Determination of Soil Quality in Maykop Based on the Content Analysis of Soil Algae and Cyanobacteria

EMILIYA A. SIROTIUK, SAIDA R. ZHEMADUKOVA

Maykop State Technological University, Russia

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Abstract
The paper presents the results of the study on soil quality in Maykop using algae indication. The findings suggest soil contamination by heavy metals and oil products, and the beginning of destructive processes. The city center is recognized to be the most unfavorable ecological area of the city. There are no diatoms in soil cyanoalgological sinusiae – a key indicator of oil contamination of soils. On the contrary, cyanobacteria prevail, which are resistant to soil contamination with oil products and heavy metals. One of the main environmental problems in Maykop is soil contamination with heavy metals and oil products. The main contributor to soil contamination is city transport and housing and public services. Pollutants enter soil through precipitation and leaf and branch shedding, deposit from the air, and are directly absorbed by moist soil. The results of algological studies suggest that destructive processes have begun in the soils in Maykop. This is evidenced by the composition of soil cyanoalgological sinusiae and by the population of main groups of microphototrophs. The most ecologically disadvantaged city district is «Central Market».

Key words: Republic of Adygeya, Maykop city, soil, heavy metals, oil and oil products, soil algae, cyanobacteria, cyanoalgological sinusiae, algae indication.

Introduction

Soil ecosystems as complex hierarchical systems have a whole set of mechanisms to resist destruction. Soil algae and cyanobacteria contribute to the maintenance of the ecosystem stability. The system stability is linked to their ability to resist to the environmental impact of specific elements.

In the process of evolution, soil algae and cyanobacteria adapt to the conditions of a particular habitat. This allows them to withstand prolonged changes in the environment through the development of resistant forms. This leads to formation of ecological populations, which are different in their resistance to environmental factors. In this context, the age structure is of great importance (Paul 2014). Populations that have individuals of different age, at different stages of their life cycle, react differently to the impact of environmental factors.

Soil algae are involved in the creation of systemic mechanisms of stability (Shtina 1990). Each ecosystem creates and maintains a special internal environment, which helps to reduce the impact of external factors. Soil algae participate in this process. They synthesize and release into the environment a variety of substances, change pH of the soil solution, improve the water regime and soil aeration, and prevent erosion.
(Shtina 1990). Through selective absorption and concentration of certain chemical elements in their cells, including radioactive ones, they affect the salt balance and soil composition of microelements.

Soil algae interrelate as «predator – prey», «parasite – host», have relations of protocooperation and competition, creating a network of complex relationships. In particular, with higher plants they compete for mineral nutrition elements; when settling on anthills, they act as commensals; provide bacteria and microscopic fungi, living in their mucus covers, with «food and shelter» (Kabirov et al. 2008). Thus, soil algae occupy one of the cells in the network of the living components of the ecosystem, and through feedback mechanisms they contribute to maintaining the ecosystem stability.

Ecosystem resistance is also ensured by «redundant functional components». This mechanism is called «congeneric homotaxis» (Elshina 1983). The mechanism idea is that some functional elements may be replaced by other elements. This allows the system to appropriately respond to the disturbance and maintain its stability.

In the conditions of technogenic press, suppression of higher plants, reduction of their photosynthetic activity, the role of soil algae increases, which is reflected in the increase in their species diversity and abundance. For example, in areas with oppressed higher plants, the population of soil algae quadruple, their biomass increases approximately sevenfold, their biological products increase eightfold, and their organic matter renewal speed increases 12 times compared to the background portion.

Many heterotrophic organisms can eat algae. As alternative food items, algae are involved in maintaining the stability of the heterotrophic complex of the soil population with a lack of traditional sources of food. In this case, the mechanism of «congeneric homotaxis» gets triggered (Gollerbach & Shtina 1969). In ecology, there are two types of stability of ecosystems: resistant stability (the ability to remain in a stable condition under pressure) and elastic stability (the ability to quickly recover after the removal of the disturbing factor) (Kabirov 1995).

High resistance of soil algae to adverse factors increases the resistant stability of the entire ecosystem. At the same time, due to the high reproduction rate, soil algae are an integral part of its elastic stability mechanisms. In ecosystems, which degrade because of the impact of anthropogenic factors, the intensity of soil algae development increases. This is one of the ways to maintain the stability of the autotrophic component of terrestrial ecosystems (Gollerbach & Shtina 1969).

One of the most pressing issues in Russian cities is the negative impact of automobile transport on soils (Shorina et al. 2013). Pollutants enter soils with precipitation and leaf and branch shedding. They come from the air as dust and aerosols and in dry weather are directly absorbed by moist soil. The worsened city air pollution is due to a sharp increase in the number of vehicles (Shorina et al. 2013). Automobiles with exhaust gases release into the environment up to 200 chemicals and their compounds. The most toxic ones of these are carbon oxides, sulfur oxides, nitrogen oxides, hydrocarbons, and heavy metals. The annual exhaust from one vehicle is approximately 800 kg of carbon monoxide, 40 kg of nitrogen dioxide, more than 200 unburned hydrocarbons (Morozov & Nesolenov 2003).

Communities of soil algae and cyanobacteria are a simple example of an autonomous closed-loop system. Its stability is based on trophic interaction between autotrophs and heterotrophs. Algal organic matter is a beginning of trophic chains. The main consumers of microscopic soil producers are animal-algophages (amoebae, nematodes, springtails, and others) which eat them up, swallowing them as they are, together with soil or leaf and branch shedding (Shtina & Gollerbach 1976).

Soil algae and cyanobacteria are sensitive organisms. They are indicators of contamination of roadside areas of soils with heavy metals (Krivorotov & Bukareva 2005). The dust-gas jet is emitted at a low height above soils. The distance of dispersion of exhaust gases, including aerosols of heavy metals, soot and other substances, does not exceed 100-150 meters from the highway in the direction of prevailing winds. For example, the maximum concentration of lead is usually observed at a distance of 5-7 meters from the road.

Emissions are known to accumulate in soil surface layers. Heavy metals (Fe, Mn, Ti, Cu, Cr, Zn, Pb, Ni, and others) are absorbed in the upper 2-5 cm of soil. Pollution of lower soil layers occurs because of soil handling, and as a result of the diffusion and convective transport through cracks, passages of animals and plant roots. Therefore, analysis of top soil layers can provide the best picture of contamination of soil by heavy metals and their compounds (Krivorotov, 1995, Krivorotov & Bukareva 2005).

If soil quality rapidly alters, fundamental changes occur in the composition of cyanalgalogical sinusiae. The main soil algal reactions to different types of impacts from automobiles are as follows:

1) depression and loss of some algal groups;
2) complete replacement of one algal group by another;
3) partial soil sterilization, that is, complete disappearance of algological sinusiae (Shtina et al. 1998).

A specific test of algal biodiversity per unit area is used to test soils, which are contaminated with heavy metals. Most diagnostic species belong to the *Pinnularia* Ehrenberg genus of diatoms (five species). The second highest number of species has the *Chlamydomonas* Ehrenberg genus (green algae) – four species, the third place belongs to the cyanobacteria of the *Anabaena* Bory genus – three species.

Soil phototrophic microorganisms vary in their resistance to pollutants (Galaktionov & Yurin 1980). Species that disappear when exposed to soil pollutants belong to the group of unstable species; species found in soils of low impact belong to the group of semi-stable species; species found in soils experiencing a strong impact belong to the group of stable species.

Green algae are noted to be highly resistant to surface-active substances; diatoms, yellow-green, and cyanobacteria are a bit less resistant (Kabirov 1995). Green algae and diatoms are more tolerant to heavy metals; cyanobacteria and yellow-green algae are more sensitive to heavy metals in the environment. Yellow-green algae are considered to be indicators of soil cleanliness. Their presence in the soil is considered by researchers to be a sign of its self-cleaning, and their disappearance is deemed to be a signal of the beginning of contamination.

The results of studies on oil influence on soil algae communities have shown that oil and oil products provide a strong acidic reaction to the soil solution, which has an adverse impact on them (Steubing 1967; Shtina 1977). Diatoms and yellow-green algae are less resistant to oil pollution. They are the first to disappear from algological complexes and for a long time are not detected in the oil decomposition process and soil self-purification. In oil-polluted soils, cyanobacteria usually prevail, as they are resistant to this pollution type.

![Figure 1. Soil sampling sites in Maykop](image-url)
Algae and cyanobacteria are permanent components of soil microbiocenosis and sensi
tively respond to changes in the soil environment. The main factors that influence the spread of soil algae are: climatic conditions (wind speed and direction, air temperature and humidity, atmospheric pressure, quantity of clear and cloudy days in a year), spatial dispersion of emissions. In dispersion and redistribution of emissions, geomorphology of the region, precipitation, vegetation, soil erosion, types and intensity of soil treatment play an important role.

In urbanization processes, soils experience significant technogenic pressure. Maykop is the capital of the Republic of Adygeya. It is located on the right bank of the Belaya River at an altitude of 210-230 meters above sea level (Fig.1). Its geographical coordinates are: 44°36' N and 40°06' E. The territory of Maykop with suburban area is about 60 km². It consists of eight settlements. There are about 180 thousand people of over 80 nationalities in the city. The climate in Maykop is mild temperate. The average annual temperature is +11.8°C. The coldest month in Maykop is January: the average minimum temperature is -4.9°C. The hottest month is July with the average maximum temperature + 28.9°C. The number of sunny days in a year in Maykop is about 250 days, the duration of the summer period is 180–198 days. Considerable total radiation provides for a long growing season – up to 242 days. The average annual precipitation in Maykop is 772 mm. The average annual relative humidity is 74%. The snow cover is unstable, with a low height of 6-10 cm. The average maximum snow depth is 25-30 cm (Bouzarov et al. 2001).

Maykop area has pronounced vertical zonality of climate, vegetation and soil. Starting from the northern part of the territory towards the south, there is a forest-steppe zone, which gives way to foothill oak forests. On the territory of the city and in its surroundings, there are leached thin-humus powerful black soils. Most of the soil in the city is under asphalt, houses and lawns. Natural soils can be found in suburban forests within the city.

Material and methods

Soil samples from lawns of several streets in five city districts were taken in spring 2012 for the study on soil quality by algae indication in Maykop. These city districts have different traffic intensity: «Cheremushki» and «Central Market» have higher traffic intensity, «Station», «Pulp and Paper Plant» and «Sunrise» have less intense traffic (Fig 1).

The examined territory in the «Cheremushki» district has considerable vegetation, asphalt road coating with two lanes, and intense traffic. The distance from the sampling place to the road is eight meters. There are high-rise buildings, housing development is not continuous.

The examined territory in the «Pulp and Paper Plant» district has well-developed vegetation, asphalt road coating with two lanes, and not very intense traffic. Opposite the sampling place there is a railroad. The distance from the sampling place to the road is ten meters. Buildings are single-storey, housing development is not continuous. There is an abandoned railway line nearby.

The examined territory in the «Station» district has a substantial number of lawns, an asphalt road with two lanes with not very intense traffic. The distance from the sampling place to the road is about eight meters. There are both high-rise and single-storey buildings, housing development is not continuous.

The examined territory in the «Central Market» district has scarce vegetation, asphalt road coating with two lanes. The traffic is very intense. There are many stops located close to each other. The distance from the sampling place to the road is 1.5 m. The area is poorly ventilated, as housing development is continuous.

The examined territory in the «Sunrise» district has scarce vegetation, asphalt road coating with two lanes. The area is well ventilated. Building development is not continuous.

Sampling and identification of the taxonomic composition of algal flora and cyanobacteria were carried out by conventional for soil algological research methods.

A soil sample as a surface layer of 10-50 cm² and about 1 cm thickness were gently taken off in a place most typical for this area (10 samples from each site). Samples were taken by a sterile knife. Soil and algae samples were placed in glass flasks, which were then put into boxes. Each bottle had a label with a number of the sample, sampling horizon, collection date and collector’s surname.

To ensure relatively uniform species distribution, stirred and dried soil was spread over in a smooth level of 0.5 cm in the form of a rectangle, which was divided into squares. For the weighed portion preparation, a small soil amount from the full depth was taken from each square. Weighed portions of 1 g
were then placed in penicillin flasks, with soil lumps having been destroyed beforehand. Homogenization of samples was made without prior drying by suspension preparation (1 g of soil to 4-5 water parts) and mixing it by hand for 15-20 minutes.

The number of algae and cyanobacteria was determined using the MBS-10 optical microscope by the direct counting method, using fresh soil brought to the air-dry condition. If immediate treatment was impossible, a soil sample (1 cm³) without preliminary drying was tubed and fixed by 4% formalin (4.5 ml volume).

A weighed portion of 5 mg was stirred in a small drop of water on a microscope slide. Large soil particles were removed. The drop was covered by cover glass and wholly viewed under a microscope at high magnification (lens 40). All the detected cells were counted. Viewing and counting were carried out moving the device by the substage and looking at the strips. Obtained figures were multiplied by 200, which gave the number of cells in 1 g of soil. We took the average value of calculations from 10 different weighed portions.

Cyanobacteria were identified by color – blue and green with different shades, olive-green or dirty-yellow-green, as well as by the absence of a nucleus and chloroplasts. They have pigments concentrated in the outer layer of the cytoplasm. Green algae were identified by chloroplasts of various shapes in the cells, of a purely green colour. Some species of green algae produced massive growths on the soil surface, contributing to light greening noticeable to the naked eye. Yellow-green algae are present in the soil mostly in unicellular filamentous forms. Their main characterizing features are disc-shaped yellowish-green chloroplasts, oil as a product of assimilation, formation of a shell of filamentous forms of two N-shaped halves. Diatoms grow well in various soils and are always easily identified by transparent bivalve shells of their cells, saturated by silica (crust).

Results

The results of the study showed that low species diversity is common for cyanoalgalogical sinusiae in Maykop soils. In five city districts, the study has identified 21 species of cyanobacteria and green, diatomic, and yellow-green algae.

In soils, of cyanobacteria, there are mainly Chroococcales, Nostocales and Oscillatoriales orders; of green algae – Chlamiydomonadales, Chlorococcales, Ulotrichales; of yellow-green algae – species of the order Vaucheriales, genus Pleurochloris and a number of other genera, different in cell shapes, number and shape of chloroplasts; of filamentous forms – genera Heterothrix, Bumilleria, and Tribonema; of diatoms – unicellular free-living forms, having elongated cells, symmetric along the longitudinal axis; common species of genera Navicula, Hantzschia, etc. A big form of yellow-green algae, which gives massive growths on the drying mud or moist soil surface, is only Botrydium granulatum Grev. Thalli of this alga of the noncellular structure have the form of green balls of a large pinhead size, spreading their rhizoids into the soil.

In the soil in the «Cheremushki» district, there are cyanobacteria, yellow-green, and green algae. Here, there is a significant dominance of cyanobacteria – they are 2.6 times more than yellow-green and green algae combined.

In the «Pulp and Paper Plant» district, the study detected yellow-green, diatomic and green algae, as well as cyanobacteria. Of these, in the composition of cyanoalgalogical sinusiae, yellow-green algae prevail: they are 2.2 times more than diatoms, and 4 times more than green algae. The least of all are cyanobacteria.

In soil in the “Station” district, there have been found representatives of two algal divisions: diatoms and green algae, and cyanobacteria. The number of cyanobacteria exceeds the number of green algae by 1.6 times and the number of diatoms by 1.7 times. Yellow-green algae are not represented in algological sinusiae.

The soil samples of the «Central Market» district reveal representatives of green and yellow-green algae, and cyanobacteria. Cyanobacteria considerably dominate here: their number exceeds the number of green and yellow-green algae species, combined, by almost three times.

In the soil of the «Sunrise» district, there have been found green, yellow-green, and diatomic algae. The number of diatoms is 5.6 times higher than the number of green algae and 35.5 times higher than the number of yellow-green algae. Cyanobacteria have not been found here.
Figure 2. Total number of cyanobacteria and algae in the soil of Maykop city districts: 1 – «Pulp and Paper Plant»; 2 – «Station»; 3 – «Cheremushki»; 4 – «Sunrise»; 5 – «Central Market»; 6 – Total number of species.

Most soil algae have been found in the «Cheremushki» district (2433 specimens), with substantial domination of cyanobacteria (72%). The least soil algae have been found in the «Central Market» district (1138 specimens). The «Pulp and Paper Plant», «Station», and «Sunrise» districts have about the same number of soil algae.

By the total number (Fig. 2), in the test samples, cyanobacteria significantly dominate (3569 specimens). The total number of diatoms is 1828 specimens, of yellow-green algae – 1702 specimens, of green algae – 1493 specimens.

Consequently, in cyanoalgological sinusiae in the soil of five Maykop city districts, there have been found 21 species of soil microphototrophs of three algal divisions: green (17.4%), yellow-green (19.8%) and diatoms (21.3%), and 1 division of Schizophyta – cyanobacteria (41.5%).

Discussion

There are about 700 industrial and municipal food and agricultural enterprises in Maykop, more than 1500 vehicles (except personal cars), which are potential air pollution sources. The main contribution to air pollution comes from vehicles, housing services, construction industry, agriculture, wood industry (Zavgorodny & Skobchenko 2015).

This is evidenced by the results of laboratory tests, carried out by two laboratories: the Federal Budget Health Institution «Center of Hygiene and Epidemiology in the Republic of Adygeya» and the Department of the Russian Federal Service for Consumer Rights Protection and Human Welfare (Rospotrebnadzor) in the Republic of Adygeya. Monitoring is carried out every month in sixteen monitoring places located in the areas of intense traffic and in residential areas.

Of chemical indicators, they test for carbon monoxide, nitrogen dioxide, sulfur dioxide, suspended matter; of heavy metals – lead, cadmium, zinc, mercury, arsenic, copper; of microbiological indicators – coliform bacillus index, enterococci index, pathogenic bacteria; of parasitological indicators – fly larvae and pupae, helminth eggs. Ranking of air pollutants by specific weight of samples exceeding the TLV indicates that main air pollutants in Maykop are suspended matter and carbon monoxide (The State Report 2015).
Maykop City Soil Quality Determination

Reduction of emissions of harmful substances into the air is hampered by poor quality roads, the absence of alternative routes for trucks, high rate of growth in the number of old cars, significant wear or absence of dust and gas cleaning equipment in enterprises. Due to the increase in the number of vehicles in the city, there is a need for the development of the infrastructure for vehicle maintenance service (gas stations, car service, carwashes, garages, parking lots, etc.).

These objects also have a negative impact on the environment. In private automobile repair shops, there are no containers for the collection of waste, contaminated with oil products (filters, rubber products, oily rags, etc.). The issue of disposal of used motor oils and other technical fluids has not been resolved, which results in unorganized landfills in the city. Most carwashes work without circulating water systems, hence a significant portion of liquid waste contaminated with oil products is transported to the city disposal site.

In the soil of most city districts («Cheremushki», «Central Market» and «Station»), cyanobacteria dominate, which indirectly indicates its contamination, and perhaps not only with heavy metals, since these organisms are highly resistant to many chemical toxicants and may exist in extreme environmental conditions. The presence of diatoms in the soil synusiae of the «Station» district indicates that soil oil contamination is negligible here. However, the complete absence of yellow-green algae and a substantial proportion of cyanobacteria indicate clear restructurisation of cyanoalgological sinusiae and alarms about the beginning of soil contamination.

The «Central Market» district should be recognized as the most polluted city district, because there are no diatoms in soils here, which indicates soil contamination with oil and oil products. At the same time, there are a significant number of cyanobacteria and the total number of species of all the studied city districts is the lowest here (1138 specimens).

The cleanest areas of the city in terms of content of heavy metals and oil products in the soil are the «Pulp and Paper Plant» and «Sunrise» districts. In the «Pulp and Paper Plant» district, there are a small number of cyanobacteria, there are diatoms, and there prevail yellow-green algae. Significant development of yellow-green algae here, which are susceptible to vehicle pollution, can be considered to be a sign of soil self-purification. In the soil of the «Sunrise» district, there are no cyanobacteria, and the number of diatoms is very high, which indicates no significant soil contamination with oil products.

One of the groups of microphototrophs is not present in four city districts out of five («Station», «Cheremushki», «Sunrise» and «Central Market»), which is indicative of the unfavorable ecological condition.

Conclusions

One of the main environmental problems in Maykop is soil contamination with heavy metals and oil products. The main contribution to soil contamination in the city is made by vehicles and housing and utilities. Pollutants enter the soil with precipitation and leaf and branch shedding, deposit from the air, and are directly absorbed by moist soil.

The results of algological studies suggest that destructive processes have begun in the soils in Maykop. This is evidenced by the composition of soil cyanoalgological sinusiae and by the population of the main groups of microphototrophs. The most ecologically disadvantaged city district is «Central Market».

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