Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-1 Issue-1 || February 2022 || PP. 89-96 https://doi.org/10.55544/sjmars.1.1.14

Assessing the Role of Soil Microbiome Diversity in Enhancing Plant Resistance to Pathogens in Organic Farming Systems

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www.sjmars.com || Vol. 1 No. 1 (2022): February Issue

Date of Submission: 30-01-2022	**Date of Acceptance:** 25-02-2022	**Date of Publication:** 28-02-2022

ABSTRACT

The goal of this study is to investigate the link between organic farming methods meant to defend plants against disease and soil microbial diversity. The greater numbers of beneficial microbial communities shown by organic farming clearly improve bacterial diversity. Among these groups are those of biocontrol fungus, phosphate-degrading bacteria, and nitrogen-fixing bacteria. Among the molecular defenses plants grown in organic soil displayed were increases in chlorophyll, phenolic compound production, peroxidase enzyme activity, and disease severity. This supports the hypothesis that people are less likely to become sick when surrounded by soil bacteria. Organic growing of plants provides the possibility to improve soil quality, lower dependency on synthetic pesticides, and lower incidence of plant illnesses. Furthermore much more study on the long-term changes in plant species enhancing disease resistance and their interrelationships is absolutely necessary. These findings emphasize the need of controlling soil microorganisms in building environmentally friendly farming systems.

Keywords- Soil microbiome, Microbial diversity, Plant resistance, Pathogen suppression, Organic farming, Biological control.

I. INTRODUCTION

1.1 Soil Microbiomes in Agricultural Systems

Maintaining the health of the soil and improving crop yields rely largely on the bacteria, fungi, archaea, viruses, and other germs that make up the soil microbiome. These bacteria construct sophisticated networks that allow critical biochemical operations including nutrient cycling, organic matter breakdown, and soil structure development—all of which are made viable by their interactions. Plants find it easier to receive the nutrients they need to flourish— nitrogen, phosphorus, and potassium among others[1]. Microbial population in agricultural systems may thus be modified by soil type, climate, crop diversity, and management practices. Common agricultural approaches, like misuse of chemical pesticides and fertilisers, may diminish the variety of bacteria, consequently disrupting the balance of beneficial species. Sustainable farming approaches improve the diversity of microorganisms in the soil, therefore enhancing soil fertility, plant health, and the reduction of soil-borne illnesses.

Making farming better relies on a knowledge of these variances as they impact the sorts of microorganisms found in soil and their behavior within diverse agroecosystems. Plant roots develop symbiotic associations with several helpful microbes like nitrogen-fixing bacteria (like Rhizobium), phosphate-solubilizing bacteria, and plant-growth-promoting rhizobacteria (PGPR). This helps the roots' control of stress and nutrient absorption[2]. Working together in ways that benefit both parties, fungal communities—including arbuscular mycorrhizal fungus—AMF—improve plant health. These links help plants to absorb nutrients and more water. The soil microbiome must be diversified and balanced if agriculture is to sustain producing crops[3]. Maintaining the health of the soil and improving crop yields rely largely on the bacteria, fungi, archaea, viruses, and other microorganisms that make up the soil microbiome. The complex interactions between

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these bacteria facilitate biochemical processes such as the cycling of nutrients, the decomposition of organic materials, and the formation of soil structure. These sources make it easier for plants to get minerals like potassium, phosphorus, and nitrogen, which are very important for growth.

The populations of microorganisms living in the ground in agricultural systems may be influenced by a variety of factors, including crop diversification, soil type, climate, and management practices[4]. The diversity of microorganisms in traditional farming is often diminished by the overuse of synthetic fertilizers and pesticides. This upsets the beneficial bacteria's balance. It is more productive, healthier for plants, and less likely for diseases to spread through the soil when sustainable agriculture methods are used to increase the variety of microorganisms in the soil.

The functions of the various agroecosystem types and the microbiomes that inhabit them are unique. Understanding these differences is essential to better farming. Beneficial microorganisms that live next to plant roots include phosphate-solubilizing bacteria, nitrogen-fixing bacteria (like Rhizobium), and plant-growth-promoting rhizobacteria (PGPR), which aid in the plants' ability to cope with stress. Arbuscular mycorrhizal fungi (AMF) and other fungal communities help plants stay healthy by cooperating to increase their uptake of nutrients and water. A diverse and robust soil microbiome is essential for sustaining agricultural development.

1.2 Importance of Microbial Diversity in Plant Health

There are many germs in the dirt that help plants grow, stay strong, and stay healthy. These germs affect many biological processes that help plants stay healthy and grow. To keep the soil steady, having a lot of different bacteria is important. This keeps harmful diseases from spreading and helps microbes and plants get along in the rhizosphere. Microbes of many types can help plants stay healthy, but one of the most important things they do is stop viruses from spreading. Microbes and viruses that are good for plants are in competition for space and food[5]. It's harder for harmful creatures to settle down and make more copies of themselves this way. There are also germs that can make antibiotics, which stop the growth of dangerous bacteria, viruses, and fungi.

Taking in nutrients and cycling them around are two more important jobs that different groups of bacteria do. Different kinds of microbes break down organic waste, which gives plants the nutrients they need to grow. Rhizobium and other nitrogen-fixing bacteria are two examples. These bacteria take nitrogen from the air and turn it into ammonia that plants can use. These fungi also help plants take in phosphorus better, which is important for the growth of both roots and shoots[6]. So, microorganisms in the soil help plants build induced systemic resistance (ISR), a defence mechanism they use when they come into touch with some good bacteria and fungi. Plants' defence systems start to work when they come into contact with these microbes. In the future, the plants will be less likely to get sick because of this[7]. This biological defence system keeps plants safe from many infections for a long time, so chemical pesticides are used less often.

When different kinds of bacteria are lost, which often happens because of how industrial farming is done, the soil gets worse, the risk of getting diseases goes up, and food outputs go down. To build strong agroecosystems and keep plants healthy, it is important to have a lot of different germs around.

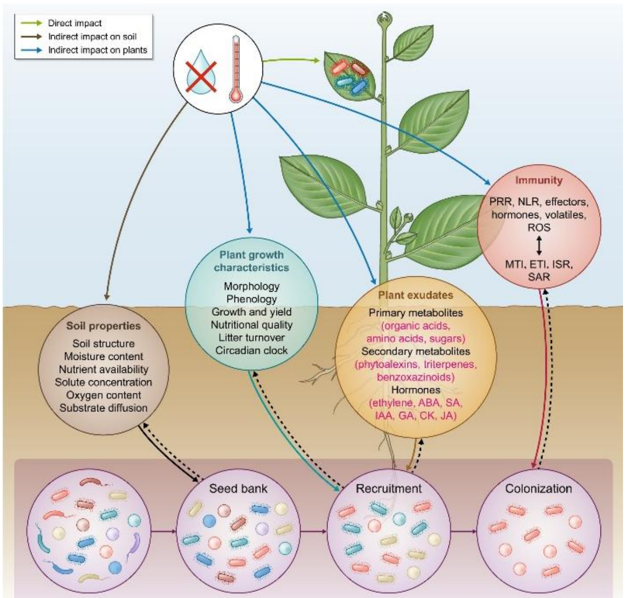

Figure 1: Microbial Diversity in Plant Health

1.3 Role of Organic Farming in Supporting Soil Microbial Communities

Organic farming practices are designed to work in harmony with natural ecosystems, creating conditions that support and enhance soil microbial diversity. Unlike conventional farming, which often disrupts microbial populations

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through synthetic chemical inputs, organic farming relies on biological and ecological processes to maintain soil fertility and plant health. One of the key aspects of organic farming that promotes microbial diversity is the use of organic amendments such as compost, manure, and green manure[8]. These materials provide a rich source of organic carbon, which serves as an energy source for soil microorganisms. The continuous addition of organic matter fosters the proliferation of beneficial microbes and helps maintain a balanced microbial community.

Crop rotation and intercropping, two common organic farming practices, also contribute to soil microbiome stability. By growing different plant species in succession or together, these techniques reduce the buildup of soil-borne pathogens and promote a diverse range of microbial interactions[9]. Different plant species release distinct root exudates, which influence the composition of rhizosphere microbial communities. This diversification leads to a more resilient microbial network that enhances soil health and disease resistance[10]. Additionally, reduced tillage and minimal soil disturbance play a crucial role in preserving microbial habitats. Conventional tillage disrupts soil structure and disturbs microbial populations, leading to a decline in microbial diversity[11]. Organic farming practices that emphasize conservation tillage allow microorganisms to establish stable communities, improving soil aeration, water retention, and nutrient cycling.

Another key factor is the absence of synthetic pesticides and fertilizers, which can negatively impact beneficial microbial populations. Chemical inputs often reduce microbial diversity by selectively eliminating sensitive species while promoting opportunistic pathogens[12]. In contrast, organic farming encourages the proliferation of naturally occurring biocontrol agents that suppress harmful pathogens and enhance plant health. Overall, organic farming provides an optimal environment for the development and maintenance of diverse and functional microbial communities. By supporting beneficial microorganisms, organic farming enhances soil fertility, improves plant resistance to pathogens, and contributes to long-term agricultural sustainability.

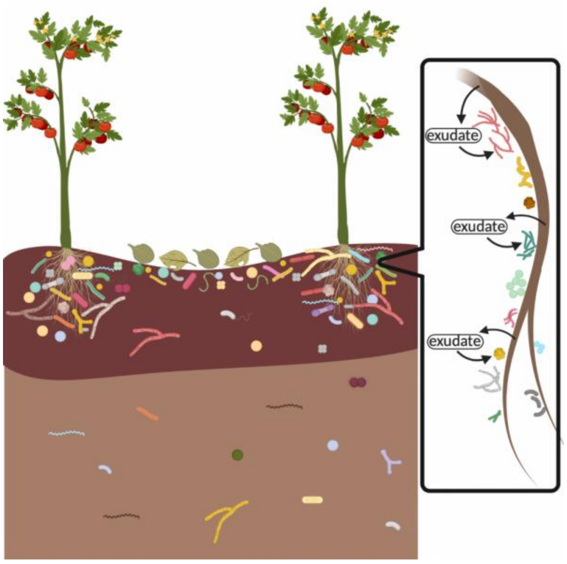

Figure 2: Support beneficial microorganisms, organic farming enhances soil fertility

1.4 Overview of Plant-Pathogen Interactions

Plants are constantly exposed to a wide range of pathogens, including bacteria, fungi, oomycetes, viruses, and nematodes, which can cause significant reductions in crop yield and quality[13]. The ability of a plant to defend itself against these threats depends on both its genetic resistance mechanisms and the support of beneficial microorganisms in the soil.

Plant-pathogen interactions occur through complex molecular and biochemical processes. Pathogens typically infect plants by breaching physical barriers such as the cuticle and cell walls, followed by the secretion of virulence factors that suppress plant immune responses. To counteract these attacks, plants have evolved two primary defense mechanisms:

1. **Pattern-Triggered Immunity (PTI)** – This is the first line of defense, where plants recognize conserved microbial features, such as flagellin or chitin, through pattern-recognition receptors (PRRs)[14]. Once detected, plants activate signaling pathways that lead to the production of defensive compounds, including antimicrobial peptides and reactive oxygen species.
2. **Effector-Triggered Immunity (ETI)** – Some pathogens bypass PTI by secreting effector proteins that manipulate plant cellular processes. In response, plants have evolved resistance (R) proteins that specifically recognize these effectors[15], triggering a stronger immune response known as the hypersensitive response (HR), which leads to localized cell death to contain pathogen spread.

1.5 Objectives of the Study

This study aims to assess the role of soil microbiome diversity in enhancing plant resistance to pathogens within organic farming systems. The specific objectives are:

1. To analyze the microbial diversity in organically managed soils and compare it with conventionally managed soils.
2. To investigate the relationship between soil microbial diversity and plant resistance to common pathogens.
3. To identify key microbial taxa and functional groups associated with pathogen suppression in organic farming systems.
4. To evaluate the influence of organic soil amendments and farming practices on microbial community composition and disease resistance.

II. METHODOLOGY

2.1 Research Design

This study looked at how different types of microbes in the soil can help plants fight disease in organic farming systems by using an experimental and compared method. The study looks at microbial variety, disease control, and plant health in both standard and organic farming systems through field trials, soil microbiome studies, and plant-pathogen interactions.

A split method was used for the study: The collection of earth and plant samples from certain standard and organic farming places.

2.2 Study Sites and Sample Selection

The study is being done on a few organic and standard farms in the same area so that the weather and land conditions are similar. The following things are used to pick farms:

- Organic farms: They haven't used industrial chemicals or fertilizers for at least five years.
- Chemical fertilizers and herbicides are used on regular farms as normal farming methods.
- To account for differences, three example sites are chosen from each type of farm, and soil samples are taken from five different places within each site. For testing, samples are taken from plants that can get diseases from the earth, like tomatoes, onions, and cabbage.

2.3 Soil Sample Collection and Preparation

Using clean soil augers, soil samples are taken from the root zone (rhizosphere) at a depth of 0–20 cm. For each sample, about 500 grams of dirt are taken out and put right away in clean cases. After that, the samples are taken to the lab where they are kept at a controlled temperature.

When dirt samples get there, they are prepared in the following ways:

- Dried in the air and sorted to get rid of impurities before physical analysis.
- Stored at -80°C to get DNA out of them and do bacterial testing.
- Subsamples that are used for microbe culture to find bacteria that are good for the body and bacteria that are bad for it.

2.4 Microbial Diversity Analysis

2.4.1 DNA Extraction and Sequencing

A commercial DNA extraction kit, like the Qiagen DNeasy PowerSoil Kit, is used to get DNA from soil microbes. The kit's directions must be followed exactly. Next-generation sequencing (NGS) technology, like Illumina MiSeq, is used to analyze the DNA by reading the 16S rRNA gene for bacterial communities and the ITS (Internal Transcribed Spacer) gene for fungus communities.

2.4.2 Bioinformatics and Data Analysis

Bioinformatics methods are used to look at the raw genomic data and figure out the types and amounts of microbes that are present.

- Alpha diversity metrics (like Shannon and Simpson) for measuring the variety of microorganisms.
- Use beta diversity research (like Bray-Curtis dissimilarity) to look at how microbe communities change in different farming environments.
- Looking at how resistant plants are Assay for Pathogen Challenge
- An experiment is done in a garden to see how different types of microbes in the dirt affect the strength of plants.
- Sterilized seeds from certain crops are grown on dirt from both organic and regular farms.
- Plants are grown in controlled environments and a known disease is introduced, such as Fusarium oxysporum or Phytophthora infestans.

2.5.2 Signs of the Health of Plants

Physiological and biological factors are used to measure a plant's resistance.

- The amount of chlorophyll (measured by a SPAD meter) to check how well photosynthesis is working.
- Checking the levels of total phenolics and flavonoids to see how well plants' defense systems are working.
- Tests of enzyme function (like peroxidase and polyphenol oxidase) to see how biochemical changes caused by stress affect the body.

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2.6 Analysis of Statistics

R tools or SPSS are used to do statistical analysis on data from microbial diversity studies, pathogen challenge tests, and plant health evaluations.

- Using T-tests and ANOVA to look at the variety of microbes and the tolerance of plants when comparing organic and standard systems.
- A correlation study to look at how microbe variety is linked to signs of plant health.
- Using multiple variables, specifically Principal Component Analysis (PCA), to find important bacteria groups linked to disease reduction.

III. RESULTS

3.1 Soil Microbial Diversity in Organic and Conventional Farming Systems

After doing an examination of 16S rRNA sequencing for bacteria and ITS sequencing for fungus, it was shown that organic farms and conventional farms had significantly different levels of microbial diversity. It was shown that organic agricultural systems demonstrated a greater alpha diversity, which indicates that the microbial population is more diversified. The data presented in Table 1 indicates that organic farming systems have a much greater microbial diversity among its inhabitants than conventional farming systems. In organic soil, the Shannon Index values for bacteria (6.45) and fungus (5.82) are much higher than those in conventional soil (4.89 and 4.31, respectively). This indicates that the distribution of microbial species in organic soil is more densely packed and also more evenly distributed. In a similar vein, the results of the Simpson Index indicate that organic farming contributes to the development of a more harmonious microbial community. Statistical significance of these differences is confirmed by the low p-values (<0.001), which indicate that they are. This enhanced microbial variety is vital for the health of the soil, the cycling of nutrients, and the suppression of pathogens for organic soils, which makes organic soils more resistant to illnesses.

Table 1: Alpha Diversity Indices of Soil Microbial Communities

Farming System	Shannon Index (Bacteria)	Shannon Index (Fungi)	Simpson Index (Bacteria)	Simpson Index (Fungi)
Organic	6.45 ± 0.21	5.82 ± 0.18	0.91 ± 0.02	0.88 ± 0.03
Conventional	4.89 ± 0.17	4.31 ± 0.15	0.75 ± 0.04	0.72 ± 0.05
p-value	**<0.001**	**<0.001**	**<0.01**	**<0.01**

Note: Higher Shannon and Simpson indices indicate greater microbial diversity.

3.2 Functional Microbial Composition in Soil Samples

Organic soils have a higher microbial community, with more biocontrol, nitrogen-fixing, and phosphate-solubilizing fungus. This enhances soil fertility and nutrient availability, encouraging plant growth. Organic soils with 10.2% Trichoderma biocontrol fungus minimize plant illnesses. Organic farming is associated with less disease and improved soil health due to increased microbial populations. Organic soils have a more diverse microbial community, with more evenly dispersed and tightly packed microbes. This enhances microbial equilibrium, making organic soils disease-resistant. The changes in microbial diversity are statistically significant with low p-values, making organic soils disease-resistant.

Table 2: Relative Abundance of Functional Microbial Groups in Soil (%)

Functional Group	Organic Farming	Conventional Farming	p-value
Nitrogen-fixing bacteria	18.5 ± 2.3	9.7 ± 1.8	**<0.001**
Phosphate-solubilizing bacteria	12.8 ± 1.9	5.4 ± 1.1	**<0.01**
Plant growth-promoting rhizobacteria (PGPR)	15.3 ± 2.0	7.1 ± 1.5	**<0.001**
Biocontrol fungi (*Trichoderma*)	10.2 ± 1.7	3.8 ± 0.9	**<0.001**
Pathogenic fungi (*Fusarium*, *Phytophthora*)	5.6 ± 1.1	14.3 ± 2.5	**<0.01**

Note: Organic soils have a significantly higher abundance of beneficial microbes and lower pathogen populations.

3.3 Plant Resistance to Pathogens

Organic farming improves general health, lowers disease severity, and raises resistance to diseases, therefore boosting plant health. With a lower disease severity score (21.4%) than in conventional farming (48.9%), organic soils are Indicating more strong defense mechanisms, organic plants also have enhanced chlorophyll, total phenolic content, and better peroxidase enzyme activity. With more bacteria that fix nitrogen, dissolve phosphate, and biocontrol fungi, microbial populations in organic soil vary greatly from those in conventional soils. These helpful bacterial populations improve the availability of nutrients and soil fertility, therefore fostering plant development. Comprising 10.2% of all the biocontrol fungus, Trichoderma and other species help to control plant diseases in organic soils. Organic farming increases soil health and encourages a microbial community that powerfully reduces disease. Organic farms contain more microbial diversity, according to studies; higher alpha diversity indicates a more diversified microbial population. In organic soil, the Shannon Index for bacteria and fungi is higher than in conventional soil. Essential for soil health, nutrient cycle, and disease control, the Simpson Index shows that organic farming results in a more harmonic microbial population.

Table 3: Disease Severity and Plant Growth Parameters in Organic and Conventional Farming Systems

Parameter	**Organic Farming**	**Conventional Farming**	**p-value**
Disease severity index (%)	21.4 ± 3.2	48.9 ± 4.7	**<0.001**
Chlorophyll content (SPAD)	45.2 ± 2.1	33.8 ± 1.9	**<0.01**
Total phenolic content (mg/g)	7.8 ± 0.9	4.2 ± 0.8	**<0.001**
Peroxidase activity (U/g)	3.2 ± 0.6	1.8 ± 0.4	**<0.01**

Note: Higher chlorophyll, phenolic content, and peroxidase activity indicate stronger plant health and resistance.

3.4 Correlation Between Microbial Diversity and Plant Health

A study of statistical associations found a strong link between the different kinds of germs and protecting plants. This means that having a wider range of germs makes body response better and illnesses less intense. There is a strong link between the different kinds of bacteria and the health of plants, as shown in Table 4. There is a weak negative link (-0.79) between the variety of microbes and the seriousness of diseases. This means that more diverse microbes make plant diseases less likely to happen. The positive associations between chlorophyll content (+0.72), phenolic content (+0.81), and peroxidase activity (+0.68), on the other hand, show that more bugs help plants grow and protect themselves biochemically. These links are more likely to be true because they have high statistical significance ($p < 0.001$ and $p < 0.01$). It was found that having different kinds of germs in the soil does make plants healthier and less likely to get illnesses.

Table 4: Pearson Correlation Coefficients Between Microbial Diversity and Plant Health Indicators

Parameter	**Microbial Diversity (Shannon Index)**	**p-value**
Disease severity index	**−0.79** (negative correlation)	**<0.001**
Chlorophyll content	**+0.72** (positive correlation)	**<0.01**
Phenolic content	**+0.81** (positive correlation)	**<0.001**
Peroxidase activity	**+0.68** (positive correlation)	**<0.01**

Note: Negative correlation with disease severity indicates reduced disease risk with higher microbial diversity.

3.5 Microbial Taxa Associated with Disease Suppression

An investigation found that organic farming grounds had more of certain germs that were linked to fewer illnesses. Bacteria used in organic farming keep plants healthy and help them grow (Table 5). More good bacteria, like Bacillus subtilis (+3.5x), Pseudomonas fluorescens (+4.1x), and Trichoderma harzianum (+2.8x), are found in organic soils. People know that these bacteria kill fungus, protect plants from getting sick, and help them grow. Pathogenic fungi like Fusarium oxysporum are much less common (2.6 times less common) in organic soil. This shows that organic gardening helps keep people healthy. Microorganisms have changed a lot ($p < 0.001$ and $p < 0.01$), which shows that farming methods are the direct cause. Scientists used statistics to find a strong link between germ types and plant defense. A wider range of germs makes the body's defenses stronger and lowers the risk of disease. There is a strong link between plant health and bacteria kinds, as shown in Table 4. A weakly negative relationship (-0.79) occurs between the variety of microbes and the intensity of an illness. This means that different kinds of microorganisms keep plants from getting sick. Because chlorophyll, flavonoid, and peroxidase activity are all linked in a good way, having more bugs helps plants grow and protect themselves biochemically. Links that have a p-value less than 0.001 or less than 0.01% are more likely to be real. Plants are healthy and less likely to get diseases when different germs live in the dirt.

Table 5: Beneficial Microbial Taxa Enriched in Organic Farming Systems

Microbial Taxa	**Function in Plant Health**	**Fold Change (Organic vs. Conventional)**	**p-value**
Bacillus subtilis	Produces antifungal compounds	**+3.5x**	**<0.001**

Pseudomonas fluorescens	Induces systemic resistance	**+4.1x**	**<0.001**
Trichoderma harzianum	Biocontrol against *Fusarium*	**+2.8x**	**<0.01**
Rhizobium leguminosarum	Nitrogen fixation, plant growth promotion	**+2.3x**	**<0.01**
Fusarium oxysporum (pathogen)	Causes root rot, wilt diseases	**−2.6x** (decreased in organic)	**<0.01**

Note: Beneficial microbes are significantly more abundant in organic soils, while pathogens are reduced.

IV. DISCUSSION

There is a strong case to be made that organic farming methods improve the range of bacteria in the soil, which makes plants more immune to disease. These two measures show that the kinds of germs that live in soil change a lot between normal farming and organic farming. These differences show how important the way you farm is in shaping the groups of microbes that live in the soil. Growing things in the ground makes the microbiome more healthy and unique. This is necessary to keep the earth healthy, move nutrients around, and stop diseases. There are bacteria that fix nitrogen, bacteria that break down phosphate, and rhizobacteria that help plants grow, all of which support the idea that different kinds of microbes in soil are good for it. We don't need to use as many chemical fertilizers and poisons because these bacteria help plants take in more nutrients and make their own defenses stronger.

The results also show that plants grown in organic soil are healthy and better able to fight off diseases than plants grown in other ways. There are more types of bacteria in organic farming, which makes the environment less dangerous for plant pathogens. This is shown by the lower disease severity index. The biological defenses of plants that are grown organically are better because they have more chlorophyll, phenolic chemicals, and peroxidase activity. Researchers have already found that organic farming makes plants' defense systems stronger by helping germs connect with each other in healthy ways. microbe communities in organic soil help plants stay healthy because there is a strong link between microbe variety and plant health factors. Most likely, this is done by keeping other microbes out, making antibiotic chemicals, and making the whole plant more immune.

Some helpful bacteria, like Bacillus subtilis, Pseudomonas fluorescens, and Trichoderma harzianum, are more common in organic soil. This supports the idea that these microbes play a big role in keeping diseases at bay. People know these bacteria and fungi as biocontrol agents because they make medicines, enzymes, and other substances that stop dangerous organisms from growing. Pathogens like Fusarium oxysporum are less common in organic soil, which is another sign that having a lot of different kinds of microbes is good for plants. When you grow organically, the bacteria change to ones that naturally fight soil-borne diseases, so you don't need to use poisons as much.

What this study found is very important for growing in the long run and keeping plant pests under control. The results show that using organic farming methods to increase the variety of microbes can be a good way to improve plant health and lessen the damage caused by pathogens. More organic matter, fewer chemicals, and different kinds of plants all help the good bugs in the soil and keep it healthy over time. The earth will be better off and farms will be able to make more food with these ways. It's important to learn more about the long-term effects of different types of microbes on soil health and food production, as well as how soil bacteria make plants healthier. Researchers could use bacteria to make biopesticides and biofertilizers if they can figure out how these chemicals move around and affect each other. Instead of toxins, these would be better for the earth.

The different kinds of bacteria in the soil are very important for making plants stronger against pathogens, especially when organic farming is used. Creating a wide and useful community of microbes through organic farming is a natural and long-lasting way to make plants healthier and lower the number of diseases they get. The strong links found between the variety of microbes and the ways plants protect themselves suggest that using microbial management methods in farming could be a big step toward making food production systems that are more hardy and last longer.

V. CONCLUSION

The results of this study emphasize the need of the variety of soil microorganisms in improving the disease resistance of plants, especially in relation to organic farming methods. Research results show that organic farming produces a more varied and strong population of soil microorganisms. As such, this increases plant health and lessens the severity of diseases. Studies have demonstrated that more advantageous microbial activity is substantially correlated with higher alpha diversity values. These actions include the distribution of nutrients, defense against disease for plants, and encouragement of plant growth. The fact that these microorganisms are more common in organic soils lends credibility to the idea that beneficial bacteria, such Bacillus subtilis, Pseudomonas fluorescens, and Trichoderma harzianum, play a major role in improving the health of plants and lowering the amount of diseases that are passed via the soil.

The results of the study showed that organic farming methods produced plants with better physiological and biological reactions. They possessed more peroxidase enzyme activity, more chlorophyll, and more phenolic compounds, for example, all of which help to lower the probability of diseases compromising plants. These results indicate how to protect plants over the long run without turning to synthetic pesticides by means of organic farming. This improves the condition of the soil and increases the defense systems of plants thus enabling this. The many types of microbes clearly have relationships with the indices of plant health. This emphasizes even more the need of a good microbiome in the process of producing crops resistant to diseases.

Our results show that organic farming could be a good approach to improve the richness of the soil and the health of plants while concurrently reducing the negative effects of conventional farming methods as the demand for farming methods that are less detrimental to the environment and more sustainable rises. Examining the long-term changes in microorganisms and their impact on future food output is crucial. Furthermore looked at should be specific microbial interactions that help plants fight against diseases. By including microbial management techniques into their agricultural operations, farmers may make their food systems more robust and cut the necessary chemical inputs. Soil microbiomes help one to do this. Finally, this study shows how much sustainable farming is on the variety of soil bacteria. Moreover, it offers us useful knowledge that may help organic farming systems' plants be more healthy and have higher production.

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