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Soil microbiome analysis

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Introduction

Soil is one of the most essential natural resources for humans, providing the foundation for agriculture and sustaining ecosystems. Microorganisms play a vital role in the health and productivity of soil, making them crucial to the well-being of the planet [1, 2]. Microorganisms are tiny organisms, including bacteria, fungi, protozoa, and viruses, that are present in soil in large numbers. They play various essential roles in the soil ecosystem, including breaking down organic matter, cycling nutrients, and maintaining soil structure. One of the most critical functions of microorganisms in soil is their ability to break down organic matter, such as dead plant and animal material. This process, known as decomposition, releases nutrients such as phosphorus, nitrogen, and sulfur, which are essential for plant growth. Without microorganisms, organic matter would accumulate and remain locked in a complex form, making it inaccessible to plants. Microorganisms are also involved in nutrient cycling, the process by which nutrients are transformed and transferred through the soil ecosystem [3]. They play a key role in converting nitrogen from the atmosphere into a form that plants can use, known as nitrogen fixation. Other microorganisms break down nutrients like phosphorus and sulfur, making them available to plants.

In addition to these functions, microorganisms are crucial to maintaining soil structure. They create pore spaces in the soil, allowing for water and air to flow through, which is necessary for plant roots to access nutrients and oxygen. Microorganisms also produce compounds that bind soil particles together, improving soil stability and preventing erosion. Despite their critical importance, microorganisms in soil face various threats, including pollution, intensive agriculture practices, and climate change. These threats can negatively impact their populations, leading to reduced soil fertility and ecosystem health.

Importance of soil microbiome (SM) profiling

SM profiling is the process of identifying and characterizing the microbial community in soil. This technique has become increasingly important in recent years, as scientists recognize the critical role that microorganisms play in soil health and productivity. The SM is a complex community of microorganisms, including bacteria, fungi, protozoa, and viruses [4]. These microorganisms play a crucial role in soil processes such as nutrient cycling, organic matter decomposition, and plant-microbe interactions. Profiling the SM allows scientists to understand the function and composition of this community, providing valuable insights into productivity and soil health. One of the main reasons why profiling SM is essential is that it allows for the identification of beneficial microorganisms [5]. Beneficial microorganisms are those that promote plant growth and health, protect against pathogens and pests, and improve soil structure. By identifying and characterizing these microorganisms, scientists can develop strategies to promote their growth and activity, leading to improved soil health and productivity.

Profiling the SM can also help identify harmful microorganisms, such as plant pathogens or antibiotic-resistant bacteria. Understanding the composition of the SM can help farmers and land managers develop strategies to prevent the spread of these harmful microorganisms, reducing the need for chemical interventions. In addition to identifying beneficial and harmful microorganisms, profiling the SM can also provide valuable information about soil health and productivity. For example, changes in the SM composition can indicate soil degradation or pollution. Understanding the factors that influence the SM can also help land managers develop strategies to improve soil health and productivity, such as reducing tillage, adding organic matter, or adjusting fertilizer application [6].

Steps involved in SM analysis

SM analysis is the process of studying the composition and function of the microbial community in soil. This technique has become increasingly popular in recent years, as scientists recognize the critical role that microorganisms play in soil health and productivity. Here is a step-by-step guide on how we work with microbiome analysis (Please Referee Figure 1) [7].

Sample collection

The first step in SM analysis is collecting soil samples. Samples should be collected from different locations within the area of interest to ensure that the microbial community is representative. It's important to avoid contamination during the collection process.

DNA extraction

Once the soil samples are collected, DNA is extracted from the microorganisms present in the soil. This is typically done using a commercial kit that breaks down the soil and isolates the DNA.

Sequencing

After DNA extraction, the microbial community's DNA is sequenced using techniques such as polymerase chain reaction (PCR) and high-throughput sequencing. This generates large amounts of data that can be analyzed to identify the microbial community's composition and function.

Bioinformatics analysis

The next step is to analyze the sequencing data using bioinformatics tools. This involves comparing the DNA sequences to known microbial genomes and identifying the microorganisms present in the soil. The data is then analyzed to determine the microbial community's composition and function [8].

Data interpretation

The final step is interpreting the data to gain insights into the SM's composition and function. This can help identify beneficial and harmful microorganisms, understand soil health and productivity, and develop strategies to promote soil health and productivity while reducing the need for chemical interventions.

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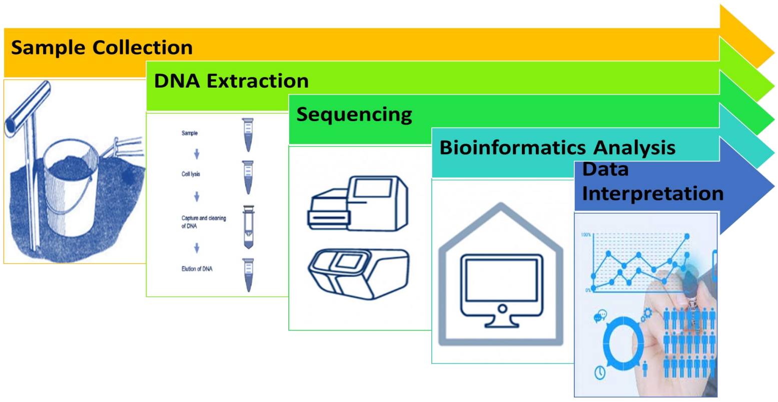

Figure 1 Steps involved in soil microbiome (SM) analysis

SM analysis and microbiome insight play an active role in farming

SM analysis and microbiome insight have become increasingly important in modern farming practices. By analyzing the microbial community present in soil, farmers and land managers can gain valuable insights into soil health and productivity, enabling them to make informed decisions about their farming practices. Here are some examples of how SM analysis and microbiome knowledge are utilized in agriculture:

Identifying beneficial microorganisms

One of the main benefits of SM analysis is the ability to identify beneficial microorganisms that promote plant health and growth. By understanding the microbial community present in the soil, farmers can develop strategies to promote the growth and activity of these microorganisms, leading to improved soil health and productivity [9].

Reducing chemical inputs

SM analysis can help reduce the need for chemical inputs such as fertilizers, herbicides, and pesticides. By promoting the growth of beneficial microorganisms and understanding the factors that influence the SM, farmers can reduce their reliance on chemical interventions, leading to cost savings and reduced environmental impact [10].

Improving soil health

SM analysis can provide valuable insights into soil health, enabling farmers to develop strategies to improve soil structure, nutrient cycling, and organic matter content. By promoting soil health, farmers can improve crop yields, reduce erosion, and minimize nutrient loss [11].

Disease management

SM analysis can help identify harmful microorganisms that cause plant diseases. By understanding the composition of the SM, farmers can develop strategies to prevent the spread of these harmful microorganisms, reducing the need for chemical interventions and improving crop yield [12].

Precision farming

Microbiome insight can be used in conjunction with precision farming techniques to optimize crop yield and minimize environmental impact. By understanding the microbial community present in the soil, farmers can tailor their farming practices to specific soil types, leading to improved crop yields and reduced environmental impact [13].

Our vision on future SM studies

SM studies have become increasingly important in recent years, as researchers and farmers recognize the critical role that microorganisms play in soil health and productivity. Here are some potential future developments in SM studies:

Integration of omics technologies

Omics technologies such as genomics, transcriptomics, and proteomics are becoming more accessible and affordable, enabling researchers to study the microbial community in greater detail [14]. Integrating these omics technologies with SM studies could provide a more comprehensive understanding of the microbial community's composition and function, leading to new insights into soil health and productivity.

Standardization of methods

Standardizing SM analysis methods could help improve the reproducibility and comparability of results across different studies. This would enable researchers to build on each other's work more easily and develop a more complete understanding of the microbial community in soil.

Increased collaboration

Collaboration between researchers, farmers, and other stakeholders could lead to more targeted and practical SM studies. By working together, researchers and farmers can identify the most pressing soil health and productivity issues and develop solutions that are tailored to specific regions and soil types.

Application of artificial intelligence and machine learning

Artificial intelligence and machine learning have the potential to analyze large amounts of SM data quickly and accurately, enabling researchers to identify patterns and make predictions about soil health and productivity [15]. These technologies could also be used to develop models that predict the impact of different farming practices on the SM, leading to more informed decision-making.

Development of microbial-based products

SM studies could lead to the development of microbial-based products such as biofertilizers and biopesticides. These products could promote soil health and productivity while reducing the need for chemical inputs, leading to more sustainable farming practices [16].

The future of SM studies is promising, with potential developments such as the integration of omics technologies, standardization of methods, increased collaboration, application of artificial intelligence and machine learning, and the development of microbial-based products. These developments could lead to a more comprehensive understanding of the microbial community in soil, promoting soil health and productivity while reducing environmental impact.

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Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Rohit Patil, Ashwini Biradar and Dinesh Nalage. The first draft of the manuscript was written by Rohit Patil and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare no conflicts of interest.

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Abbreviations

SM, soil microbiome; PCR, polymerase chain reaction.

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