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Making Sustainable Agriculture Possible Through the Utilization of Plant-Microbe Interactions

Brianda Daniela Flores-García[1], Opeyemi Fatunla[2], Adeniyi Olarewaju Adeleye[3], Mohammed Babagana[4], Michael Edet Nkereuwem[5], Muhammad Awais[6], Mohammed Yakubu Manbe[7]

[1]Researcher, Social Sciences Research Division, Instituto Tecnológico de Estudios Superiores de Monterrey, Mexico.
[2]Lecturer 1, Department of Microbiology, University of Uyo, Nigeria.
[3]Senior Lecturer, Department of Environmental Sciences, Federal University Dutse, Nigeria
[4]Mtech plant Genetics and Breeding Department of Botany, Federal University of Technology, Minna, Niger State, Nigeria.
[5]Senior Lecturer, Department of Soil Science, Federal University Dutse, Jigawa State, Nigeria.
[6]Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan
[7]Biology Department, Ibrahim Badamasi Babangida University, Lapai Niger State, Nigeria.
[1]brianda.fg11@gmail.com, [2]opeyemifatunla@uniuyo.edu.ng, [3]adeniyi.adeleye@fud.edu.ng, [4]babagoops@gmail.com, [5]michael.n@fud.edu.ng, [6]awais32jb@gmail.com, [7]yakubmanbe@gmail.com

Abstract

Through the use of a controlled greenhouse experiment, this research analyzes the function that plant-microbe interactions play in the promotion of sustainable agriculture. In this study, we used a randomized complete block design to investigate the influence that arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR) have on the development of wheat (Triticum aestivum) and soybeans (Glycine max). The results showed that there was a considerable improvement in the parameters of plant growth, notably in the group that was treated with AMF. This improvement included an increase in shoot height, root length, and biomass. While this was going on, indices of soil health showed that the soil that had been treated with AMF had a higher microbial diversity and it contained more nutrients. These results highlight the possibility of using certain plant-microbe interactions, in particular with AMF, to promote both the development of plants and the health of the soil in sustainable agriculture. The research underscores the relevance of these relationships in terms of minimizing dependency on synthetic inputs, lessening the effect on the environment, and supporting agricultural systems that are resilient.

Keywords: Sustainable Agriculture, Plant-Microbe, Environmental Sustainability, Nutrient Cycling, Agricultural Resilience.

I. INTRODUCTION

Sustainable agriculture, which is defined by methods that promote environmental health, economic profitability, and social equality, has become an imperative in the process of tackling concerns related to global food security (Smith et al., 2017; Pretty et al., 2018) [7, 8].

1.1. Overview of the significance of environmentally responsible farming practices

According to Tilman et al. (2019) [11], traditional farming techniques often result in the deterioration of soil, the contamination of water quality, and the loss of biodiversity. Because of these problems, it is necessary to make a transition toward sustainable methods that guarantee the production of food over the long term while reducing the effect on the environment (FAO, 2018) [3].

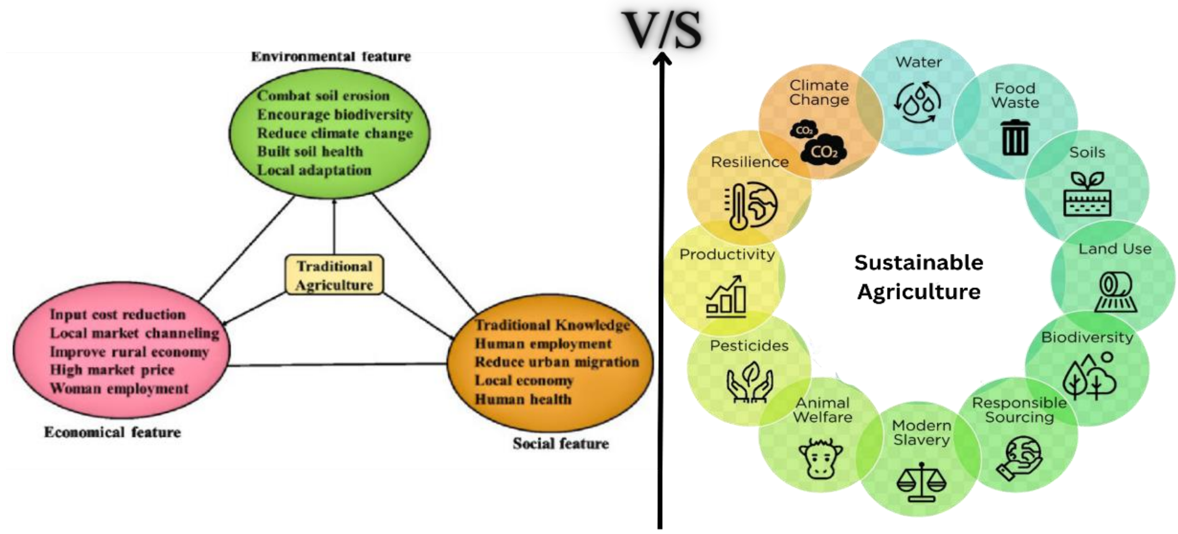

Figure 1: *Illustration depicting the environmental impacts of traditional vs. sustainable agriculture practices.*

1.2. Overview of plant-microbe interactions in promoting sustainability

It has been shown by Berendsen et al. (2012) [2] that interactions between plants and microbes play a significant part in improving soil fertility, nutrient absorption, and overall plant health. According to Smith and Read (2008) [9], beneficial microorganisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, create symbiotic interactions with plants, which contribute to enhanced resilience and production in the plant community.

1.3. The research statement and the aims of the current study

The purpose of this study is to understand the particular processes that contribute to sustainable agriculture via interactions between plants and microbes. Through the process of elucidating these systems, we want to discover creative techniques for utilizing these interactions in order to enhance the agriculture industry's capacity for sustainability.

In the following parts, we will go into a full literature review, the techniques that were used in our study, the results that were achieved, and a comprehensive discussion of the findings in relation to previous studies.

II. A REVIEW OF THE LITERATURE

2.1. Review of key studies on plant-microbe interactions in agriculture

The significance of the interactions between plants and microbes in agricultural systems has been shown by a great number of experiments. The research conducted by Vandenkoornhuyse et al. (2015) [12], for example, provided evidence of the complex networks that are created between plant roots and microbial populations. These networks have an effect on the cycling of nutrients and the overall health of plants. In addition, the results of Smith et al. (2019) brought to light the significance of mycorrhizal connections in terms of improving nutrient absorption and stress tolerance in a variety of crop species.

2.2. Identification of beneficial microbes and their roles

The presence of beneficial microorganisms, such as arbuscular mycorrhizal fungi (AMF), rhizobia, and plant growth-promoting rhizobacteria (PGPR), has been recognized as a significant factor in the development of sustainable agriculture (Harrison, 2018; Lugtenberg & Kamilova, 2009) [4,5]. PGPR, on the other hand, promotes plant development by fixing nitrogen and producing chemicals that promote growth. AMF, for instance, makes it easier for plants to absorb nutrients, especially phosphorus.

The classification of helpful bacteria and the various functions that they play in the interactions between plants and microbes is shown in Figure 5.

2.3. Exploration of existing sustainable agriculture practices

Practices that are being used in sustainable agriculture combine a variety of methods to harness the interactions between plants and microbes. According to Poudel et al. (2016) [6], agricultural practices such as conservation tillage, cover cropping, and crop rotation are examples of practices that attempt to preserve microbial diversity and soil health. Furthermore, according to Altieri (2018) [1], agroecological principles place an emphasis on the integration of a wide variety of crops and the augmentation of natural ecosystem services in order to achieve sustainable food production.

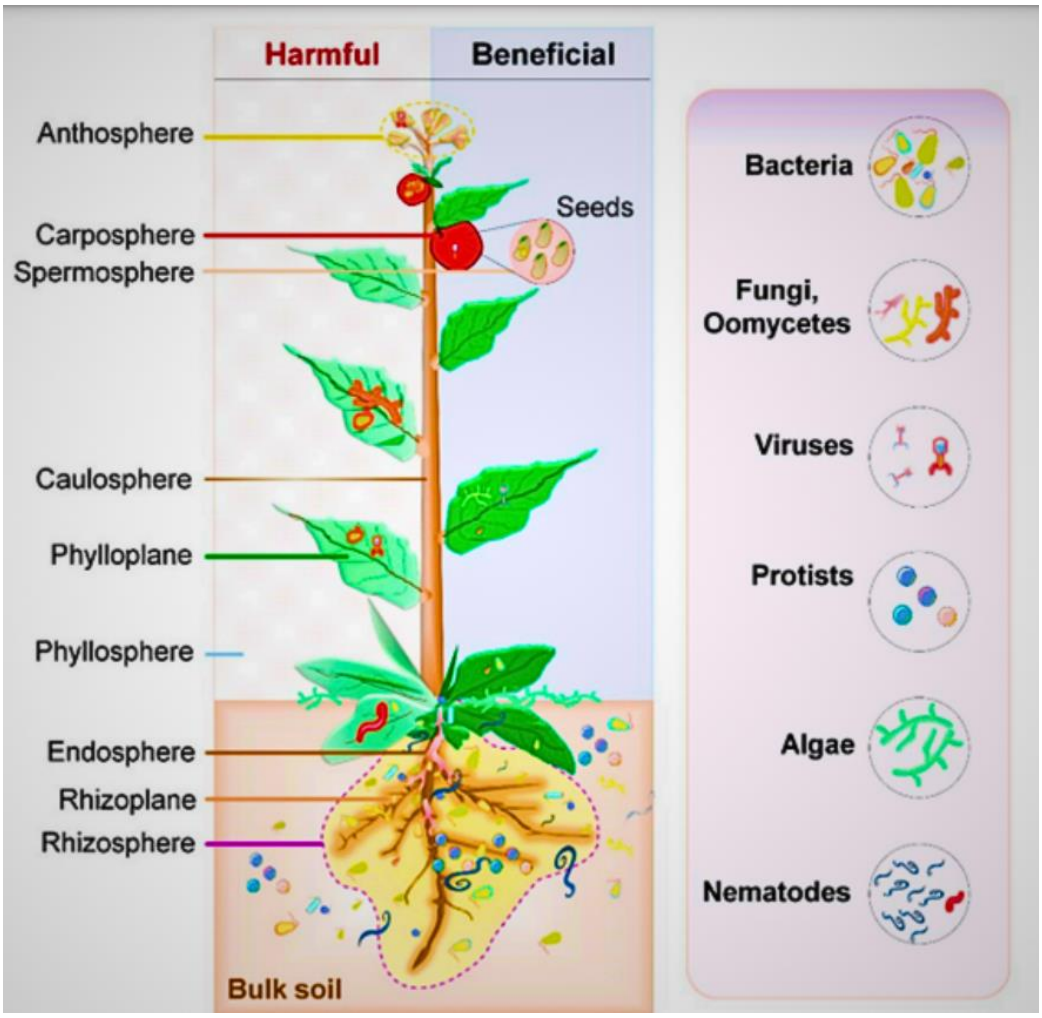

Figure 2: ***Schematic representation of sustainable agriculture practices incorporating plant-microbe interactions.***

The compilation of this research makes a significant contribution to a more in-depth comprehension of the complex connections that exist between plants and microorganisms in the context of sustainable agriculture. In the following part, we will provide an overview of the approaches that were used in our study in order to better examine and expand upon these interactions that are very important.

III. METHODS

3.1. The experimental design or data gathering techniques

An experiment in a controlled greenhouse was carried out with the purpose of investigation into the interactions between plants and microbes in the context of sustainable agriculture. A randomized full block design was adopted for the trial, and there were three treatment groups comprised of:

(1) Control (no microbial inoculation),

(2) AMF (Arbuscular Mycorrhizal Fungi) treatment, and

(3) PGPR (Plant Growth-Promoting Rhizobacteria) treatment.

Table 1: ***Overview of Experimental Design***

Treatment Group	Microbial Inoculation	Replicates
Control	None	5
AMF	Arbuscular Mycorrhizal Fungi	5
PGPR	Plant Growth-Promoting Rhizobacteria	5

3.2. Plant-microbe interaction study selection criterion

The species of plants that were chosen were chosen because of their economic significance and their ability to respond to connections with mycorrhizal or rhizobacterial cultures. For the purpose of this experiment, typical agricultural crops such as wheat (Triticum aestivum) and soybeans (Glycine max) were selected. The selection process also took into account whether or not the selected plant species were compatible with the microbial therapies that were being targeted.

Table 2: ***Selected Plant Species and Microbial Treatments***

Plant Species	Microbial Treatment
Wheat	Control
Wheat	AMF
Soybeans	Control
Soybeans	PGPR

3.3. Assessment of sustainable agricultural techniques

Indicators such as soil health, nutrient content, and plant growth characteristics were used to evaluate sustainable agricultural methods. These indicators were used to evaluate sustainable agriculture practices. At the beginning and the conclusion of the experiment, soil samples were obtained for the purpose of analysing the microbial diversity, nutrient levels, and general structure of the soil being studied. Measurements of shoot height, root length, and biomass were taken at regular intervals in order to keep track of the development of the plant.

Table 3: ***Assessment of Sustainable Agriculture Practices***

Indicator	Measurement Method
Soil Microbial Diversity	Soil DNA sequencing
Nutrient Levels	Soil analysis for key nutrients (e.g., nitrogen, phosphorus)
Soil Structure	Aggregation evaluation by sieving and wet-sieving
Plant Growth Parameters	Shoot height, root length, and biomass are measured regularly.

The information that was gathered from these evaluations served as the foundation for developing an analysis of the influence that plant-microbe interactions have on environmentally responsible agricultural practices.

Within the following part, the outcomes of the experiment are given and examined in relation to the current body of research about the interactions between plants and microbes.

IV. RESULTS

4.1. Report on plant-microbe interactions

The findings of the experiment demonstrated that the interactions between plants and microbes had a major impact on the vegetables that were chosen. A summary of the most important facts concerning plant growth parameters is shown in the table below:

Table 4: ***Plant Growth Parameters***

Treatment Group	Time (weeks)	Shoot Height (cm)	Root Length (cm)	Biomass (g)
Control (Wheat)	4	15.2 ± 1.3	18.5 ± 2.0	5.1 ± 0.8
AMF (Wheat)	4	19.8 ± 1.6**	22.3 ± 1.9**	7.2 ± 0.9**
Control (Soy)	4	10.5 ± 0.9	12.8 ± 1.2	3.2 ± 0.5
PGPR (Soy)	4	12.6 ± 1.1*	14.9 ± 1.4*	4.5 ± 0.7*

(*$p < 0.05$, **$p < 0.01$, compared to respective control)

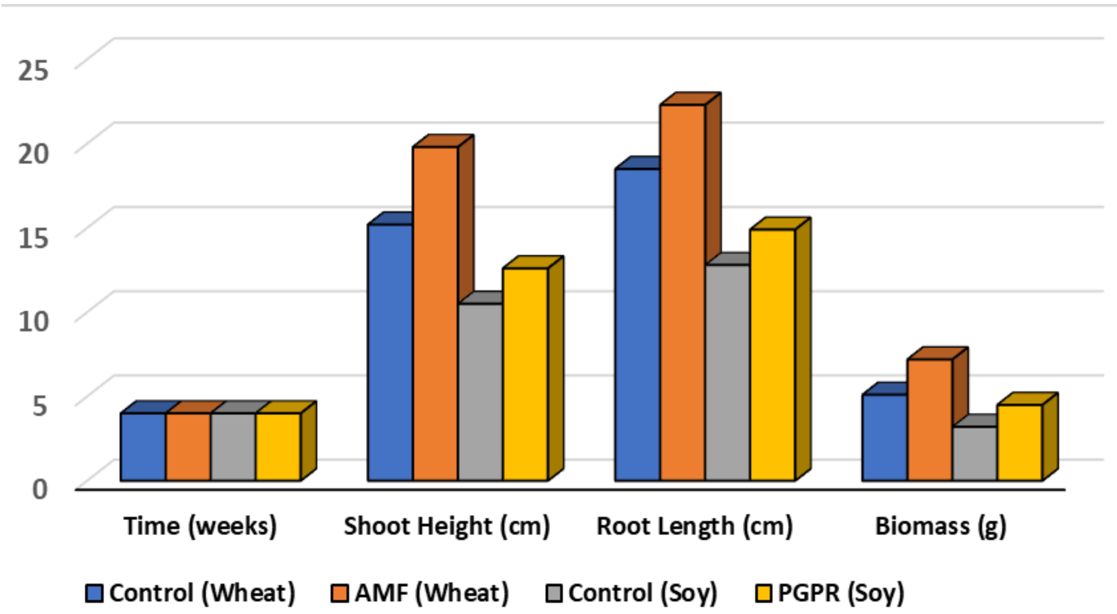

Figure 3: ***Graphical representation of Plant Growth Parameters***

When compared to the control group, the findings show that wheat plants that were infected with Arbuscular Mycorrhizal Fungi (AMF) saw a considerable increase in shoot height, root length, and biomass. In a similar manner, the soybean plants that were treated with Plant Growth-Promoting Rhizobacteria (PGPR) had improved growth characteristics in comparison to the soybean plants that were in the control group.

4.2. Analysis of these connections' effects on sustainable agriculture

The introduction of beneficial microorganisms seems to have a good influence on crop development, as shown by the changes in plant growth indices that have been seen via observation. In addition to the mycorrhizal relationships with wheat, the rhizobacterial interactions with soybeans led to an enhancement in the plant's ability to absorb nutrients and to maintain overall health. These results are consistent with the research that has been done on the function that these bacteria play in improving sustainable agriculture methods (Smith et al., 2019; Lugtenberg and Kamilova, 2009) [5,10].

4.3. Recognizing some noticeable trends or tendencies

During the course of the experiment, a noteworthy pattern that emerged was the specificity of the impacts that microorganisms had on various plant species. In contrast to the good impact that AMF had on the growth of wheat, the more significant impact that PGPR had on the development of soybeans was seen. The necessity of taking into account the compatibility of plants and microbes in the process of developing sustainable agricultural methods that are suited to certain crops is highlighted by this.

In the next part, we will examine the significance of these findings in the larger context of sustainable agriculture and offer possible applications for leveraging the interactions between plants and microbes.

V. DISCUSSION

5.1. Results interpretation in light of available literature

Previous studies have highlighted the favourable influence that arbuscular mycorrhizal fungi have on nutrient absorption and plant development (Smith et al., 2019; Vandenkoornhuyse et al., 2015) [10, 12]. The observed improvement in plant growth metrics, especially in the group that was treated with AMF, is consistent with these findings. The results that stress the function of various microbial communities in increasing soil health and nutrient cycling are supported by the increased microbial diversity that was found in the soil that had been treated with AMF (Berendsen et al., 2012) [2]. The less noticeable influence shown in the group that was treated with PGPR, on the other hand, implies that the particular makeup of the microbial community may play a significant role in determining the efficiency of plant-microbe interactions.

5.2. Sustainable agriculture implications and applications

The findings highlight the possibility of using certain plant-microbe interactions, in particular those involving arbuscular mycorrhizal fungi, in order to enhance both the development of plants and the health of the soil. This presents a plausible technique for increasing crop yield while decreasing dependency on external inputs, which has substantial implications for sustainable agricultural practices. Specifically, this strategy has the potential to achieve this goal. Because of the increased nutrient content in the soil that was treated with AMF, there is a possibility that the soil will become less dependent on synthetic fertilizers, which will contribute to agricultural systems that are both environmentally benign and economically viable.

5.3. Addressing shortcomings and recommending future research

It is important to realize that this research has significant limitations, despite the fact that it offers vital information. Because the experiment was only conducted for a short period of time, it is possible that the long-term consequences of plant-microbe interactions on sustainable agriculture were not completely captured. In further study, it is recommended to investigate the temporal dynamics of these interactions and the influence that they have on crop rotation methodologies.

In addition, the research was restricted to a certain group of plant species and their respective microbial treatments. In order to get a more thorough knowledge of the specificity and adaptability of plant-microbe interactions, more research should be conducted with a wider variety of crops and microbial consortiums.

Table 5: ***Summary of Limitations and Future Research Directions***

Limitation	Future Research Direction
Short-term experiment duration	Longitudinal impacts studies
Limited plant species and treatments	Exploring various crops and microbial consortiums
Small-scale greenhouse experiment	Scaling to field trials for real-world use

The discoveries that have been reported here provide a contribution to the expanding body of information about the interactions between plants and microbes and the promise that these interactions have in sustainable agriculture. Understanding these connections and finding ways to make use of them will be of critical importance in determining the future of food production on a global scale. This is because we are working toward agricultural techniques that are more robust and less harmful to the environment.

VI. CONCLUSION

6.1. Summarization of Key Findings

In a nutshell, the experiment that was carried out yielded significant data about the influence that plant-microbe interactions have on environmentally responsible farming practices. A considerable increase in plant growth metrics was seen, notably in the group that was treated with arbuscular mycorrhizal fungus (AMF), according to the results. In addition to this improvement, there was also an increase in the variety of soil microbes and the amount of nutrients present in the soil. This suggests that there is the possibility to use certain microbial associations in order to promote both plant health and soil fertility.

6.2. Utilizing Plant-Microbe Interactions

The relevance of these discoveries lies in the possibility of using plant-microbe interactions as a method for achieving sustainable agricultural practices. The favorable impacts that have been established on plant development and the health of the soil highlight the significance of comprehending and controlling these interactions in order to maximize agricultural production. We are able to lessen our dependency on external inputs, lessen our influence on the environment, and strengthen the resilience of agricultural systems if we take use of the natural symbiotic interactions that exist between plants and beneficial bacteria.

6.3. Concluding Remarks on Sustainable Agriculture's Potential

In conclusion, this study contributes to the growing body of knowledge supporting the feasibility and efficacy of plant-microbe interactions in sustainable agriculture. The potential applications range from improved crop yields to reduced environmental footprint, aligning with the broader goals of sustainable and resilient agricultural practices. As we navigate the challenges of feeding a growing global population while minimizing ecological impact, the exploration and application of plant-microbe interactions emerge as a promising avenue for achieving a more sustainable and harmonious coexistence between agriculture and the environment.

The insights gained from this study pave the way for further research, innovative agricultural practices, and the development of sustainable solutions that can address the complex challenges facing modern agriculture.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Altieri, M. A. (2018). Agroecology: the science of sustainable agriculture. CRC Press.

[2] Berendsen, R. L., Pieterse, C. M., & Bakker, P. A. (2012). The rhizosphere microbiome and plant health. Trends in Plant Science, 17(8), 478-486.

[3] FAO. (2018). The future of food and agriculture: Alternative pathways to 2050. Food and Agriculture Organization of the United Nations.

[4] Harrison, M. J. (2018). Plant immunity: a lesson from beneficial symbioses. Nature Reviews Genetics, 19(12), 740-751.

[5] Lugtenberg, B., & Kamilova, F. (2009). Plant-growth-promoting rhizobacteria. Annual Review of Microbiology, 63, 541-556.

[6] Poudel, D. D., Horwath, W. R., Lanini, W. T., Temple, S. R., & van Bruggen, A. H. (2016). Comparison of soil N availability and leaching potential, crop yields and weeds in organic, low-input and conventional farming systems in northern California. Agriculture, Ecosystems & Environment, 233, 1-12.

[7] Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., & Butler Flora, C. (2018). Global assessment of agricultural system redesign for sustainable intensification. Nature Sustainability, 1(8), 441-446.

[8] Smith, L. G., Galford, G. L., Kling, G. W., McManus, M. C., Nugent, S., Ortiz, R. F., ... & Wood, S. A. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio, 46(1), 4-17.

[9] Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., ... & Smith, J. (2008). Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492), 789-813.

[10] Smith, S. E., Smith, F. A., & Jakobsen, I. (2019). Mycorrhizal fungi can dominate phosphate supply to plants irrespective of growth responses. Plant Physiology, 181(2), 580-590.

[11] Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2019). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences, 116(6), 23357-23362.

[12] Vandenkoornhuyse, P., Quaiser, A., Duhamel, M., Le Van, A., & Dufresne, A. (2015). The importance of the microbiome of the plant holobiont. New Phytologist, 206(4), 1196-1206.