Sustainable agriculture for the future

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Biodiversity supporting sustainable agriculture and bioenergy production

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As spring gradually covers the landscape with a myriad of colours and vast diversity of birds and animals, we turn our attention to the less visible but just as important force constantly working beneath our feet: soil biodiversity. Microbes form the heartbeat of agricultural systems where they drive nutrient acquisition, improve soil structure and facilitate nutrient cycling. In fact, plant growth in soil would be impossible without the aid of microbes. These organisms are so small that they often receive minimal consideration, but it is amazing to note that a single teaspoon of soil may contain as many microbes as the people on Earth! This army of microbes including bacteria, fungi, archaea and microscopic nematodes are constantly hard at work in agricultural systems. Like plants and animals, the rich biodiversity of microbes needs to be protected and nurtured to ensure that we continue reaping the benefits of their presence in soils.

Microbes: Nature's tiniest engineers

Microbes are indeed nature's tiniest and most efficient engineers. They recycle organic matter in the soil, thereby improving soil structure and promoting plant growth. Apart from soil, this strong workforce has also been adopted in engineered systems to convert waste into a nutrient-rich product and gases through sequential intricate biochemical reactions. Interestingly, anaerobic digestion (AD), which is the microbe-mediated conversion of organic waste to renewable energy (biogas), mirrors the natural process of soil microbes in a controlled environment. Hence, diverse microbes not only drive sustainable agriculture but may also be used to facilitate biotechnological applications, such as renewable energy generation. This emphasizes the need to protect microbes to ensure that they can protect us, by provisioning food and energy, amongst several other environmental services.\

Closing the circular loop between soil biodiversity and renewable energy production

In general, nature operates in a circular manner where nothing is wasted and every process feeds into another, with soil biodiversity lying at the heart of this cycle. In the soil, an array of microbial communities breakdown organic residues, release nutrients and stabilize carbon. These same microscopic processes that support plant growth and ecosystem health also inspire technologies for renewable energy production.

Microbes serve as nature's recyclers in both natural and engineered systems, such as the soil and anaerobic digesters, respectively. In the soil, microbes convert organic matter (like leaves) into nutrients that support other lifeforms, whereas in biotechnological systems such as anaerobic digesters they convert organic waste (like food and agricultural waste) into biogas, which is a renewable

energy source that can be combusted for heating, lighting, cooking and electricity generation. This distinct parallel in the biodiversity of soils and the biodiversity within engineered systems speaks to the importance of microbial diversity in all aspects of life, from 'from provisioning the food on our tables to the energy required for food preparation.

In anaerobic digestion systems, the output from the system is biogas (gas fraction) and digestate (semi-solid fraction). Following proper handling, digestate can be returned to the land as it can enrich the soil with both nutrients and beneficial microorganisms for crop growth. This "soil-to-energy-to-soil" cycle underpins the circular and sustainable conversion of organic waste by microbial biodiversity to various products. It demonstrates how microbial ecosystems can transform waste organic matter into energy and improved crop production.

At the Agricultural Research Council (ARC), this principle is brought to life through a project titled **"Water wise waste management: Two ends of the size scale, macro and nano augmentation for dry anaerobic digestion optimisation (W3M-Dry AD)"** which is being conducted in partnership with Mozambique and Japan. Inspiration was drawn from natural soil ecosystems where microbial diversity impacts crop production and soil structure. Through this project we anticipate creating solutions for improving microbial cooperation to optimize renewable energy generation while producing nutrient-rich digestate that restores soil health (Figure 1). By mimicking nature's loops, the W3M-Dry AD project displays how protecting and learning from nature's tiniest engineers can drive innovation for cleaner energy, climate resilience and sustainable agriculture.

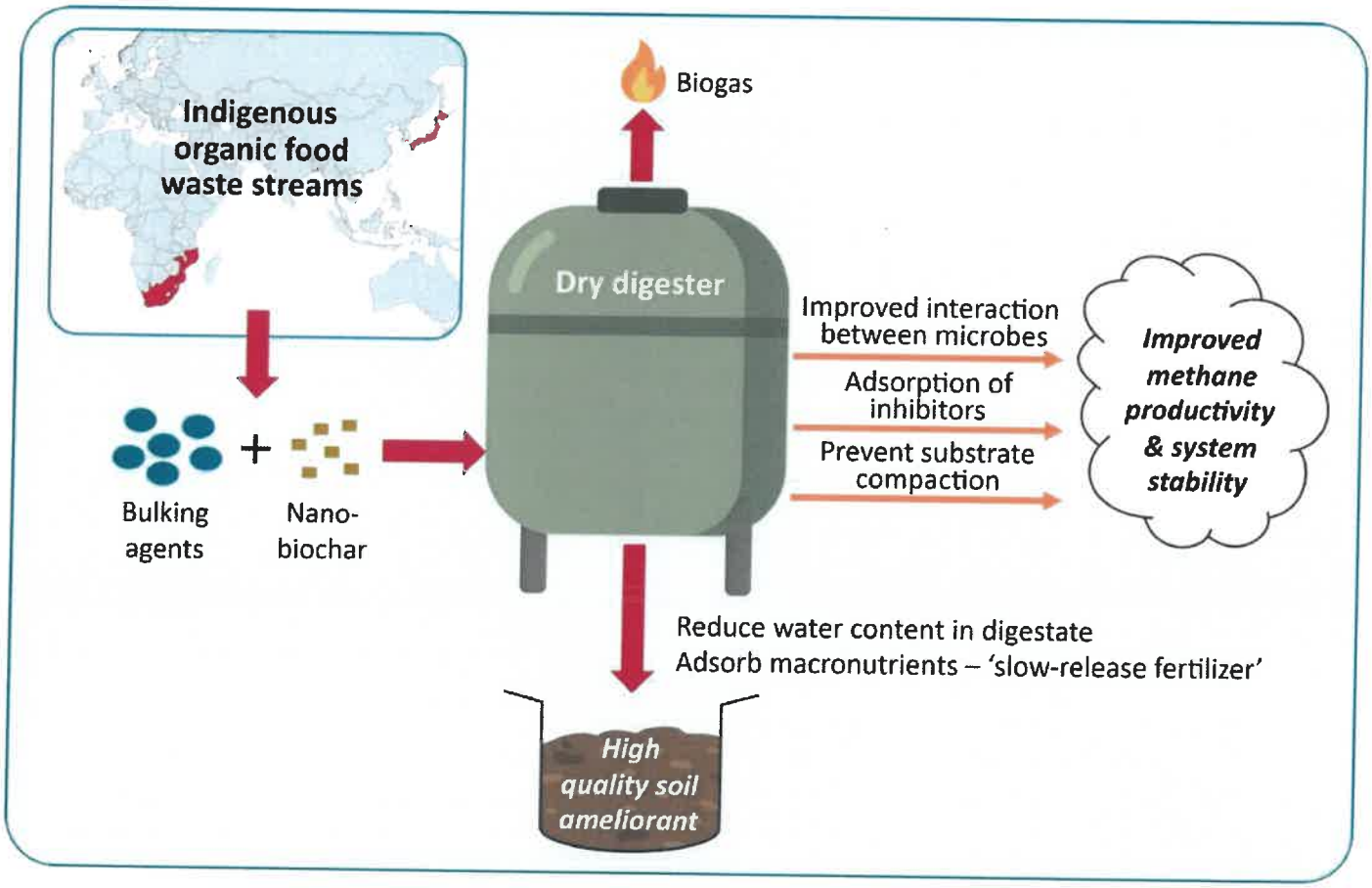

Figure 1: Overview of the W3M-Dry AD project showing the integration of indigenous organic food waste streams with bulking agents and nano-biochar to enhance microbial interaction, stabilize the dry anaerobic digestion process, and generate high quality soil ameliorants.

Microbes, farmers, and the future of innovation

Globally, farmers are benefitting from microbes through several innovations such as composting, organic farming and renewable energy initiatives – just like those that form the basis of the W3M-Dry AD project. By forming a bridge between waste management, renewable energy and soil health, this project aims to show how innovation can work hand in hand with nature, not against it.

On 24 September, each year South Africa celebrates Heritage Day, a time to honour and celebrate our diverse traditions, rich cultures and beautiful landscapes that shape who we are. Beyond food, art and music, our heritage also lies in the living biodiversity that nourishes and sustains us. The soils under our feet, teeming with microbial life, are part of that heritage. We have inherited a beautiful ecosystem that is constantly evolving with our farming and energy practices. It is our responsibility to protect this biological legacy, which means that we need to value and nurture all lifeforms that inhabit our environment, including those that are invisible to the naked eye. In projects like W3M-Dry AD, this spirit of heritage extends to conserving the natural microbial wealth that supports clean energy, fertile soils and climate resilience for future generations.

The SA W3M-Dry AD project team is funded by the National Research Foundation (NRF) with team members affiliated to the Agricultural Research Council (ARC), University of South Africa (UNISA) and University of Venda (UNIVEN).

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