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Factors determining the occurrence and number of bacteria of the genus *Azotobacter* in the soil environment

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Abstract. Bacteria belonging to the genus *Azotobacter* are microorganisms commonly found in various soils all over the world and capable of fixing atmospheric nitrogen. The biological nitrogen fixation (BNF) process annually supplies approximately 140–170 million tons of this element to the nitrogen cycle, which is of great importance from an ecological and practical point of view. Although the efficiency of atmospheric nitrogen fixation by *Azotobacter* spp. is relatively high and amounts to 20 mg N per 1 g of glucose used, these bacteria are sensitive to various environmental factors, including soil reaction, contents of organic matter, soil humidity or nutrient content, and their abundance in soils is small. These bacteria secrete numerous biologically active substances into the soil environment, which have a beneficial effect on the development of plants, which from the ecological point of view plays an important role in the functioning of agricultural ecosystems. An additional advantage of bacteria belonging to the genus *Azotobacter*, which speaks for their use in agriculture, is the ability to produce antifungal and solubilization of insoluble phosphates. Research on *Azotobacter* spp. proves that the concentration of hydrogen ions (pH) is a significant factor which determines the presence of this group of bacteria in the soil environment. Many other soil properties have a large impact on the presence and development of this important agricultural group of bacteria.

The aim of the work was to systematize the knowledge on the known occurrence conditions and ecological relationships and interactions between environmental factors and the presence and abundance of *Azotobacter* bacteria in soils.

Keywords: soil properties, pH, *Azotobacter* spp., atmospheric nitrogen fixation

INTRODUCTION

Many species of microorganisms inhabit the soil. Fertile soil can contain up to one billion bacteria per 1 g of fresh soil mass (Gałązka et al., 2016). The composition of microorganisms significantly affects the rate of organic matter decomposition and nutrient cycling, as well as their availability in the soil environment. Soil microorganisms play an essential role in, among other things, the mineralization of organic matter, the formation of soil humus, the supply of nutrients to plants and the reduction of pathogens, thereby contributing to the appearance of soil fertility and wholesomeness (Bielińska et al., 2013; Gałązka, 2019).

Soil is a habitat for the life and multiplication of bacteria of the genus *Azotobacter*. Interest in this group of bacteria is primarily related to their properties that can be applied in agriculture – the ability to fix atmospheric nitrogen and provide it in a bioavailable form to plants, producing several compounds that stimulate plant growth and development (Aasfar et al., 2021; Jain et al., 2021). In addition, bacteria belonging to the genus *Azotobacter* are excellent indicators of soil fertility (Lenart, Chmiel, 2008; Natywa et al., 2013). The abundance of *Azotobacter* spp. in temperate zone soils is low, ranging from a few to several thousand cells in 1 gram of soil. The bacteria are detected in 30–80% of analyzed soil samples collected from various regions worldwide (Kennedy et al., 2004). The occurrence and population size of this group of bacteria is influenced by many environmental factors, i.e. soil properties (pH, organic matter content, moisture content, fertility, C/N ratio) or climatic conditions (Tejera et al., 2005). The abundance of *Azotobacter* spp. varies depending on the depth of the soil profile. These bacteria colonize rhizosphere soil in more significant numbers, and the type of crop grown affects their abundance (Kaviyarasan et al., 2020). Fluctuations in *Azotobacter* abundance reflect changes in the soil environment, as these microorganisms respond strongly to physical and chemical factors (Lenart, Chmiel, 2008; Lenart, 2012; Kozieł et al., 2018). Increasingly, strains of *Azotobacter* spp. isolated from soils are being used to produce biopreparations applicable to agriculture. Therefore, it is essential to know and carefully study the interactions

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