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Editorial

Editorial to the Thematic Topic “Towards a more sustainable agriculture through managing soil microbiomes”

Consistent with the concept of ecosystem sustainability—defined as ‘the ability of an ecosystem to maintain its potential for self-regulation in the long term’ (Bender, Wagg and van der Heijden 2016)—sustainable agricultural production aims to meet future food, feed and fibre demands with the given natural resources and without adverse environmental impact or greater land consumption. However, intensification of modern agricultural practices over recent decades with the ultimate aim of higher yields widely neglected environmental consequences—in particular with respect to soils. This has resulted in several negative impacts such as reduced soil fertility and biodiversity, accumulation of plant pathogens, environmental contamination with agrochemicals, or soil erosion jeopardizing soil health. Soil health is defined as the capacity of a soil to function as a vital living system to maintain environmental quality, sustain biological productivity and promote health of various organisms (Larkin 2015). In view of the limited arable land, we urgently need to restore soil health, i.e. with appropriate farming practices in order to ensure agricultural productivity for future generations. Soil microorganisms are critical for soil-related ecosystem services. Harnessing their huge untapped and largely unexplored taxonomic and functional diversity, and gaining a better mechanistic understanding of plant-microbe interactions under various agricultural management practices can open up new ways to support economically efficient and environmentally-benign plant production (Bakker *et al.* 2012; Bender, Wagg and van der Heijden 2016).

This was the motivation for the Julius Kühn Institute (JKI, Germany) and the Instituto Nacional de Investigación Agropecuaria (INIA, Uruguay) to organize an international workshop from 14th to 16th November 2019 in Montevideo. South America is one of the leading regions in the agricultural sector worldwide and exhibits a tremendous record in agricultural research. The workshop was attended by fifty researchers from South American and European countries and served as a forum to inform each other about research projects, to exchange ideas and define future research needs. Twenty-eight speakers gave presentations across six sessions, covering aspects as diverse as below/aboveground plant-microbe interactions, microbiome-based optimization of farming practices, soil quality risk assessment, development of efficient plant probiotics, and microbiome-based plant breeding approaches. Participants took time out to visit the long-term field trials managed by INIA at their Las Brujas experimental station. This Thematic Topic on ‘Sustainable Agriculture through Managing Soil Microbiomes’ was compiled as a result of the workshop and includes nineteen research articles, three minireviews, one current opinion and one perspective. The articles span a broad range of topics, including various crop plants, soil ecosystems, geographic locations, and climatic conditions discussed by the attendees.

A prerequisite of enhancing selected indigenous beneficial microorganisms for improved crop performance and soil health is to understand the response of soil and plant-associated microbiomes to various conventional and sustainable agricultural management practices. In addition, it is essential to identify commonalities and site- or cultivar-dependent differences in microbiomes. Simonin *et al.* (2020) identified the wheat rhizosphere core microbiome across various African and European soils, conventional or organic cultivation and wheat genotypes. Management type (organic *vs.* conventional) in combination with previous land use and plants' stand age also shaped the microbial community composition in shade coffee plantations with implications for long-term soil fertility as revealed by a study across nineteen individual farms in Nicaragua (Jurburg, Shek and McGuire 2020). Garaycochea *et al.* (2020) investigated soil prokaryotic communities of five soils typical of the Uruguayan Campos biome, one of the most fertile and biologically diverse natural grasslands in South America. Another vulnerable habitat is the Amazon rainforest which is threatened by increasing deforestation. Pedrinho *et al.* (2020) combined metagenomic sequencing with quantitative real-time PCR to reveal that the effect of the conversion of rainforest to pasture on nitrogen-related microbial groups and functions can be reversed by reestablishment of forest growth. The rhizosphere microbiota of rice was shown to be affected by water management (lowland *vs.* upland) but independent of plant developmental stage with consistent shifts in putative saprotrophs, pathogens and beneficials (Chialva *et al.* 2020). In commercial apple production, soils often show the problem of apple replant disease (ARD) with unknown etiology and few ecological management options. By growing a susceptible apple rootstock in split-root set-ups, Balbín-Suárez *et al.* (2020) and Balbín-Suárez *et al.* (2021) revealed that ARD is a local, non-spreading soil phenomenon linked to microbial dysbiosis along the soil-root continuum when compared to healthy soils.

Neal *et al.* (2021) demonstrated that the source of phosphate fertilization (rock phosphate *vs.* triple superphosphate) exerted a minor role for phosphohydrolase gene abundance and diversity in the rhizosphere when compared to the crop type adding

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to the knowledge base of alternative phosphorus fertilizers. Gabbarini *et al.* (2021) studied the response dynamics of different biotic and abiotic parameters in soils under long-term conventional or no tillage practice to the switched management. Conservation practices (e.g. cover crops, crop rotation, reduced tillage, organic fertilization) were shown to have the potential to restore soil quality by recovering physical, chemical and biological parameters in degraded South American soils under long-term conventional soybean (Fernandez-Gnecco *et al.* 2021), common bean (Abán *et al.* 2021), or intensive vegetable production (Cerecetto *et al.* 2021). Long-term farming practices can result in a soil biotic legacy modulating the rhizosphere microbiome and affecting the performance of the model plant lettuce via altered plant-microbe interactions in the rhizosphere (Babin *et al.* 2021). For instance, bacterial *N*-acyl homoserine lactones (AHLs) are a group of molecules that mediate inter-kingdom interactions. Shrestha & Schikora (2020) elucidated the mechanism of plant priming via AHLs for enhanced resistance, yield and tolerance towards (a)biotic stresses and its potential to reduce fertilizer and pesticide inputs. Evidence for the effect of the barley rhizosphere microbiome on the plant defense response towards *Blumeria graminis* was given by Bziuk *et al.* (2021) when comparing differently managed agricultural to potting soils.

Besides molecular techniques, isolation of bacteria coupled with functional screens allows for phenotypic characterization. Using cultivation-dependent techniques Elsayed, Grosch and Smalla (2021) demonstrated that the potato plant sphere, and to a lesser extent the soil type, affected the diversity and proportion of bacteria showing *in vitro* antagonistic activity towards the soil-borne pathogen *Ralstonia solanacearum*. Another study described how long-term nitrogen fertilization in soils under maize monoculture resulted in fewer actinomycetes with *in vitro* inhibitory capacities towards other actinomycetes compared to non-fertilized soils, while crop residue incorporation showed no effect (Gieske and Kinkel 2020).

As an alternative to the management-dependent support of the indigenous microbiome, the external manipulation by inoculation of soils or plants with beneficial microbial strains or multi-species consortia holds great promise for an enhanced sustainable agriculture. Since plants interact with a multitude of microbes at their roots, Tsiknia *et al.* (2021) emphasized the need for proceeding from pairwise interaction studies to an understanding of multi-species relationships of the plant-microbiome-soil continuum, in this case with a special focus on legume roots. The work of Heijo *et al.* (2021) added to the understanding of plant-endophyte interactions in agro-ecosystems by investigating the effect of diazotrophic bacterial endophyte inoculation on sweet sorghum performance depending on nitrogen fertilization doses and the sorghum cultivar. Figueiredo dos Santos *et al.* (2021) showed that maize seed-borne bacteria are crucial for germination and development of maize seedlings. Combining *in vitro* functional screening for plant growth promotion with whole genome sequencing provided new insights into the mechanisms of two tropical *Bacillus* inoculant strains on different maize genotypes (Vieira Velloso *et al.* 2020). In view of the intensive rice and wheat cultivation in the Indo-Gangetic Plains of India jeopardizing soil quality, Sarkar & Rakshit (2020) promoted the application of microbial delivery systems i.e. bioaugmentation to enable bioremediation of polluted sites and/or bio-priming with bio-inoculants in order to stimulate plant growth and reduce the requirement for agrochemical use. Microbiome-based approaches can also be important for improving fruit/vegetable production as well as for the biological control of postharvest and storage pathogens (Kusstatscher *et al.* 2020). As a follow-up of the miCROPe 2019 symposium, Hohmann, Schlaeppi and Sessitsch (2020) summarized research needs for a successful implementation of microbe-assisted cultivation approaches with focus on the management of plant genetics or of the microbiome via single or combined strain inoculation.

We agree strongly with the authors that microbiome-assisted agriculture offers a promising new toolkit. As a result of this Thematic Topic, *FEMS Microbiology Ecology* organized a webinar (https://www.youtube.com/watch?v=2YOqB-O3Jnc) with Gabriele Berg, Rodrigo Mendes and Doreen Babin on the current agricultural microbiome research. The high number of participants of the webinar as well as of the numerous contributions to this Thematic Topic showed the huge interest of the scientific community. As a next step, mechanistic understandings under consideration of various environmental conditions should be brought into focus to improve efficiency and stability of biological solutions. New analytical methods and multidisciplinary approaches are essential. We should aim at developing models to predict the response and functioning of the soil-microbiome-plant system and to fine-tune measures in a targeted way. Finally, we strongly encourage scientists to disseminate their knowledge to stakeholders, policy makers, and the public to promote the acceptance of microbial solutions.

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REFERENCES

Abán CL, Verdenelli R, Gil SV *et al.* Service crops improve a degraded monoculture system by changing common bean rhizospheric soil microbiota and reducing soil-borne fungal diseases. *FEMS Microbiol Ecol* 2021;**97**:fiaa258.

Babin D, Sommermann L, Chowdhury SP *et al.* Distinct rhizomicrobiota assemblages and plant performance in lettuce grown in soils with different agricultural management histories. *FEMS Microbiol Ecol* 2021;**97**:fiab027.

Bakker MG, Manter DK, Sheflin AM *et al.* Harnessing the rhizosphere microbiome through plant breeding and agricultural management. *Plant Soil* 2012;**360**:1–13.

Balbín-Suárez A, Jacquiod S, Rohr A-D *et al.* Root exposure to apple replant disease soil triggers local defense response and rhizoplane microbiome dysbiosis. *FEMS Microbiol Ecol* 2021;**97**:fiab031.

Balbín-Suárez A, Lucas M, Vetterlein D *et al*. Exploring microbial determinants of apple replant disease (ARD): a microhabitat approach under split-root design. *FEMS Microbiol Ecol* 2020;**96**:fiaa211.

Bender SF, Wagg C, van der Heijden MGA. An Underground Revolution: Biodiversity and Soil Ecological Engineering for Agricultural Sustainability. *Trends Ecol Evol* 2016;**31**:440–52.

Bziuk N, Maccario L, Douchkov D *et al*. Tillage shapes the soil and rhizosphere microbiome of barley-but not its susceptibility towards *Blumeria graminis* f. sp. *hordei*. *FEMS Microbiol Ecol* 2021;**97**:fiab018.

Cerecetto V, Smalla K, Nesme J *et al*. Reduced tillage, cover crops and organic amendments affect soil microbiota and improve soil health in Uruguayan vegetable farming systems. *FEMS Microbiol Ecol* 2021;**97**:fiab023.

Chialva M, Ghignone S, Cozzi P *et al*. Water management and phenology influence the root-associated rice field microbiota. *FEMS Microbiol Ecol* 2020;**96**:fiaa146.

Elsayed TR, Grosch R, Smalla K. Potato plant spheres and to a lesser extent the soil type influence the proportion and diversity of bacterial isolates with *in vitro* antagonistic activity towards *Ralstonia solanacearum*. *FEMS Microbiol Ecol* 2021;**97**:fiab038.

Fernandez-Gnecco G, Smalla K, Maccario L *et al*. Microbial community analysis of soils under different soybean cropping regimes in the Argentinean south-eastern Humid Pampas. *FEMS Microbiol Ecol* 2021;**97**:fiab007.

Figueiredo Dos Santos L, Fernandes Souta J, De Paula Soares C *et al*. Insights into the structure and role of seed-borne bacteriome during maize germination. *FEMS Microbiol Ecol* 2021;**97**:fiab024.

Gabbarini LA, Figuerola E, Frene JP *et al*. Impacts of switching tillage to no-tillage and vice versa on soil structure, enzyme activities and prokaryotic community profiles in Argentinean semi-arid soils. *FEMS Microbiol Ecol* 2021;**97**:fiab025.

Garaycochea S, Romero H, Beyhaut E *et al*. Soil structure, nutrient status and water holding capacity shape Uruguayan grassland prokaryotic communities. *FEMS Microbiol Ecol* 2020;**96**:fiaa207.

Gieske MF, Kinkel LL. Long-term nitrogen addition in maize monocultures reduces *in vitro* inhibition of actinomycete standards by soil-borne actinomycetes. *FEMS Microbiol Ecol* 2020;**96**:fiaa181.

Heijo G, Taulé C, Mareque C *et al*. Interaction among endophytic bacteria, sweet sorghum (*Sorghum bicolor*) cultivars and chemical nitrogen fertilization. *FEMS Microbiol Ecol* 2021;**97**:fiaa245.

Hohmann P, Schlaeppi K, Sessitsch A. miCROPe 2019 - emerging research priorities towards microbe-assisted crop production. *FEMS Microbiol Ecol* 2020;**96**:fiaa177.

Jurburg SD, Shek KL, McGuire K. Soil microbial composition varies in response to coffee agroecosystem management. *FEMS Microbiol Ecol* 2020;**96**:fiaa164.

Kusstatscher P, Cernava T, Abdelfattah A *et al*. Microbiome approaches provide the key to biologically control postharvest pathogens and storability of fruits and vegetables. *FEMS Microbiol Ecol* 2020;**96**:fiaa119.

Larkin RP. Soil health paradigms and implications for disease management. *Annu Rev Phytopathol* 2015;**53**:199–221.

Neal AL, McLaren T, Lourenço Campolino M *et al*. Crop type exerts greater influence upon rhizosphere phosphohydrolase gene abundance and phylogenetic diversity than phosphorus fertilization. *FEMS Microbiol Ecol* 2021;**97**:fiab033.

Pedrinho A, Mendes LW, Merloti LF *et al*. The natural recovery of soil microbial community and nitrogen functions after pasture abandonment in the Amazon region. *FEMS Microbiol Ecol* 2020;**96**:fiaa149.

Sarkar D, Rakshit A. Safeguarding the fragile rice-wheat ecosystem of the Indo-Gangetic Plains through bio-priming and bioaugmentation interventions. *FEMS Microbiol Ecol* 2020;**96**:fiaa221.

Shrestha A, Schikora A. AHL-priming for enhanced resistance as a tool in sustainable agriculture. *FEMS Microbiol Ecol* 2020;**96**:fiaa226.

Simonin M, Dasilva C, Terzi V *et al*. Influence of plant genotype and soil on the wheat rhizosphere microbiome: evidences for a core microbiome across eight African and European soils. *FEMS Microbiol Ecol* 2020;**96**:fiaa067.

Tsiknia M, Tsikou D, Papadopoulou KK *et al*. Multi-species relationships in legume roots: from pairwise legume-symbiont interactions to the plant - microbiome - soil continuum. *FEMS Microbiol Ecol* 2021;**97**:fiaa222.

Vieira Velloso CC, Oliveira CA de, Gomes EA *et al*. Genome-guided insights of tropical *Bacillus* strains efficient in maize growth promotion. *FEMS Microbiol Ecol* 2020;**96**:fiaa157.

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