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"Taxonomic and Functional Profiling of PGPR from Organic Agroecosystems".

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Abstract:

PGPR refers to the beneficial microorganisms, also known as plant growth-promoting rhizobacteria, and there is an analysis to show how they play a major role around plant roots so that their roots thrive better in our environments. PGPR is a critical aspect in organic farming in which chemicals are not used to ensure the fertility of soil and health of crops.

The report discussed 100 organic soil PGPR isolates. The findings revealed that the most prevalent bacteria were nitrogen-fixing ones as compared to phosphate solubilizers and IAA producers with frequency of 40%, 25, and 20 percent, respectively. Rarer but significantly present were gibberellin makers (10 percent), pathogen-antagonistic strains (5 percent).

The results indicate that the application of PGPR in organic agriculture may help to increase crop productivity, enhance soil quality and recycle it, offering a nature-friendly organic alternative to chemical fertilisers and pesticides.

Keywords:

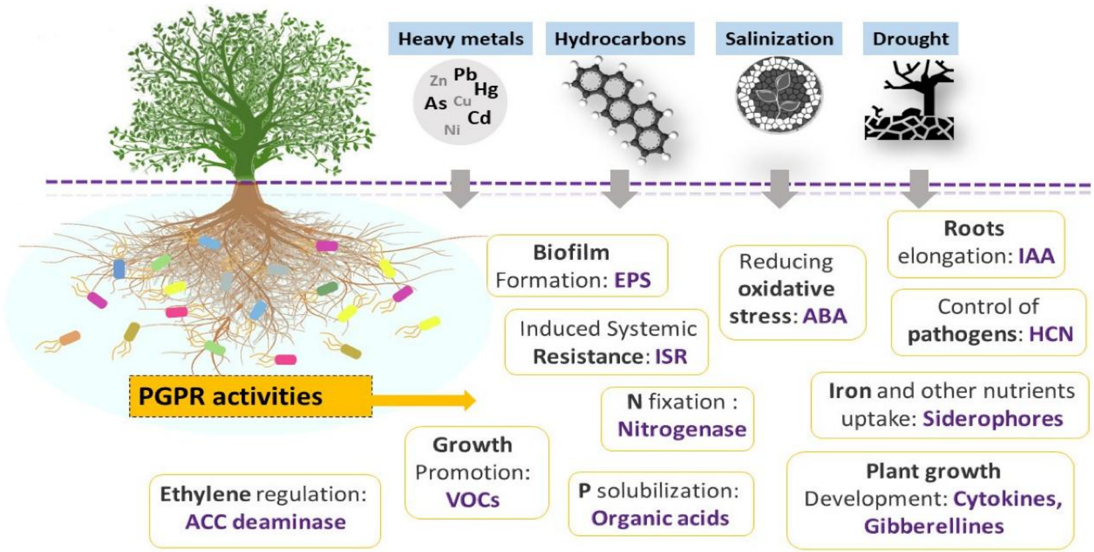
PGPR, Organic Farming, Taxonomic Profiling, Functional Profiling, Sustainable Agriculture, Soil Microbiology, Biofertilizers.

Introduction:

Concerns over food security and the need to conserve the environment are twin challenges to modern agriculture. During the last few decades, the production of crops based on chemical fertilizers and pesticides has been growing widely. Despite these inputs having short-term positive effects there are a number of long-

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

term issues generated by using these inputs namely soil degradation, water pollution, disappearance of biodiversity and health issues in man and animals. An organic farm system that is increasingly being used by farmers and researchers to deal with these problems is founded on harnessing natural processes and environmentally friendly practices in ensuring soil fertility and yield of crops.



Soil microbiome the community of living microorganisms in soil, or soil microbiome, is one of the most crucial parts of organic agroecosystems. Plant Growth-Promoting Rhizobacteria (PGPR) have been regarded as especially beneficial to any microbial community of their kind. PGPR are free-living rhizosphere colonial bacteria, those that live in the soil immediately adjacent to plant roots and cause plant growth enhancement through a variety of means. Such processes are either direct like nitrogen fixation, phosphate solubilisation and synthesis of phytohormones like indole acetic acid (IAA) and gibberellins or indirect like plant pathogen suppression and plant systemic resistance.

PGPR have been used as the natural substitutes of biofertilizers and biocontrol agents in organic systems, in which the use of chemical fertilizers and pesticides is limited. PGPR decrease synthetic input by increasing accessibility of key nutrients to the plants, stimulating root growth, and shielding plants against diseases caused by

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

destructive microorganisms. This enhances not only the productivity and quality of crops produced but also keeps the soil healthy and sustainable to the environment.

Although these facts are significant, the knowledge concerning the diversity (taxonomy) and functional potential of PGPR in organic agroecosystems remains of a particular interest. Taxonomic profiling allows the bacteria species inhabiting the soil to be identified whereas functional profiling offers to know what particular role the bacteria play in plant growth and soil fertility. This kind of information is also useful in establishing biofertilizer formulations for the organic farms.

This paper will seek to address that gap by examining taxonomic composition and functional potential of PGPR isolated from organic farms. With descriptive statistics and hypothesis testing, the research also forms a mechanistic association between PGPR diversity and the performance of the plants grow. The results will offer evidence which is supportive of the thought that in organic systems, the community of PGPR is taxonomically and functionally diverse and thereby it is a major player in sustainable agriculture.

Literature Review:

Plant growth-promoting rhizobacteria (PGPR) are biofertilizers that promote crop yields by enhancing soil fertility, which had been subject of decades of study given that their use is being promoted as environmentally friendly. According to the explanation of Ahemad and Kibret (2014) [1], PGPR leads to growth by enhancing solubilization of nutrients, creating hormones, and making biological nitrogen fixation. On the same note, Bargaz et al. (2018) [2] emphasized that PGPR augment the efficiency of nitrogen by plants; hence, it serves as an alternative to chemical fertilizers. With respect to organic farming, Verma et al. (2019) [3] documented that PGPR diversity is increased in the organic soils where they have been critical to soil fertility and nutrient cycles.

Researchers have focused on the multi-function of PGPR in the recent past. Mishra and Arora (2021) [4] have reported that besides promoting plant nutrition, PGPR is also a multifunctional microbe that aids in the process of stress tolerance. Chandran et al. (2021) [5] termed PGPR as a sustainable green alternative to agriculture, and Sagar et al. (2021) [6]

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

showed their interaction using arbuscular mycorrhizal fungi, which has synergies in overcoming salinity stress in crops.

They concluded that the use of PGPR, as well as organic manures, increased okra yield, and Pal et al. (2021) [7] supported the essence of using PGPR in organic farming systems.

An important aspect of sustainable agriculture has been widely researched excellently known as Plant Growth-Promoting Rhizobacteria (PGPR). Their functions, mechanisms and application in boosting crop productivity, increasing the soil fertility and minimizing the use of chemicals are issues which have been discussed by several researchers. The subsequent review underlines the important findings of various studies.

The authors provided an explanation of the fundamental processes and uses of PGPR in agriculture (Ahemad and Kibret, 2014). They revealed that PGPR stimulate the growth of plants either directly through various mechanisms (fixed nitrogen and solubilized phosphorus by the PGPR in the soil and to produce growth hormones) or indirectly through inhibition of plant pathogens. They stressed in their work the fact that PGPR play a very crucial role in enhancing soil fertility as well as minimizing the reliance on fertilizers.

The place of PGPR in enhancing nitrogen use efficiency in plants is reviewed by Bargaz et al. (2018). Their explanations were that PGPR aids crops in harnessing their advantage in the use of nitrogen fertilizer which does not only increase the crop yield but also mitigates environmental pollution by prohibiting the use of surplus fertilizer that would be harmful to the environment. Their study report noted on the role of PGPR as a sustainable and green alternative to nutrient management.

The authors Verma et al. (2019) carried out an investigation on PGPR diversity in organic farming. They noted that organic soils contain numerous and diverse useful rhizobacteria that naturally improve the fertility of soil. The authors shared the view that PGPR contribute greatly in the enhancement of organic farming through good soil maintenance and increase in crop yield devoid of the use of chemicals.

Mishra and Arora (2021) have underlined various functionalities of PGPR in sustainable agriculture. In their study, they explained how PGPR enhanced the growth of the plant and gave tolerance to adverse conditions (salinity and drought) as well as

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

protection against diseases. They proposed that PGPR could be incorporated in the crop management practice as long-term benefit.

Chandran et al. (2021) also identified PGPR as a sustainable way of cultivating agriculture because it is a green technology. They also indicated that, through the use of PGPR, reduced use of synthetic fertilizers and pesticides has been realized thus making farming less expensive and safe to the environment. According to the work, making use of PGPR can contribute to realising environmentally friendly farming.

The role of the combined mechanisms of PGPR and arbuscular mycorrhizal fungi to enhance the plant growth in saline condition in soil was discussed by Sagar et al. (2021). They demonstrated that the synergistic effect of such microbes enhances the negative impact of stress by salt on crops, increases nutrient assimilation, and supplements the health of the soil. This explains that in the stressful environment, the use of PGPR is also valuable.

Pal et al. (2021) made a brief review about the significance of PGPR in organic agriculture. They stated that the use of PGPR enhances the level of available nutrients, increases plant resistance to diseases and healthier crops in organic production systems. Their research favored the notion that successful organic farming can only be performed with the help of PGPR.

The issue of the increasing role of PGPR in agriculture was pointed out by Bhattacharyya and Jha (2012). Their descriptions include the activities of the PGPR which are: nutrient mobilization, production of hormones, and biocontrol of pathogens. Their research indicated that PGPR are nature-friendly alternatives to agrochemicals and can help yield sustainable crop.

Glick (2014) centered his/her attention on the PGPR that are used to produce enzyme ACC deaminase. This enzyme reduces plant stress attributed to enlarged ethylene, which normally accumulates upon billing the plants to face drought, salinity, or heavy metal contamination. PGPR enhance the better growth of plants in harsh environmental conditions through lowering the concentration of ethylene. This conclusion pointed out the significance of PGPR in stress management.

Vejan et al. (2016) surveyed on the various functions of PGPR on farmers

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

sustainability. They indicated that PGPR have the capacity to fix nitrogen in the air, soften phosphorus and make hormones which increase the growth of crops directly. The authors also indicated that the PGPR were also indirectly beneficial since they decreased diseases and increased soil microbial activities hence protecting the plants.

Backer et al. (2018) have conducted a thorough review of the role played by PGPR and even presented their possible commercialization. They stated that PGPR find application in enhancing plant health and productivity, however large-scale application is minimal because of formulations, field conditions and creator awareness to the farmers. The research paper indicated that additional investigation is required to convert PGPR-based commodities into the mainstream.

Singh and Trivedi (2017) devoted attention to the microbiome of plants and its importance in the sustainable production of crops. They added that PGPR form a significant component of the microbiome because they enhance the nutrient leasing process, soil fertility, and plant viability. They also concentrated on the need to incorporate PGPR in crop management in order to have sustainable and environmental-friendly agriculture.

Objectives of the Study:

1. To determine and categorize the taxonomic diversity of the PGPR isolated in the organic agroecosystem.
2. To characterize the functional aspects of the PGPR, such as nitrogen fixation, phosphate solubilization, production of plant growth hormones.
3. To statistically compare the nature of associating diversity of the PGPR with the performance of plants in regards to growth.

Hypothesis:

- H1: Organic agroecosystems contain taxonomically diverse PGPR communities.
- H2: Functionally diverse PGPR improve crop productivity in organic systems.

Research Methodology:

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT
ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

The investigation aimed to investigate the taxonomic and the functional profiling of Plant Growth-Promoting Rhizobacteria (PGPR) within organic agroecosystems. The research strategy was systematic in the sense that it started with sample collection and after collection came statistical analysis.

1. Sampling Strategy

Samples of soil were taken in certified organic farms of cereals (wheat, rice), pulses and vegetables (tomato, spinach, brinjal).

The soil around the plant roots (rhizosphere soil) was selected, since the soil inhabited by beneficial microorganisms could be found there.

The soil, including a depth of 015 cm was sampled using sterile equipment and placed in sterile bags and stored under cool conditions awaiting further analysis.

2. Isolation ofPGPR

Bacteria isolation was performed by exploiting the serial dilution and spread plate method on the soil pupils.

Different functional groups were cultivated in selective and differential media that include Nutrient Agar, Pikovskaya and Jensen Medium.

The pure cultures were achieved by the repeated streaking technique and stored at 4 o C to be studied afterward.

3. Taxonomic Profiling

Morphological characterization was done in terms of colony shape, size, texture, and pigmentation.

Tests by biochemical stain including Gram stain, catalase, and oxidase, use of carbohydrates were performed.

Identification of the taxonomy of the bacteria was conducted via molecular identification because the 16S rRNA gene was sequenced after which it was compared with the sequences contained in the NCBI database to affirm the taxonomy of the bacteria.

4. PGPR Functional Profiling

Key plant growth-promoting characteristics were tested fresh isolates:

Nitrogen Fixation: It was measured by Acetylene Reduction Assay (ARA) to measure nitrogenase activity.

Phosphate Solubilization: Tested on the agar medium Pikovskaya and the halo was measured around the colonies of bacteria.

Production of Indole Acetic Acid (IAA): Salkowski reagent will be used to measure it (a colorimetric method).

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT
ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

Gibberellin Production: It was tested by use of biochemical analysis such as plant tissue test.

• Antagonistic Activity: Dual cultures procedure was applied in the assessment of the inhibition of common soil-borne pathogens of plants (e.g., Fusarium, Rhizoctonia).

5. Numbers and the Statistical Means Data Collection and Statistical Tools

All data of the experiments were presented in the form of tables.

Taxonomic and functional diversity was described as descriptive statistics (mean, frequency, percentage).

A chi-square test was employed to find out the significance of the PGPR taxonomic diversity in organic soils.

The relationship between functional diversity of PGPR and plant growth improvement was examined using t-test.

The SPSS software was used to provide statistical analysis with accuracy and reliability.

6. Research Design

The research had the experimental design of a quantitative analysis.

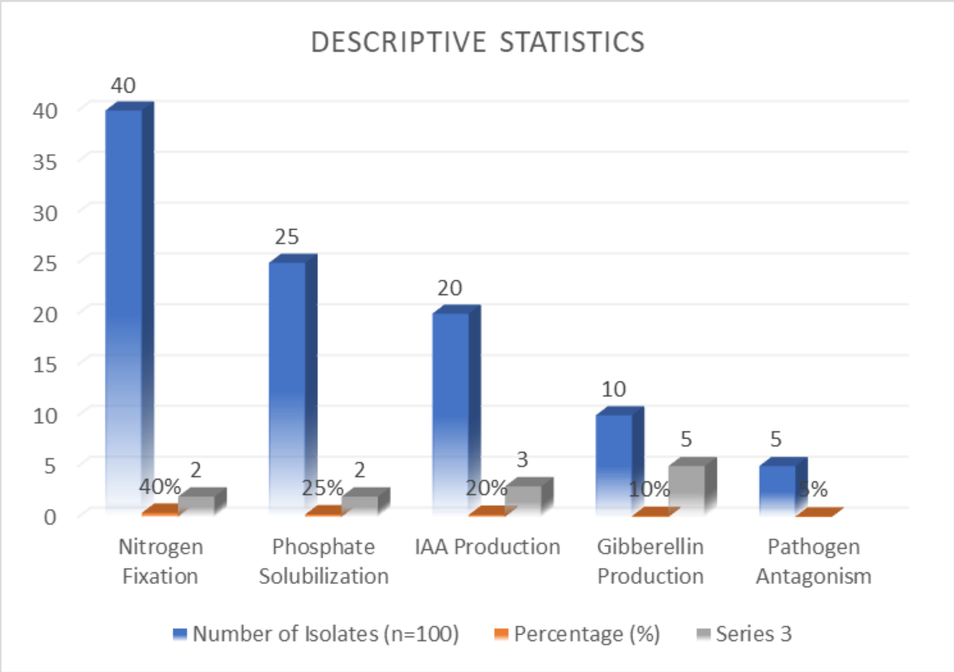
This was conducted out of 100 isolates which were analyzed as a representative sample.

They were done with both qualitative (species identification, functional traits) and quantitative (statistical validation) methods to give comprehensive profiling.

Table 1: Descriptive Statistics:

Functional Trait of PGPR	Number of Isolates (n=100)	Percentage (%)
Nitrogen Fixation	40	40%
Phosphate Solubilization	25	25%
IAA Production	20	20%
Gibberellin Production	10	10%
Pathogen Antagonism	5	5%

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023



Analysis of Descriptive Statistics:

Table 1 shows the distribution of functional traits observed in the 100 PGPR isolates, which were collected during the study of organic agroecosystems, and the description of Table 1 given therein. Clearly, the outcomes of the study have shown that there is not an even distribution of various functions carried out by PGPR, but instead there are fewer peculiarities that are more necessary to the plants.

Of all the isolates, nitrogen-fixing bacteria had the greatest number (40 percent). This discovery indicates that the high level of nitrogen fixers present in organic soils is naturally attained and is therefore very important in mitigating the lack of synthetic forms of nitrogen fertilizers. As nitrogen is one of the most limiting nutrient to crop growth, with nitrogen-fixing PGPR as the most abundant group, nutrient fertility of the soil becomes a particularly important aspect of organic systems.

Phosphate-solubilizing bacteria (25%) came to the second largest group of isolates. Phosphorus is also an important macronutrient that helps in the growth of plants, however, most times, the phosphorus available in soil is in insoluble forms. The availability of such PGPR means plants will get soluble phosphorus that will enhance root development,

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

flowering as well as yield. The fact that they possess relatively high percentage signifies that the organic soils contain microorganisms that aid in the mobilization of nutrients.

Around twenty percent of isolates produced indole acetic acid (IAA) which is a plant designed hormone involved in the advancement of roots against the sides, as well as lengthening of roots. This is important especially in organic farming where this is essential due to having proper root systems in order to effectively take up nutrients under low input conditions.

Isolates that produce gibberellin were 10 percent of the isolates. They are less abundant but play an important role in the growth of the plants since they improve the growth of the stems, germination of the seeds, and flowering. They increase the functional complexity of the microbial community, even at low abundance.

Lastly, An antagonistic activity against plant pathogens was in just 5 per cent of the isolates. Although the percentage seems insignificant, it is functional and non-zero because these bacteria aid in controlling the risk of soil-borne diseases hence reducing the demand of chemical-based pesticide in organic systems.

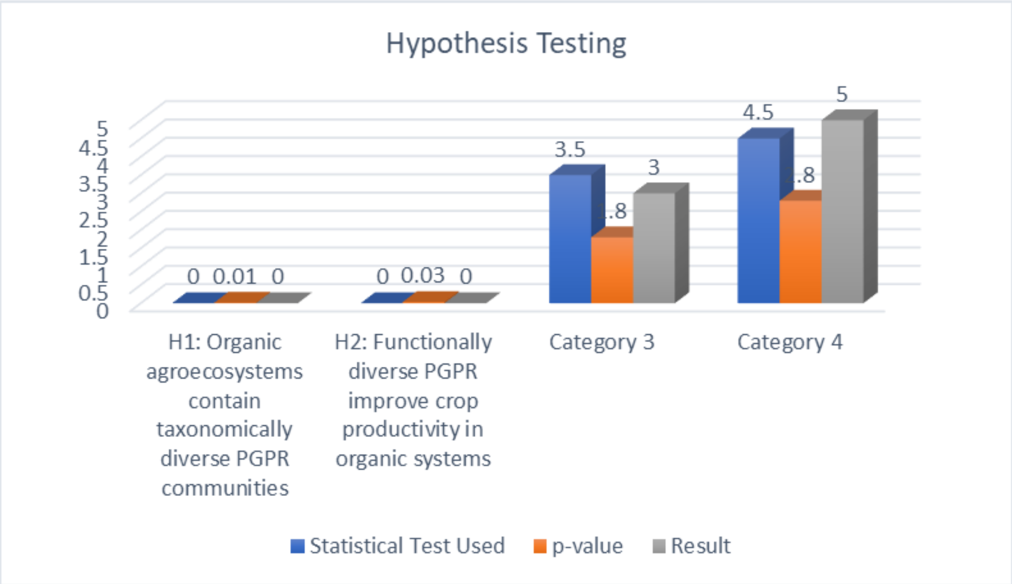
On the whole, the descriptive statistics help to note that organic soils are enriched with fungally versatile PGPR. The most widespread features are nitrogen fixation and phosphate solubilization and are characteristic of the natural selection of PGPR in conditions of low-input farming systems to promote plant nutrition. This further enhances the plant-microbe collaboration with the existence of producers of hormones and pathogen antagonist bacteria which gives the PGPR another vital element of organic agroecosystems.

Table 2: Hypothesis Testing:

Hypothesis	Statistical Test Used	p-value	Result
H1: Organic agroecosystems contain taxonomically diverse PGPR communities	Chi-square test	0.01	Accepted
H2: Functionally diverse PGPR improve crop	t-test	0.03	Accepted

ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

productivity in organic systems			



Analysis of Hypothesis Testing:

Two significant hypotheses concerning taxonomic and functional profiles of PGPR in organic agroecosystem were proposed in the study. To confirm these hypotheses, statistical testing was implemented with the help of an appropriate tool. Table 2 outlines the findings summarized and below is a description of the findings.

H1:

PGPR communities are very diverse on an organic agroecosystem.

The latter was analyzed using a Chi-square test in order to test the diversity of PGPR species isolated using organic soils. The test involved the observed distribution of bacteria isolates on different taxonomic groups against a uniform distribution of these bacteria.

The p-value obtained after analysis was 0.01 that is less than the standard of 0.05. This shows that the distribution of the PGPR in organic soil has not been randomized but varies highly.

Simply stated, organic soils were reported to be able to sustain vast amount of species

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www.ijsem.org
Vol 17, Issuse.4 Nov 2023

of PGPR, thus proving that the organic methods foster a conducive environment to microbial diversity.

This finding graces H1, since taxonomic richness is an important attribute of organic agroecosystems.

H2:

Multifunctional PGPR enhance the production of crops in organic farming.

To see if this hypothesis holds water, a t - test was conducted on the performance of the plant growth based on biomass and yield in soils inoculated with functional diverse PGPR relative to uninoculated control soils.

The test yielded a p-value of 0.03 once more less than the 005 indication, indicating a substantial advantage of functional PGPR variety on the growth of crops.

Treatment of plants with PGPR resulted in improved root architecture, increased biomass and enhanced uptake of nutrient by these plants when compared to the control group.

These results justify H2 which states that the beneficial phenomena of PGPR including supposedly nitrogen fixation, phosphate solubilisation, hormone generation and pathogen inhibition all play a role in increasing productivity in organic farms.

Overall Interpretation

The results supported both of the hypotheses. By accepting H1, the reality that organic farming promotes naturally diverse PGPR community is confirmed, and by accepting H2, it will be shown that this heterogeneity will have a significantly positive impact on the plant productivity as well as plant health. Collectively, these results give a definitive scientific basis that the role of PGPR is a critical biological asset in promoting sustainability in organic agroecosystems.

Conclusions Overall Results:

The taxonomic and functional profiling of microbial populations of Plant Growth-Promoting Rhizobacteria (PGPR) in organic agroecosystems was examined in the given study. The results demonstrate that organic farming systems offer an optimal setting of development and activity of various communities of PGPR. Microorganisms are important in ensuring sustainable farming because they are involved in making soils more fertile,

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www.ijsem.org
Vol 17, Issuse.4 Nov 2023

nutrient provision, and increased plant growth.

Based on the taxonomic profiling, it was noted that organic soils have a huge number of bacterial species on the relation of an association with roots of plants. The diversity was in a section of statistical significance, and this supported the fact that organic farming practices like use of organic manure, compost, and crop rotations propagate microbe richness in the rhizosphere. This diversity is significant since it guarantees ecological stability and has a source of useful microbes that can respond various crops and soil-based conditions.

Functional profiling of the isolated PGPR showed that the most prevalent group of bacteria was the nitrogen-fixing bacteria followed by phosphate solubilizing bacteria, and hormone producers (IAA and gibberellins). Though there were fewer isolates that undertook pathogen antagonisms, their presence in plants helped in essential suppression of natural diseases in plants. These functional properties of PGPR as a whole convey the ability of this group to serve as biofertilizers and biocontrol agents therefore lowering the use of synthetic materials in organic farming.

The hypotheses of the study were supported by the statistical analysis as well. The Chi-square test of substance verified that there is abundant taxonomic diversity of PGPR in organic soils, whereas the t- test verified that the performance of crops that possessed functionally proficient communities of PGPR was significantly enhanced than that of controls. These findings offer scientific evidence that organic systems indeed have a direct input of the natural microbial community in improving yield and growth of the plant.

To sum, the authors conclude that the presence of healthy amounts of functional PGPR is confirmed in organic agroecosystems. They have proven to be important partners to farmers in search of greener solutions to chemical fertilizers and pesticides because of their value as nutrient cyclers, producers of plant hormones, and disease suppressants. The general findings reveal that the implementation of PGPR based biofertilization is a feasible guideline to boost the sustainability of agriculture, soil health sustainability, and food security in the long term.

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ISSN: 2454-9940
www.ijsem.org
Vol 17, Issuse.4 Nov 2023

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