

Plant Microbiome for Improving Productivity and Resilience of Crops

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Agriculture has to provide increased yields to feed the growing global population, which is expected to reach 9.7 billion by 2050 [1]. In 2010-2012, 12.5% of the world population, about 7.6 billion population, was estimated to be malnourished [2]. Agricultural yields are limited and made unpredictable by abiotic and biotic stresses. As example, fungal pathogens of wheat alone are estimated to cause yield losses of up to 29%, and other pathogens and various abiotic threats, such as flooding, drought and soil fertility, are causing further reduction of productions [3]. Moreover, climate change is predicted to increase the frequency and severity of these threats [4]. Thus, agro-ecological challenges of the 21st century should be the minimization of the threat of pathogens and abiotic stresses and the reduction of the negative environmental impacts on agriculture through a sustainable intensification of management under fluctuating and unpredictable conditions [5]. The challenge to sustainable intensified agriculture practices is the deep exploitation of the plant microbiome both in the endosphere and rhizosphere in order to define strategies for the application of endophytes, symbionts and other beneficial microorganisms to agricultural systems [6]. However, an overlooked aspect is the negative impact of agrotechnical interventions, such as intensive tillage and chemical treatments, on plant microbiome.

Microbiome, similarly to gut microbiome, is now known as the 'second genome' of plants that strongly influences plant health, nutrient uptakes as well as growth and development [7]. A better understanding of the plant microbiome in term of genetic diversity and functionality, allowed by the use of next-generation omics technologies, is expected to contribute to the development of a 'personalized agriculture'. For plants, it was suggested that plant growth promoting bacteria (PGPB) act as probiotics for roots, and substrates or additives, such as soil amendments, act as prebiotics

for plants [8,9]. Microbial communities can live inside plants (endosphere) and/or externally to roots (rhizosphere and mycorrhizosphere). Inside and around the roots, bacteria and fungi are shaped by root exudates, soil pH, salinity, soil organic matter, and moisture, determining their composition, structure and functions [10-12]. The endophytic microbial communities confer multiple beneficial effects to the host plant, promoting plant growth, producing phytohormones, and controlling plant pathogens, by the induction of systemic resistance or siderophore production [13]. The beneficial microbes living in the rhizosphere, include a high numbers of diverse plant growth promoting microbial communities, arbuscular mycorrhizal fungi (AMF, Glomeromycota) and bacteria, such as Acidobacteria, Bacteroidetes, Proteobacteria, Planctomycetes, and Actinobacteria [14]. Moreover, diverse bacterial communities live in the mycorrhizosphere, i.e., associated with mycorrhizal roots, spores, sporocarps and extraradical hyphae. Moreover, some rhizospheric and mycorrhizospheric bacteria are able to colonise plant roots, thus becoming endophytes [15].

Soil inoculants composed by biofertilizers and biostimulants have been shown to be beneficial for boosting plant productivity and protection against pathogens generally in microcosm experiments. However, the tested soil inoculants include individual or a limited number of known microbial strains isolated from few plant species. These strains have been originated from soil under intensive agricultural managements and thus we can question whether the services they provide are effective only in these specific conditions. In this context, Xia, *et al.* [16] investigated the effect of agricultural practices, such as organic and conventional management, and found that organic agriculture increased endophyte presence and diversity in 32 crops, including corn, tomato, melon, and pepper. Following their reintroduction to tomato plants, 61% and 64%

of the endophytes isolated from organic agriculture promoted tomato growth and biomass accumulation. Moreover, overall, the strains studied in literature have not been selected for secondary services, such as the production of metabolites beneficial for human health, and thus plant microbiome diversity is under-exploited for these functions. However, recent researches have addressed the possibility of manipulating the communication between plants and their microbiota to modify the abundance and diversity of microorganisms of the endosphere and rhizosphere [17,18].

Thus, further studies should start from the hypothesis that a high inter- and intraspecific variability in genetic diversity, infectivity and effectiveness occur in plant microbiome. Further studies should thus isolate and propagate endophytic bacteria through single-strain cultures and AMF through single-spore cultures, both collected from rhizospheric soil and/or roots of plants occurring in secondary successions and conventional agricultural systems from vulnerable areas, such as the Mediterranean ones. There is a need of testing the hypothesis that the abandonment of agriculture (fertilization and ploughing) that occurred in the secondary successions changes soil parameters and consequently promotes microbial community and strains with high infectivity and effectiveness, in terms of promotion of crop productivity and resilience to biotic and abiotic stress. The detection of the soil-plant and/or abiotic drivers positively affecting the infectivity and effectiveness of plant microbiome need to guide new programmes of selection of efficient strains dedicated to specific crops/environments or the management of crops in order to shape the plant microbiota with the prospect to promote green agriculture.

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