
REVIEWS

Soil Microbiology at the Institute of Microbiology, Russian Academy of Sciences

D. I. Nikitin

Winogradsky Institute of Microbiology, Russian Academy of Sciences,
pr. 60-letiya Oktyabrya 7, k. 2, Moscow, 117312 Russia

Received May 24, 2004

Foundation

In 1930, Georgii Adamovich Nadson, one of the pioneers of radioecology in Russia, founded the Laboratory of Microbiology at the USSR Academy of Sciences. In 1934, this laboratory was transferred from Leningrad to Moscow and later was transformed into the Institute of Microbiology. Nadson was director of this institute until 1937, when he was falsely accused of participating in so-called anti-Soviet sabotage and terrorism and arrested. On April 14, 1939, he was sentenced to death by the Military College of the Supreme Court of the USSR. The sentence was executed on the following day [1].

Boris Lavrent'evich Issatchenko, a leading microbiologist in Russia at that time, became the second director of the institute. During his directorship, the range of fundamental microbiological problems studied at the institute was considerably widened to include those of soil and agricultural microbiology. The most interesting publications of that time were "Soil Microbiology" by E.N. Mishustin [2], *Ray Fungi and Related Organisms* by N.A. Krasil'nikov [3], and *The Structure of Bacteria* by A.A. Imshenetskii [4]. The institute established the first Russian microbiological journal, *Mikrobiologiya*.

In 1935, the institute invited D.M. Novogradskii, a talented microbiologist, who later had to leave Moscow for Karaganda, Kazakhstan. There, Novogradskii continued his research, concentrating on the study of natural and cultured forms of soil microorganisms [7] and those invisible under the light microscope [6]. Novogradskii proposed some new approaches to the study of various soil prokaryotic and eukaryotic microorganisms and wrote the comprehensive textbook *Soil Microbiology* [5].

In 1939 and 1940, respectively, two famous soil microbiologists, Krasil'nikov and Mishustin, began their scientific careers at the institute. However, the war years, 1941–1945, were very difficult for the country and for the institute in particular. There were hardly a few scientific papers published annually by an author, but the postwar years saw a drastic increase in research activity and the appearance of new names in microbiology.

The Role of the Scientific Background

No science can stagnate for long: it will either degenerate or revive due to the activity of the scientific community. Fortunately, microbiology began to develop rapidly in the postwar years. Already in the late 1940s and the early 1950s, several books devoted to soil microorganisms were published [7–9], followed by such interesting and nontraditional monographs as *The Microbiology of Podzolic Soils* by T.V. Aristovskaya [10], *Microbiological Processes in the Soils of Pacific Islands* by Ten Khak Mun [11], *Volcanos and Life* by E.K. Markhinin [12], *Soil Enzymology* by V.F. Kuprevich and T.A. Shcherbakova [13], and *The Theory of Podzol Formation* by V.V. Ponomareva [14]. It should be noted that most of the textbooks of that period, including those of the known foreign authors [15–17] treated the problems of ecological microbiology fragmentarily and schematically.

Renaissance

The years 1960–1980 witnessed a veritable explosion of Russian science, including microbiology. On the other hand, new analytical approaches and promising modern methodologies motivated some researchers to revise some established concepts in microbiology and microbial ecology and to concentrate their efforts on the solution of particular applied problems, often neglecting the fundamentals of soil microbiology.

This was not the case with the leading soil microbiologists Mishustin and Krasil'nikov, who worked at the institute in the second half of the 20th century. During his long scientific career, Mishustin published more than 600 works in the field of soil microbiology and related sciences. Beginning in the 1920s, he worked at the Timiryazev Agricultural Academy, the All-Union Institute of Fertilizers, the Erisman Sanitary Institute, the Institute of Municipal Hygiene of the USSR Academy of Medical Sciences, and the Institute of Food Preservation. Beginning from 1960, he headed the Department of Microbiology of the Timiryazev Agricultural Academy.

The scope of Mishustin's interest was very wide. He fruitfully participated in the study of many important

problems of soil microbiology and made far-ranging contributions to related sciences. Mishustin was the author of several tens of monographs, such as *The Microbiology of Grain and Meal* [18], *Microbes and Grain* [19], *The Sanitary Microbiology of Soils* [20], and *Silage* [21]. His main subjects of research were the ecological–geographic variability of soil bacteria and the structure of microbial communities and the biological fixation of atmospheric nitrogen, areas in which large groups of Soviet and foreign scientists were involved.

The most appreciable achievements made by Mishustin were in the study of the structure of soil microcenoses and the specific microflora of particular soil types. He hypothesized that soil microflora consists of four groups: zymogenous, autotrophic, oligotrophic, and chemoautotrophic. The first two groups are involved in the processes of humus formation and degradation, whereas the other two groups are responsible for other processes in soils. The soils of different climatic zones, for instance, northern and southern, are dominated by different microbial groups. This hypothesis has been the subject of discussion (in particular, it was criticized by N.A. Krasil'nikov and A.A. Imshenetskii) for about 37 years, since the time when Mishustin's monograph *The Ecological–Geographic Variability of Soil Bacteria* [22] was published. However, in the course of time, the hypothesis was confirmed by Zvyagintsev and other soil scientists from Moscow State University, who studied the vertical distribution of microorganisms in various terrestrial ecosystems [23]. The modern concept of the formation of soil microbial communities takes into account their geographic location and local environmental conditions, the major problem being how to obtain statistically significant experimental results and how to estimate the actual cosmopolitanism of microorganisms [24]. Latitudinal zonality in the distribution of soil microorganisms of different taxonomic groups, which was hypothesized and studied by Mishustin in the 1940s and 1950s, was confirmed by researchers from the Department of Soil Biology, Moscow State University, in the 1990s. The ecological studies of Mishustin have greatly enriched soil microbiology with important data on the strain, specific, and generic diversity of soil microflora.

Between 1955 and 1965, Mishustin was involved in the study of the effect of subsurface tillage on soil microbial communities. In collaboration with A.N. Naumova, V.A. Mirzoeva, E.P. Gromyko, I.S. Vostrov, D.I. Nikitin, T.A. Kalininskaya, and B.G. Murzakov, he devised a simple method for the determination of the total activity of microorganisms in soil horizons from the degree of staining of a flax fabric after its contact with the soil. This research group investigated the protective mycorrhization of pine and oak trees, the role of microorganisms in the formation and degradation of humus, and the application of azotobacterin as a bacterial fertilizer.

New Ideas, Methods, and Results

In the 1960s and 1970s, the laboratory headed by Mishustin began to investigate the diversity of soil microorganisms in relation to their morphology and physiology. The employment of methods of direct qualitative and quantitative analysis of microorganisms in soil suspensions with the aid of the electron microscope [25, 26] allowed new groups of prosthecate and budding bacteria to be discovered [27]. These studies were carried out in collaboration with D.I. Nikitin, L.V. Vasil'eva, R.A. Lokhmacheva, and students from Moscow State University. In the late 1970s, a series of studies on the effect of gamma radiation on the dynamics of soil oligotrophic bacteria and the composition of microbial communities was carried out [28, 29]. The use of nonstandard soil and laboratory media in combination with the direct observation of cell morphology made it possible to reveal a predominance of small soil bacteria (0.3 μm or less in diameter) [30], which are now known as ultramicrobacteria. The comprehensive study of the interaction of the parasitic bacterium *Bdellovibrio* with the host gram-negative soil bacteria conducted in 1970–1974, as well as investigations of the morphological diversity of soil bacteria, the formation and autoregulation of microbial communities, and the maintenance of microbial homeostasis, were described in the monograph [31] and the review paper [32].

After Mishustin's retirement in 1988, the newly formed Laboratory of Oligotrophic Microorganisms headed by D.I. Nikitin extended the study of the cytological and physiological characteristics of oligotrophs isolated from different natural sources. New data on the structure of live bacterial cells were obtained by atomic force microscopy. The specific lipid composition of the cell membranes of these oligotrophs and the species specificity of their responses to various environmental factors, including stresses, allowed these soil oligotrophs to be grouped in clusters. The oligotrophs of some clusters were found to contain unique membrane lipid complexes and hitherto unknown lipids. The results of these studies, carried out in collaboration with L.E. Nikitin, M.S. Oranskaya, I.A. Pitryuk, and O.I. Slabova, were published in *Biochimica et Biophysica Acta* [33].

The Biological Fixation of Atmospheric Nitrogen

Another fundamental problem studied in the Laboratory of Soil Microbiology was the biofixation of atmospheric nitrogen. This problem engaged many researchers from this and other laboratories, including those of foreign countries. The work along this research line began in the 1930s, when Mishustin pioneered large-scale experiments on the inoculation of legume plants with rhizobacteria, and was in progress for about 60 years. In the 1970s, N.M. Shemakhanova, E.N. Gromyko, R.R. Oleinikov, G.A. Bonartseva, V.L. Myshkina, and L.V. Vernichenko from the Institute of Microbiology and B.K. Shil'nikova and V.T. Emtsev from the

Timiryazev Agricultural Academy combined their efforts to study some agriculturally important problems, in particular, the correlation between the colonizing efficiency of rhizobacteria, the activity of the tricarboxylic acid cycle enzymes, and the intracellular concentration of amino acids and vitamins. These studies allowed some recommendations on the selection of actively colonizing rhizobacteria to be proposed.

The laboratory was also concerned with the study of soil free-living aerobic and anaerobic nitrogen-fixing bacteria (predominantly, of the genus *Clostridium*), namely, their geographic distribution, media for counting, and the effect of root exudates and organic fertilizer. One of Mishustin's important achievements was the understanding of the causes of the instability of the beneficial effect of azotobacterin on plants. Together with T.A. Kalininskaya, T.V. Red'kina, and I.K. Kravchenko, Mishustin showed that the nitrogen fixer *Azotobacter* can actively fix nitrogen only under optimal conditions, i.e., in fertile soils rich in organic substances. The monograph *The Biological Fixation of Atmospheric Nitrogen* written by Mishustin and Shil'nikova [34] is well known around the world. In the 1960s and 1970s, Mishustin and collaborators also gave considerable attention to the study of soil humus and the role of cometabolism in the degradation of humic acid under natural conditions.

Mishustin's research activity in the Laboratory was mainly aimed at developing Winogradsky's ideas. His studies culminated in publishing of the monographs *The Soil Microflora of the Northern and Central Parts of the USSR* [36] and *The Soil Microflora of the Southern Part of the USSR* [37].

The Last Page of the Chronicle of the Department of Soil Microbiology

In 1988, Mishustin retired and the chair of the Department of Soil Microbiology was given to N.S. Panikov. This chairman paid great attention to the computerization of scientific research and to the study of gas exchange between soils and the atmosphere. In 1994, six years after Panikov came to work at the institute, it became evident that the laboratory had diverged from investigation of microbial processes in soil. Along with studying gas exchange between bogs and atmosphere, the laboratory focused on elaboration of methods for introduction of degrading microorganisms into soils contaminated with oil and chloroanilines. Regrettably, the problems of general soil microbiology received insufficient attention, as a result of which the Department of Soil Microbiology was disbanded in 2003.

N.A. Krasil'nikov and His School of Soil Microbiology

In 1934, Krasil'nikov began his research career as a microbiologist in the laboratory headed by G.A. Nadson. In 1937, he was appointed chairman of the Department of Soil Microbiology and three years later

employed E.N. Mishustin. In 1944, this department was divided into the Department of Soil Microbiology, headed by Mishustin, and the Department of Plant-Microbial Interactions, headed by Krasil'nikov. In 1958, Krasil'nikov published *The Microbiological Fundamentals of Bacterial Fertilizers* [38]. He formulated the important idea that plant cover is a factor responsible for the selection and accumulation of microorganisms in soil and proposed the conception of soil as a specific habitat of microorganisms. Krasil'nikov was the first to observe the microlocal distribution of microorganisms in soil with the aid of luminescent dyes. In 1953, he established the world's first department of soil biology at Moscow State University and was head of it during all his life, remaining, at the same time, chairman of the Department of Plant-Microbial Interactions at the Institute of Microbiology. A man of outstanding personality and original thinking, Krasil'nikov introduced a nontraditional approach to educational and research processes. At the Department of Soil Biology, he united researchers into teams to investigate particular groups of microorganisms, such as aerobic bacteria, anaerobic bacteria, actinomycetes, mycelial fungi, and yeasts. These teams were supervised by the leading researchers in their fields: Yu.P. Khudyakova, M.N. Sushkina, T.G. Mirchink, I.P. Bab'eva, and I.V. Aseeva. The world-reknowned microbiologists L.V. Kalakutskii and V.I. Duda, who are now working at the Skryabin Institute of Biochemistry and Physiology of Microorganisms, are graduates of the Department of Soil Biology. Krasil'nikov's monograph *Soil Microorganisms and Higher Plants* [39] has become an example of a creative approach to the study of micro-plant interactions.

Since 1973, the Department of Soil Biology has been headed by the versatile scientist D.G. Zvyagintsev. The staff of the department includes highly qualified and skilled researchers such as T.G. Dobrovol'skaya, L.V. Lysak, O.E. Marfenina, V.S. Guzev, P.A. Kozhevnikov, L.M. Polyanskaya, I.Yu. Chernov, B.A. Byzov, and others, all of whom can be considered pupils of Krasil'nikov. Let us outline the major scientific problems that were and are being studied by Krasil'nikov's pupils.

The basic research line initiated by Zvyagintsev is the *specificity of soil as a habitat of microorganisms*. He devised new experimental approaches to the investigation of soil microorganisms such as the direct microscopic observation of microorganisms in soil with the aid of luminescent dyes and the study of the mechanisms of microbial adhesion in nature. He formulated the functional principles of soil microflora, including the principle of soil saturation with microorganisms, the principles of duplication and limitation, and the principle of reversibility of physiological processes. The results of these studies are summarized in the monograph *Soil and Microorganisms* by Zvyagintsev [40] and *The Structure of Soil Bacterial Communities* by Dobrovol'skaya [41].

The study of particular groups of soil microorganisms turned out to be very fruitful and included the study of the distribution of soil microorganisms, their isolation in pure cultures, their identification, and the characterization of their ecological niches, as well as cytological and physiological investigations. Of great interest are the cytological studies of spore formation performed by Duda, who was the first to describe multiple spores in bacteria and unusual tubular and lenticular outgrowths in the spores of anaerobes, which are important in spore maturation [42]. Currently, Duda is involved in investigations of the ultrastructure of bacteria by electron microscopy at the Skryabin Institute of Biochemistry and Physiology of Microorganisms.

Noteworthy is the study of the ecology of particular physiological groups of soil microorganisms conducted by M.M. Umarov, Lysak, and others.

In the 1960s and 1970s, considerable research effort in the department was devoted to the study of the cytology, physiology, diversity, and distribution of actinomycetes in nature. The results of these studies were summarized in the monograph *The Development of Actinomycetes* by Kalakutskii and Agre [43]. In the following years, a new promising line of research, the interaction of mycelial prokaryotes with soil algae and invertebrates, was developed by Kalakutskii, G.M. Zenova, V.S. Soina, B.A. Byzov, and L.M. Polyanskaya.

For more than 20 years, research in the field of soil mycology at the Department of Soil Biology was directed by the outstanding mycologist T.G. Mirchink. These investigations included the study of the toxicosis of soils, the study of fungal pigments and their role in humus formation, and the study of the effect of environmental conditions and anthropogenic impact on the viability of spores and the growth rate of fungal mycelia in soil. This research line is now being extended by O.E. Marfenina and A.V. Kurakov.

Soil mycology is a traditional research line at the Department of Soil Biology. I.P. Bab'eva and her collaborators have greatly contributed to the development of this line of research. They were successful in creating a collection of soil yeasts and in investigating their distribution and role as stimulants and inhibitors of plant growth [45].

Zvyagintsev and Kozhevnikov initiated interesting and promising research in the field of the populational microbiology of soil. They proposed original methodological approaches to the quantitative estimation of the survival, development, migration, and death of microbial populations (including introduced ones) in soils with allowance for their ecological strategies [46].

Another interesting direction in microbial ecology is the study of the succession of microbial communities in soil with the estimation of relevant parameters (the population density, the proportion between various microbial groups, the intensity and direction of biochemical processes) under both laboratory and field conditions. The data obtained can be used to determine

the total amount of living biomass in the biosphere and the contribution of particular microbial groups to global biogeochemical cycles. This direction of research was greatly contributed to by L.M. Polyanskaya.

The Department of Soil Biology at Moscow State University is presently undoubtedly the leading institution in the field of soil microbiology in Russia.

REFERENCES

1. Mishustin, E.N., *Moya zhizn' v nauke* (My Life in Science), Moscow: Nauka, 1997.
2. Mishustin, E.N., Soil Microbiology, in *Osnovy sel'skokhozyaistvennoi mikrobiologii* (Fundamentals of Agricultural Microbiology), Moscow: Sel'khozgiz, 1933, pp. 148–251.
3. Krasil'nikov, N.A., *Luchistye gribki i rodstvennye im organizmy* (Ray Fungi and Related Organisms), Moscow: Izd. Akad. Nauk SSSR, 1938.
4. Imshenetskii, A.A., *Stroenie bakterii* (The Structure of Bacteria), Moscow: Izd. Akad. Nauk SSSR, 1940.
5. Novogradskii, D.M., *Pochvennaya mikrobiologiya* (Soil Microbiology), Alma-Ata: Izd. Akad. Nauk Kaz. SSR, 1956.
6. Novogradskii, D.M., Invisible Forms of Visible Bacteria, *Mikrobiologiya*, 1933, no. 2.
7. Novogradskii, D.M., Natural and Cultured Forms of Soil Microorganisms, *Izv. Akad. Nauk Kaz. SSR, Ser. Mikrobiol.*, 1949, no. 5.
8. Kholodnyi, N.G., On the Aerial Nutrition of Soil Microorganisms, *Mikrobiologiya*, 1945, no. 14.
9. Vinogradskii, S.N., *Mikrobiologiya pochvy. Problemy i metody* (Soil Microbiology: Problems and Methods), Moscow: Izd. Akad. Nauk SSSR, 1952.
10. Aristovskaya, T.V., *Mikrobiologiya podzolistykh pochv* (The Microbiology of Podzolic Soils), Moscow: Nauka, 1965.
11. Ten Khak Mun, *Mikrobiologicheskie protsessy v pochvakh ostovov pritikhookeanskoj zony* (Microbiological Processes in the Soils of Pacific Islands), Moscow: Nauka, 1977.
12. Markhinin, E.K., *Vulkany i zhizn'* (Volcanos and Life), Moscow: Mysl, 1980.
13. Kuprevich, V.F. and Shcherbakova, T.A., *Pochvennaya enzimologiya* (Soil Enzymology), Minsk: Nauka Tekhnika, 1966.
14. Ponomareva, V.V., *Teoriya podzoloobrazovatel'nogo protsessa: biokhimiicheskie aspekty* (The Theory of Podzol Formation: Biochemical Aspects), Moscow: Nauka, 1964.
15. *Soil Microbiology*, Walker, N., Ed., New York: Prentice-Hall, 1970.
16. Alexander, M., *Microbial Ecology*, New York: Wiley, 1971.
17. *The Ecology of Soil Bacteria*, Gray, T. and Parkinson, D., Eds., Liverpool Univ. Press, 1967.
18. Mishustin, E.N. and Trisvyatskii, L.A., *Mikrobiologiya zerna i muki* (The Microbiology of Grain and Meal), Moscow: Khleboizdat, 1960.

19. Mishustin, E.N. and Trisvyatskii, L.A., *Mikroby i zerno* (Microbes and Grain), Moscow: Izd. Akad. Nauk SSSR, 1963.
20. *Sanitarnaya mikrobiologiya pochvy* (The Sanitary Microbiology of Soils), Moscow: Nauka, 1979.
21. Zubrilin, A.A., Mishustin, E.N., and Kharchenko, V.D., *Silos* (Silage), Moscow: Sel'khozgiz, 1950.
22. Mishustin, E.N., *Ekologo-geograficheskaya izmenchivost' pochvennykh bakterii* (The Ecological-Geographic Variability of Soil Bacteria), Moscow: Izd. Akad. Nauk SSSR, 1947.
23. Zvyagintsev, D.G., *Perspektivy razvitiya biologii pochv* (The Prospects of Soil Biology), Moscow: MaksPress, 2001, pp. 10–21.
24. Chernov, I.Yu., *Geografiya pochvennykh mikroorganizmov: itogi i perspektivy* (The Geography of Soil Microorganisms: Achievements and Prospects), Moscow: MaksPress, 2001, pp. 34–47.
25. Nikitin, D.I., Electron Microscopy in the Study of Soil Suspensions and Microbial Cultures, *Pochvovedenie*, 1964, no. 6, pp. 140–143.
26. Nikitin, D.I. and Makar'eva, E.D., The Use of Electron Microscopes for Counting Microorganisms in Soil Suspensions, *Pochvovedenie*, 1970, no. 10, pp. 51–56.
27. Nikitin, D.I., Vasil'eva, L.V., and Lokhmacheva, R.A., *Novye i redkie formy pochvennykh mikroorganizmov* (New and Rare Species of Soil Microorganisms), Moscow: Nauka, 1966.
28. Arakelyan, R.N. and Nikitin, D.I., The Growth Dynamics of Oligotrophic Bacteria in Gamma-Irradiated Soils, *Pochvovedenie*, 1981, no. 1, pp. 169–172.
29. Shcherbakova, T.A., Nikitin, D.I., and Volkovskaya, N.G., The Use of Gamma Radiation for the Analysis of Microbial Cenoses in Soil, *Mikrobiologiya*, 1975, vol. 44, no. 2, pp. 325–329.
30. Nikitin, D.I. and Anan'eva, N.D., The Sizes of Bacterial Cells in Some Soils, *Pochvovedenie*, 1979, no. 4, pp. 132–134.
31. Nikitin, D.I. and Nikitina, E.S., *Protsessy samochishcheniya okruzhayushchei sredy i parazity bakterii (rod Bdellovibrio)* (The Autoremediation of the Environment and Bacterial Parasites of the Genus *Bdellovibrio*), Moscow: Nauka, 1978.
32. Nikitin, D.I. and Kunc, F., Structure of Microbial Soil Associations and Soil Mechanisms of Their Autoregulation, in *Soil Microbial Associations*, Praha: Academia, 1988, pp. 157–190.
33. Batrakov, S.G., Nikitin, D.I., and Pitryuk, I.A., A Novel Glycolipid, 1,2-Diacyl 1-3- α -D-Glucuronopyranosyl-sn-Glycerol Naurintfavide, from the Budding Seawater Bacterium *Hyphomonas jannaschiana*, *Biochim. Biophys. Acta*, 1996, vol. 1302, pp. 167–176.
34. Mishustin, E.N. and Shil'nikova, V.K., *Biologicheskaya fiksatsiya atmosfernogo azota* (The Biological Fixation of Atmospheric Nitrogen), Moscow: Nauka, 1968.
35. Mishustin, E.N. and Nikitin, D.I., The Susceptibility of Humic Acids to Soil Microflora, *Mikrobiologiya*, 1961, vol. 30, no. 5, pp. 841–849.
36. Mishustin, E.N., *Mikroflora pochv severnoi i srednei chasti SSSR* (The Soil Microflora of the Northern and Central Parts of the USSR), Moscow: Nauka, 1965.
37. Mishustin, E.N., *Mikroflora pochv yuzhnoi chasti SSSR* (The Soil Microflora of the Southern Part of the USSR), Moscow: Nauka, 1965.
38. Krasil'nikov, N.A., *Mikrobiologicheskie osnovy bakterial'nykh udobrenii* (The Microbiological Fundamentals of Bacterial Fertilizers), Moscow: Izd. Akad. Nauk SSSR, 1958.
39. Krasil'nikov, N.A., *Mikroorganizmy pochvy i vysshie rasteniya* (Soil Microorganisms and Higher Plants), Moscow: Akad. Nauk SSSR, 1968.
40. Zvyagintsev, D.G., *Pochva i mikroorganizmy* (Soil and Microorganisms), Moscow: Mosk. Gos. Univ., 1987.
41. Dobrovol'skaya, T.G., *Struktura bakterial'nykh soobshchestv pochv* (The Structure of Soil Bacterial Communities), Moscow: Akademkniga, 2002.
42. Duda, V.I., The Cytology of Spore-Forming Bacteria, *Usp. Mikrobiol.*, 1982, vol. 17, pp. 87–117.
43. Kalakutskii, L.V. and Agre, N.S., *Razvitie aktinomitsetov* (The Development of Actinomycetes), Moscow: Nauka, 1976.
44. Mirchink, T.G., *Pochvennaya mikologiya* (Soil Mycology), Moscow: Mosk. Gos. Univ., 1976.
45. Bab'eva, I.P. and Gorin, S.E., *Pochvennye drozhzhi* (Soil Yeasts), Moscow: Mosk. Gos. Univ., 1987.
46. Kozhevina, P.A., *Mikrobnye populyatsii v prirode* (Microbial Populations in Nature), Moscow: Mosk. Gos. Univ., 1989.