BRIEFING

Food Security from the Soil Microbiome

- **Soil micro-organisms are vital for soil health and food security.**
- **Intensive agricultural production often impacts the soil microbiome at a cost to productivity, sustainability and the environment.**
- **Microbiologists are investigating how the soil microbiome can be harnessed as a tool for sustainable agricultural intensification.**

SUMMARY

Sustainable agricultural intensification (SAI) is a concept that challenges global agriculture to increase world food production while sustaining the environment we live in. Protecting and harnessing healthy soils is important to help us achieve this.

The soil microbiome – the community of micro-organisms found in soil – is crucial for soil health. Microbiologists are investigating the diversity and function of the soil microbiome, and the potential for farmers to harness it as a tool for SAI. The impact of this science can be maximised by policies that recognise the importance of monitoring and managing the biological health of soils and investing in agricultural and soil science skills and research.

FUNCTIONS OF THE SOIL MICROBIOME

One gram of healthy soil usually contains a microbiome comprising many millions of microbes, including archaea, bacteria and fungi. Some microbes colonise the area around plant roots, known as the rhizosphere, forming mutually beneficial associations (symbioses) with plants. These symbiotic microbes, and other free-living soil microbes, contribute to crop growth and soil health by:

- Cycling nutrients, including nitrogen and phosphate, which are essential for plant growth. These microbial processes are also important for global biogeochemical cycles.
- Improving soil structure and increasing organic matter content, which are important for fertility, water retention, and minimising erosion and flood risk.
- Conferring disease resistance to crops by out-competing pathogenic microbes and stimulating complex biochemical plant defences.
- Improving the resilience of plants to environmental stresses, such as fluctuations in temperature and moisture.
- Enhancing root growth and nutrient uptake.

INTENSIVE AGRICULTURE AND THE MICROBIOME

Intensive agricultural practices often underutilise and degrade beneficial soil microbiome diversity and function, or promote undesirable microbial activity; these can lead to reduced crop yields, increased costs and environmental impacts.

MICROBIOLOGY IN THE FIELD

Collaborative UK research projects, funded by the Soil Security Programme, are combining field studies, genomics and other methods to better understand the functioning of agricultural soil microbiomes, and the potential for farmers to manipulate them to increase crop yields.

The Roots of Decline[1] project is investigating how continuous cropping causes the development of diseased rhizosphere microbiomes in oilseed rape (OSR) crops, which cause a 6–25% annual decline in yield. The results will be used to investigate the potential to use different OSR varieties and cultivation methods to inhibit disease development.

The MycoRhizaSoil[2] project aims to help farmers address long-term plateaus in UK wheat yields by investigating optimal combinations of wheat varieties and cultivation methods that promote beneficial crop–microbe associations (symbioses) between wheat and mycorrhizal fungi, which can improve soil structure and fertility, and confer disease resistance.

[1] www.soilsecurity.org/roots-of-decline
[2] www.soilsecurity.org/mycarhizasoil

- **Soil degradation and erosion:** Intensive use of heavy machinery and ploughing disrupts both the soil pore spaces where microbes reside and the fungal networks that help maintain soil structure and store organic matter. Impacts of degraded soil structure and organic matter content include reduced fertility; poorer water and nutrient retention; and soil loss to wind and water erosion.
- **Disease:** Practices such as continuous cropping can increase the susceptibility of crops to soil-borne diseases. Take-all is a serious fungal root disease of wheat, which appears in the second or third year of continuous cropping. It is estimated to affect half of UK wheat crops, reducing yields by an average of 5–20%, costing farmers tens of millions of pounds each year.
- **Nitrogen crisis:** Intensive agriculture typically relies on large inputs of nitrogen fertilisers for high yields, but their usage is often very inefficient. Nitrogen-cycling soil microbes convert excess fertiliser into nitrate, which can run off into watercourses, causing environmental damage. Microbial nitrogen-cycling also releases nitrous oxide, a greenhouse gas. Nitrogen fertiliser use is a key driver of global nitrous oxide emissions.

SOIL MICROBIOME AS A SOLUTION

Microbiologists are investigating understanding and manipulation of soil microbiome diversity and function to increase crop yields and soil health, while reducing fertiliser and biocide inputs. Harnessing crop–microbe associations that increase resilience to water stress, for example, may also help to mitigate impacts of climate change on crop production. Examples of research themes:

- **Understanding soil microbiome diversity and function:** This complex microbial community needs to be better understood to both harness its function and develop biomarkers to monitor soil health. Advances in genomics are enabling microbiologists to increase understanding of which microbes are present, what their function is, and how they interact with plants. Such research may also uncover novel microbes that can be used as biofertilisers and biopesticides, or that produce useful compounds such as antibiotics.
- **Promoting crop–microbe associations:** Modern crop varieties bred for an intensive agricultural environment can exhibit a reduced ability to associate with beneficial microbes. Consequently, scientists are now breeding crop varieties with root systems that selectively encourage beneficial crop–microbe associations. Another avenue of research is the development and optimisation of microbial inocula (e.g. microbe-coated crop seeds) to introduce beneficial microbes to the rhizosphere.

SYNTHETIC SYMBIOSES

Advances in synthetic biology raise the possibility of bioengineering symbioses. The fixation of atmospheric nitrogen into a form that can be used by plants occurs naturally in leguminous crops (e.g. peas and beans) through symbioses with rhizobium bacteria, but not in cereal crops (e.g. wheat and maize) as these symbioses do not occur. Scientists are investigating transferring genes from nitrogen-fixing bacteria into other bacteria that naturally associate with cereals (www.synthsym.org). Potential impacts include increasing cereal yields from nitrogen-poor soils in low-income regions and helping to reduce nitrogen fertiliser usage in intensive agricultural regions, where overuse damages the environment. Scientific challenges and debate about genetic modification make the application of synthetic symbioses a longer-term prospect.

- **Soil management:** Scientists are also investigating enhancing beneficial soil microbiome diversity and function through optimising soil management methods, such as crop rotation, intercropping and tillage.

MAXIMISING RESEARCH IMPACT

Investment in monitoring soil microbiome health and understanding its function are important to develop the evidence base for soil management practices and policies, and to deliver agricultural biotechnologies needed for SAI.

Research Council-funded doctoral training centres for food security and soil science are examples of good practice in addressing skills and expertise gaps in agricultural and soil microbiology.

Farmers facing soil health issues can work with scientists to investigate the underlying causes and identify potential solutions. They require tools to assess the biological health of their soils; to this end, methods for measuring standardised soil health and diversity must be developed.

FURTHER READING

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MICROBIOLOGY SOCIETY BRIEFINGS

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