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On the Rhizosphere of Field Crops and Factors Influencing the Dynamics of its Microbiota

Abstract

There is presented a review of literary sources, which disclosed an importance of rhizosphere being a certain biological buffer regulating interrelations between higher plants and soil and inhabiting soil microorganisms. The main factors influencing indicators of activity of rhizosphere microbiota possessing a complex of useful qualities for plants (converting of nutrient into accessible forms, decomposition of organic materials, increase of resistance to abiotic factors, stimulating a growth, antagonism to phytopathogens, etc.) are considered. The violations of interrelations between plants and their associative microorganisms caused by different factors, including the regulating by human ones – such as cultivation technologies, are able to decrease yield potential of agricultural crops including sunflower. The analytical review certifies the prospects to conduct researches allows determining an impact of agrotechnical methods (sowing dates, seed sowing rates, fertilizer, and chemical and biological plant protection) on changes in qualitative and quantitative composition of microbiota in sunflower rhizosphere and to determine their influence on yield and quality of products.

Keywords: *soil microflora, rhizosphere, microbiota, associative symbiosis, sunflower, cultivation technology, soil*

Introduction

Soil is not a physical or chemical system, but primarily a biological and biochemical system, one of the main components of which is soil microflora. Microorganisms play a leading role in the decomposition of plant residues, the synthesis and destruction of humus, the formation of the phytosanitary state of the soil, the accumulation of biologically active substances in it, the fixation of atmospheric nitrogen, etc. In addition, soil microorganisms play an important role in the formation of soil fertility and plant nutrition (Bulgarelli, 2013, pp. 807-838; Balandreau, 2007, pp. 851-859). Higher plants, being the main source of nutrients for the predominant number of microorganisms inhabiting the soil, have a significant impact on microbial cenoses. A special zone is formed around the roots of vegetative plants, in which more favorable conditions for the existence of both plants and microorganisms are created. The number of microbes in the root zone is more significant than in the rest of the soil mass. This is primarily due to the secretion of organic substances from the roots (exoosmosomes) synthesized by plants. In addition, in the zone of abundant accumulation and development of roots, the physical properties of the soil improve: soil particles are more structured, due to which the process of respiration of roots and microorganisms improves, a stable temperature is maintained, moisture is better preserved due to the ability of plant root systems to actively change the humidity of their environment.

Research

Roots also increase the acidity of adjacent soil microlayers (within a few millimeters) by releasing carbon dioxide and H+ ions. The increased accumulation of microbes in the root soil was first noted by the German agronomist and physiologist Hiltner in 1904. He proposed the term "rhizosphere" (Bakker, 2018, pp. 1178–1180). The rhizosphere is a narrow layer of soil adjacent to the plant roots and directly exposed to root secretions and soil microorganisms, with a thickness of about 2–5 mm in diameter. The boundaries of the rhizosphere depend on the plant species, soil type,

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humidity, and a number of other factors (Dobereiner, 2001, pp. 330-350). Ulrich notes that, although morphologically the roots, soil, and microorganisms are clearly separated from each other, there is no functional boundary between them. One of the rhizosphere boundaries is defined relatively clearly and coincides with the root surface, the second is more blurred and, according to various characteristics, is at an uneven distance from the root. For the microbial population, these are fractions of a millimeter, for moisture and mobile nutrients – up to ten millimeters, for gaseous compounds – tens of millimeters. Without a deep understanding of the processes occurring in the soils of the rhizosphere, it is impossible to create sustainable farming systems and solve many environmental problems. In the modern understanding, the rhizosphere is the central component of ecosystems and biogeochemical cycles of chemical elements, the place of interaction between soil, roots, microorganisms and soil fauna (Dinesh, 2010, pp. 252-258). The relationship between plants and rhizosphere microflora is of a separate symbiotrophism nature, that is, they are mutually beneficial to both plants and microorganisms. At the same time, the most intense competition is between representatives of the biota for nutrients (Dessaux, Hinsinger, & Lemanceau, 2009, pp. 1-3).

The most important specific features of soils in the rhizosphere are associated with the continuous flow of root exudates and microbial metabolic products into the soil. The rhizosphere soil is very diverse. The rhizosphere microbiota includes various microorganisms: bacteria, actinomycetes, fungi, algae, yeast, protozoa, phages and other living beings. Bacteria are predominant in the rhizosphere of plants, regardless of their growth conditions and age, mycobacteria are in second place, actinomycetes, fungi, spore-forming bacteria, etc. are present in incomparably smaller quantities (Hartmann, Rothballer, & Schmid, 2008, pp. 179-186; Mendes, Garbeva, & Raaijmakers, 2013, pp. 634-663). Non-spore-forming bacteria constitute the main, most extensive and diverse group of rhizosphere microbiota, their number can reach 99.5 % of the microbial population of the rhizosphere. This group includes representatives of various families, genera and species: Azotobacter, nodule bacteria, thiobacteria, photobacteria, Azotomonas, sulfomonas, nitrifiers, denitrifiers, etc. One gram of soil contains billions of ammonifiers and denitrifiers, while nitrifiers and cellulolytic bacteria are comparatively few. Mycobacteria are in second place in terms of quantity, with their number reaching hundreds of thousands and millions. Spore-forming bacteria make up fractions of a percent in the rhizosphere, and are especially few in number during the period of active plant vegetation, since this group of bacteria develops mainly on dead, decaying roots. Bacteria form strong associations with the root system of plants and form specific rhizosphere bacterial communities. Such relationships are characterized by the terms “associative bacteria”, “associative relationships”, “associative symbiosis” (Philippot, 2013, pp. 789-799).

To maintain the rhizosphere bacterial community, plants lose 30–50 % of the products of photosynthesis in the form of root exudates and rhizodeposits, but this is compensated for by the fact that rhizobacteria perform the following: control of the entry of mineral elements from the soil into the root; binding of gaseous atmospheric nitrogen and improving nitrogen nutrition of plants due to it; synthesis of phytohormones; inhibition of plant growth by various metabolites; consumption and destruction of root secretions of vegetative plants, which has a positive effect on the process of root nutrition; suppression of the activity of microbiota unfavorable for plants; stimulation of endosymbiosis of plants and microorganisms; decomposition of cellulose; synthesis of vitamins, polysaccharides, heteroauxins, and thereby have a certain effect on the development of the plant organism. The function of nitrogen fixation was previously attributed only to a limited range of free-living bacteria — Azotobacter, Clostridium, Azospirillum, Beijerпckia, Derxia. Currently, it is believed that 80-90 % of all known bacteria are capable of fixing nitrogen from the atmosphere, these are representatives of the genera: Azospirillum, Herbaspirillum, Acetobacter, Agrobacterium, Azotobacter, Pseudomonas, Enterobacter, Кlebsiella, Burkholderia, Flavobacterium, Campylobacter (Raynaud, 2010, pp. 210-219).

This type of nitrogen fixation is called associative, in contrast to symbiotic, which is typical for bacteria living in the nodules of leguminous plants. This process occurs in almost all types of soil in

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the rhizosphere of plants in a wide variety of habitats. A feature of associative bacteria is that they do not form any specialized structures such as nodules on plant roots. The scale of associative nitrogen fixation in the temperate climate zone reaches 50–150 kg/ha of molecular nitrogen during the growing season, in tropical latitudes – from 200 to 600 kg/ha per year, which indicates the great ecological significance of this method of replenishing the fund of nitrogen available to plants in most natural ecosystems. It has been proven that in the soil in the presence of plants, the level of nitrogen fixation is significantly higher than in their absence. Phosphorus is present in the soil in the form of organic (deposits of plant, animal and microbial origin) and inorganic (mineral) compounds, but only about 5 % of it is available to plants, since most of it is in the form of phytin (inositol phosphoric acid salt), nucleic acids, and phospholipids. Rhizospheric bacteria play a significant role in improving the phosphorus nutrition of plants, which, due to the enzymes they synthesize – phytase, nuclease, phosphatase, phospholipase, carry out the mineralization of these compounds with the formation of accessible forms of phosphorus. Under the influence of microflora in the rhizosphere, an increase in the solubility of iron and manganese compounds and other metals is noted, since they are in compounds with organic substances formed by microbes, and therefore are better absorbed by plants. This was confirmed by Weinstein and co-authors in a laboratory experiment with sunflower, where in the absence of microbes and their metabolites, these elements were not absorbed by plants. These observations show that plants absorb iron not in the form of mineral compounds, but in the form of organo-mineral substances formed under the influence of microorganisms. Actinomycetes make up less than 1% of the total number of microorganisms in the rhizosphere and are found mainly towards the end of the plant growing season. The species of actinomycetes living in the rhizosphere and in the soil do not differ in species composition and physiology (Dinesh, 2010, pp. 252-258; Richardson & Simpson, 2011, pp. 41-63).

Conclusion

In Azerbaijan, the main oilseed and most profitable agricultural crop is sunflower. Its production in Russia is carried out on an area of more than 10 million hectares. Highly productive varieties, hybrids and various cultivation technologies are used for sowing, but in production the yield of this crop is realized at best by 50 %. One of the reasons for this is the disruption in the relationship between plants and microorganisms caused by various factors, including those controlled by man – cultivation technologies. At present, in order to move to a highly productive and at the same time environmentally friendly technology for growing sunflower, there is a need to conduct research to establish the impact of agricultural practices (sowing time, seed sowing rate, fertilization, use of chemical and biological plant protection products) on changes in the qualitative and quantitative composition of the microbiota in the rhizosphere of the crop, as well as to determine their impact on the yield and quality of the resulting products. In this case, studying the sunflower rhizosphere will allow us to determine agricultural practices that have a positive effect on its composition, which will allow us to develop technologies that contribute to obtaining high crop productivity.

Understanding and managing the rhizosphere microbiota is vital for improving crop productivity and sustainability. Future research should focus on unraveling microbial functions, enhancing beneficial plant-microbe interactions, and developing precision agriculture techniques to optimize rhizosphere dynamics for various field crops.

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