organic substance (Hunter et al., 2005).

The greatest variability in a series of experiments was demonstrated by fecal sludge, which may be due to the heterogeneity of the waste. A big error in the experiments on the decomposition of mashed potatoes and feces located on the surface of the substrate and in the case of scattering with carbide mining can be associated with a more liquid consistency of waste, compared with buckwheat and rice. These wastes can penetrate from the substrate and have a large contact surface with it, which ensures their accelerated destruction.

A decrease in the amount of organic substance below 10% of the initial one at the end of the experiment can be explained by the partial death of the microbiota, in conditions of a reduced amount of organic matter after the decomposition of waste.

## 4. Concluding remarks

As a result of the study, it was determined that in 0.5 years in the cave conditions of the Alpine type, food and fecal wastes decompose partially. Mashed potatoes and buckwheat porridge have the highest decomposition rates; all types of waste decompose faster when mixed up with soil.

It can be concluded that the disposal of organic waste into the soil has the least negative impact on cave ecosystems due to the high degree of decomposition at the highest rate and can be recommended for use in cave systems of the Alpine type.

The practice of waste disposal under the calcium carbide mining leads to a slowdown in the degradation of organic matter and an increase in the number of sanitary-indicative microorganisms, which is a negative factor for cave ecosystems.

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