Journal of Tea Science Research, 2023, Vol.13, No.5, 1-9
http://hortherbpublisher.com/index.php/jtsr

Review and Progress Open Access

The Association between Root Microbiome Diversity of Yunnan Large-Leaf Tea Trees and Soil pH

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Journal of Tea Science Research, 2023, Vol.13, No.5 doi: 10.5376/jtsr.2023.13.0005
Received: 15 Sep., 2023
Accepted: 23 Oct., 2023
Published: 01 Nov., 2023

Preferred citation for this article:
Liu N., 2023, The association between root microbiome diversity of Yunnan large-leaf tea trees and soil pH, Journal of Tea Science Research, 13(5): 1-9 (doi: 10.5376/jtsr.2023.13.0005)

Abstract Yunnan large-leaf tea (*Camellia sinensis* var. *assamica*) plays a significant role in the Chinese tea industry, known for its rich organic compounds. Soil is pivotal in tea production, and the composition and diversity of soil microbiota profoundly impact plant growth and soil ecosystem health. This review explores the relationship between the diversity of root microbiota in Yunnan large-leaf tea trees and soil pH levels. It summarizes the key factors influencing microbiota diversity and thoroughly investigates the influence of soil pH on microbial diversity. The research demonstrates a close correlation between microbial diversity and tea yield and quality. Enriched microbial diversity enhances nutrient absorption and disease resistance in plants, consequently boosting tea production and quality. Additionally, microbes play a pivotal role in regulating soil pH. These findings hold crucial significance for optimizing tea production and maintaining soil ecosystem health.

Keywords Large-leaf tea tree (*Camellia sinensis* var. *assamica*) in Yunnan; Microbial diversity; Soil pH; Soil ecosystem health

As a world-renowned agricultural product, tea has always played a crucial role in agriculture and culture. It is not only a popular beverage but also offers numerous health benefits, making it beloved worldwide. In China, the history of tea dates back thousands of years, and the Yunnan region is famous for its distinctive large-leaf tea variety. Yunnan large-leaf tea (*Camellia sinensis* var. *assamica*), known for its rich aroma and unique flavor, is one of the precious varieties of Chinese tea (Jiang et al., 2021). Therefore, optimizing the yield and quality of Yunnan large-leaf tea has been a focal point for tea growers and researchers.

Soil is one of the pivotal factors in tea production, and the composition and diversity of soil microbiota have a profound impact on plant growth and the health of the soil ecosystem (Lauber et al., 2008). Yunnan large-leaf tea trees grow under varying soil types and pH conditions, engaging in close interactions with root microbiota. Root microbiota constitute a critical component of the soil ecosystem, playing roles in nutrient cycling, pathogen suppression, and influencing plant growth and tea quality (Smith and Read, 2010). Therefore, gaining a deeper understanding of the association between the root microbiome of Yunnan large-leaf tea trees and soil pH is of paramount importance for optimizing tea production.

Currently, research on the microbial community structure in soil environments has become quite common. However, studies focusing on the rhizosphere microbiota of tea plants, particularly *Camellia sinensis* var. *assamica* in Yunnan, are relatively scarce. This review aims to explore the relationship between the root microbiome diversity of Yunnan large-leaf tea plants and soil pH levels, while analyzing the implications of this association for tea production and soil ecosystems. The review will begin by delving into the role and significance of microbes within soil ecosystems. It will then emphasize how the diversity of the root microbiome in Yunnan large-leaf tea plants is shaped and how it varies under different soil pH conditions. Additionally, a thorough analysis of relevant studies will be conducted to comprehend the practical implications of this relationship. Finally, discussions will revolve around leveraging this knowledge to optimize the production of Yunnan large-leaf tea, aiming for increased yield and improved quality while concurrently safeguarding the health and sustainability of

soil ecosystems. This review is poised to offer profound insights and guidance for the sustainable development of the tea cultivation industry.

1 Large-leaf Tea Varieties in Yunnan

Yunnan large-leaf tea (Figure 1), as one of the most primitive tea tree varieties globally, possesses unique attributes and can be categorized into sexual and clonal strains. It is distinguished by its abundant organic compounds, including tea polyphenols, caffeine, and catechins, with concentrations significantly surpassing those found in other tea tree varieties, such as medium and small-leaf types. The content of tea polyphenols in Yunnan large-leaf tea generally ranges from 30.00% to 33.00%, while caffeine content is approximately 4.00% to 5.00%. These abundant chemical constituents bestow upon Yunnan large-leaf tea its distinctive flavor profile and nutritional value.

1.1 Sexual strains

Large-leaf variety "Fengqing" is a typical representative of sexual varieties. It is a tall tree propagated through sexual reproduction. The content of tea polyphenols in "Fengqing" is 30.19%, caffeine is 3.56%, and water extract is 45.83%. This variety of tea plant exhibits strong growth vigor, with high branching, robust buds, and ease of harvesting. The tea leaves can be harvested from early March to late November, with a total of 25-26 harvests per year (Table 1). The Pu-erh tea produced from this variety is characterized by robust strips, glossy appearance, bright red infusion, and a high aroma and strong flavor. This variety is mainly distributed in Fengqing County, Yunnan Province.

Figure 1 Large-leaf tea tree (*Camellia sinensis* var. *assamica*) in Yunnan (Image Source: www.ishuocha.com)

Table 1 Sexual varieties of large-leaf tea trees (*Camellia sinensis* var. *assamica*) in Yunnan and its characteristic

No.	Variety	Polyphenol content (%)	Caffeine content (%)	Water extract content (%)	Distribution areas	Characteristic
1	Large-leaf variety "Fengqing"	30.19	3.56	45.83	Fengqing County	Vigorous growth, easily harvested. Tea is harvested throughout the year, 25-26 times
2	Large-leaf variety "Menghai"	32.77	4.06	46.86	Southern Yunnan	Early-harvest variety. Plants are tall, with tea leaves harvested 25-26 times throughout the year
3	Large-leaf variety "Jingdong"	29.52	-	46.90	Jingdong Country	Macrophanerophytes, with vigorous growth, open canopy, dense branching, easy to harvest.
4	White tea "Jinggu"	34.98	-	44.94	Yunnan Province	Macrophanerophytes, vigorous growth, uniform bud sprouting, high yield, and good quality

Furthermore, there is the large-leaf variety “Menghai”, also known as Fohaicha in Chinese. It is a small tree type with strong growth potential, exhibiting an open canopy, and reaching a considerable height. The tea leaves are harvested from late February to late November, with the possibility of 25-26 harvests throughout the year, making it a high-yield cultivar. The “Menghai” variety is characterized by its high tea polyphenol content of 32.77%, caffeine content of 4.06%, and an impressive 46.86% water extract content. This variety is primarily distributed in the southern regions of Yunnan and is well-suited for early-season tea tree cultivation (Table 1).

1.2 Clonal Varieties

After years of dedicated effort, Yunnan Tea Research Institute has successfully bred clonal varieties of tea trees from the Yunnan large-leaf population, known as the "Yunkang" and "Yunxuan" series (Table 2). These varieties have been officially recognized as superior cultivars at both the national and provincial levels (Zhang and Xiao, 1993, Guangdong Tea, (2): 64-68,104).

Table 2 Clonal varieties of large-leaf tea trees (*Camellia sinensis* var. *assamica*) in Yunnan and its characteristic

No.	Variety	Polyphenol content (%)	Water extract content (%)	Distribution areas	Characteristic
1	Yunkang14	37.37	44.20	Yunnan Province	Macrophanerophytes, with elongated elliptical leaves, rapid growth, and tea harvesting throughout the year, up to 30 times.
2	Yunkang10	33.06	44.90	Yunnan Province	Macrophanerophytes, wide canopy, dense branching. Extended tea picking season, with a total of 31 tea harvests throughout the year.
3	Yunkang43	34.98	44.94	Yunnan Province	Macrophanerophytes, Tall and erect growth habit with abundant branching. Harvested throughout the year for 26 times.
4	Changye Baihao	37.37	44.20	Yunnan Province	Macrophanerophytes, with an expansive tree structure and robust growth, harvested throughout the year for tea production up to 30 times.

Among the clonal varieties, the Yunkang series provides some excellent choices. For instance, Yunkang 14 is a tree-type tea plant with elliptical leaves, raised leaf surfaces, and abundant trichomes, making it easy to harvest. It boasts a high tea polyphenol content of up to 37.37% and is suitable for producing teas like Dianhong, Dianlv, and Dianqing (Table 2). Yunkang 10 and Yunkang 43 are also standout varieties among the clonal series, known for their high yields and superior quality, making them suitable for producing various types of teas.

These sexual and clonal varieties collectively constitute a diverse array of Yunnan large-leaf tea resources, providing a solid foundation for the development of the tea industry. The characteristics and adaptability of these varieties have allowed them to play crucial roles in the production of various tea products, thus enriching the diversity of tea culture.

2 Formation of the Root Microbiome Diversity of Yunnan Large-Leaf Tea Trees

The diversity of the root microbiome in Yunnan large-leaf tea trees is regulated by various factors, including soil characteristics, plant root exudates, and the interplay among microorganisms. In-depth exploration of how these factors influence the root microbiome of tea trees will contribute to a better understanding of the ecosystem in Yunnan tea production and provide a scientific basis for optimizing the tea industry.

2.1 Root microbiota composition

The root microbiota of Yunnan large-leaf tea trees comprises a diverse range of microorganisms, including Bacteria, Fungi, and Archaea. Among these, bacteria are one of the most abundant groups and play a crucial role in soil nutrient cycling, nitrogen fixation, and plant health maintenance (Figure 2). Fungi, on the other hand, contribute to organic matter decomposition and antagonism against root pathogens, making them vital for tea tree growth and health. Archaea, a relatively newly discovered group of microorganisms, are still under investigation

for their functions and impacts in soil ecosystems, with the potential to exert significant influence (Liu et al., 2017).

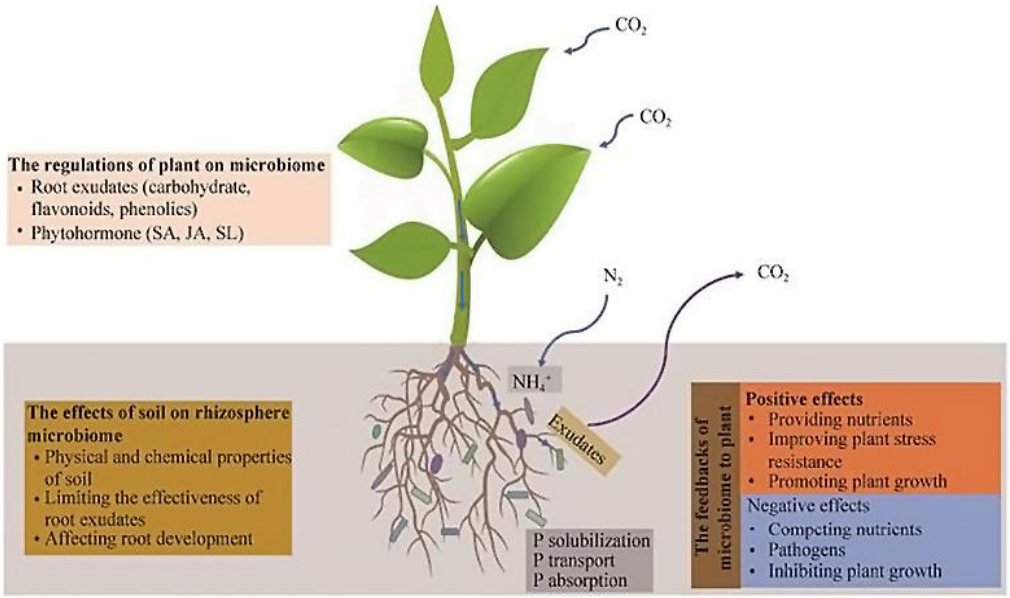

Figure 2 Construction of plant rhizosphere microbial communities (Liu et al., 2021)

2.2 The impact of soil characteristics on microbial diversity

The soil pH value is one of the key factors influencing microbial diversity. Yunnan large-leaf tea trees typically thrive in acidic soils, with the pH of their rhizosphere soil ranging between 5.5 to 6.5. Acidic soils are often rich in elements like aluminum and manganese, and the solubility of these elements is influenced by pH, subsequently affecting microbial survival and reproduction. Some microbes in acidic soils can adapt to low pH environments, but highly acidic soils may limit microbial diversity. Furthermore, the oxygen concentration in the soil is also influenced by pH, thereby impacting the distribution of aerobic and anaerobic microorganisms.

In addition to pH value, soil nutrient content also exerts an influence on microbial diversity. Nutrient-rich soils typically support more diverse microbial communities because microorganisms require nutrients for their growth and reproduction. Nutrients essential for tea tree growth, such as nitrogen, phosphorus, and potassium, are also influenced by soil nutrient content, which, in turn, affects the microorganisms interacting with tea tree roots.

2.3 Role of plant root exudates

Plant root exudates are another crucial factor in the interaction between tea plants and soil microbiota. These exudates from tea plant roots consist of organic compounds, plant hormones, secondary metabolites, and so on. They not only serve as a carbon source and energy supply for soil microbiota but also induce microbial growth. These exudates may also play a role in regulating microbial diversity since different types of root exudates can selectively promote or inhibit the growth of specific microorganisms. Furthermore, root exudates can influence soil pH value. Some plant root exudates have the ability to alter soil pH, further impacting the diversity of rhizosphere microbiota and soil chemical properties.

The formation of microbial diversity in the root microbiome of Yunnan large-leaf tea trees is a complex process influenced by a combination of soil characteristics, plant root exudates, and interactions among microorganisms. A thorough investigation into this process of microbial composition and diversity formation will contribute to a better understanding of the complexity of Yunnan tea production ecosystems, providing a scientific foundation for the sustainable development of the tea industry.

3 Relationship between Soil pH and Microbial Diversity

Soil pH is a crucial parameter determining soil chemical properties, and it directly impacts the diversity and activity of microorganisms in the soil. In the growing environment of Yunnan large-leaf tea trees, fluctuations in soil pH have a significant influence on the composition and function of root microbiota. The following section will delve into this relationship in detail.

3.1 Characteristics of acidic and alkaline soils

Acidic soils typically have a low pH value, and their acidity is primarily caused by a high concentration of hydrogen ions (H^+). These soils often contain ions such as aluminum and manganese, which are more soluble under acidic conditions, thus affecting the chemical properties of the soil. Acidic soils may also lead to a reduction in certain microbial populations since some microorganisms cannot adapt to extreme acidic environments.

On the contrary, alkaline soils possess a high pH value and are typically rich in carbonate ions (CO_3^{2-}) and hydroxide ions (OH^-). These soils are generally less sensitive to the solubility of elements like aluminum and manganese. In alkaline soils, certain microorganisms may encounter adaptation challenges that are opposite to those in acidic soils, as the solubility properties of nutrients differ under alkaline conditions.

3.2 Impact of pH on microbial diversity

Soil pH directly influences microbial growth and activity, with different microbial communities exhibiting varying degrees of adaptability to pH levels. Typically, bacteria and fungi thrive in neutral to slightly acidic soils (pH 6-7), while archaea are more commonly found in more acidic (pH below 5) or alkaline (pH above 8) soils.

Some microbial populations possess the capability to adapt to acidic or alkaline conditions. They can regulate soil pH by producing specific enzymes or by forming symbiotic relationships to utilize plant root exudates, allowing them to thrive in diverse soil environments (Rousk et al., 2009). These adaptive strategies contribute to the preservation of microbial diversity in the soil while maintaining the stability of the soil ecosystem.

4 Association between Root Microbiome of Yunnan Large-Leaf Tea Trees and Soil pH

There exists a close association between the root microbiome of Yunnan large-leaf tea trees and soil pH value. Significant variations in soil pH across different tea cultivation sites directly impact the diversity and structure of root microbiota. The diversity and abundance of root microbiota may exhibit substantial differences under varying soil pH conditions, further underscoring the correlation between the root microbiome of tea trees and soil acidity or alkalinity. Furthermore, fluctuations in the root microbiome could potentially influence tea production and quality.

4.1 Related reviews

Over the years, researchers have conducted studies on the association between the root microbiota of Yunnan large-leaf tea trees and soil pH value. These studies have not only contributed to our understanding of the microbial ecosystem in Yunnan tea production but have also provided valuable insights into how soil management can be optimized to enhance tea yield and quality.

Research has shown that soil pH is one of the key factors influencing the diversity of microorganisms in the roots of tea trees (He et al., 2021). Acidic soils typically support microbial communities different from those in alkaline soils, and these microorganisms exhibit varying adaptability and ecological functions under different soil pH conditions. Additionally, studies have revealed that certain microbial groups employ adaptive strategies to thrive and reproduce under diverse soil pH value. These adaptations encompass the regulation of metabolic pathways, the production of tolerance enzymes, and the establishment of mutualism relationships with plant roots (Jiang et al., 2015). Furthermore, the research underscores the significance of soil pH in tea production, as soil acidity or alkalinity can directly impact nutrient absorption, growth, disease resistance, and ultimately, the yield and quality of tea leaves.

By delving into the association between the root microbiota of Yunnan large-leaf tea trees and soil pH, we can not only gain a better understanding of the complexity of the tea production ecosystem but also provide practical scientific foundations for the sustainable development of the tea industry. These research findings empower agricultural practitioners with effective tools for managing soil environments more efficiently and maximizing the potential of tea production.

4.2 Microbiome analysis based on high-throughput sequencing technology

In recent years, the rapid development of high-throughput sequencing technology has provided unprecedented opportunities for studying the diversity of microbiome in tea tree root systems. The application of these technologies has not only enhanced our ability to distinguish microbial populations but has also allowed for a deeper understanding of their structure and functions (Fierer, 2017). By collecting rhizospheric soil samples, researchers can obtain detailed information about microbial communities, revealing the profound impact of soil pH on the ecological dynamics of rhizospheric microorganisms.

High-throughput sequencing technologies, particularly the sequencing of 16S rRNA and ITS sequences, have become crucial tools for studying soil microbial diversity (Lu et al., 2016). These technologies enable researchers to simultaneously analyze thousands to even millions of microbial gene sequences, revealing the complexity of microbial communities. In the study of rhizospheric microorganisms in tea trees, high-throughput sequencing technology offers a novel perspective, allowing researchers to delve into the composition and functionality of these minute organisms (Caporaso et al., 2012).

Through high-throughput sequencing technology, researchers have been able to study microbial communities under different soil pH conditions with greater precision than before. These studies have revealed that soil pH is one of the major factors influencing rhizosphere microbial diversity (Lauber et al., 2009). Specifically, acidic soils tend to be rich in acid-tolerant microorganisms, while alkaline soils support alkaline-tolerant microorganisms (Rousk et al., 2010). This pH-related variation in microbial populations reflects the adaptive strategies employed by microorganisms in response to different environmental conditions.

In conclusion, high-throughput sequencing technology has provided researchers with a powerful tool for gaining a deeper understanding of the relationship between the diversity of root microbiome in tea trees and soil pH value. These techniques enable researchers to uncover the structure and functionality of microbial communities and how they are influenced by soil environments. This profound understanding serves as a crucial foundation for optimizing tea production, facilitating higher yields and better quality tea, all while preserving the health of soil ecosystems.

4.3 Microbial diversity variation under different soil pH conditions

Studies have shown that there are significant differences in the microbial diversity of the roots of Yunnan large-leaf tea trees under varying soil pH conditions (Shen et al., 2013). In acidic soils, one typically observes a higher presence of acid-tolerant microorganisms, such as acid-producing enzyme bacteria and fungi. These microorganisms are more adept at thriving and reproducing in low-pH environments. Conversely, in alkaline soils, alkaline-tolerant microorganisms, such as ammonia-oxidizing bacteria and carbonate salt-tolerant fungi, may be more abundant. These microorganisms can adapt to high-pH environments and play vital roles in the soil.

Changes in soil pH are typically accompanied by fluctuations in microbial diversity and abundance. Under different pH conditions, microbial diversity may increase or decrease, depending on the specific soil properties and environmental conditions.By optimizing soil pH, agricultural producers can better manage soil ecosystems, enhance tea yield and quality, while also preserving soil health and sustainability.

5 Significance of Microbial Diversity for Tea Production and Ecosystems

Microbial diversity is closely linked to the maintenance of root microbiota in Yunnan large-leaf tea trees and soil pH value. This association has profound implications not only for tea yield and quality but also for the health and stability of soil ecosystems.

5.1 Impact on tea yield and quality

Rhizosphere microorganisms play a pivotal role in enhancing the growth of tea plants (Pii et al., 2015). Certain microbial communities contribute to increased nutrient uptake efficiency, with nitrogen-fixing bacteria, for instance, converting atmospheric nitrogen into plant-absorbable forms, thereby promoting tea plant growth (Philippot et al., 2013). Microorganisms also act as natural enhancers of tea plant resistance. Some microbes inhibit plant pathogens in the soil, helping reduce disease burdens on tea plants and minimizing the need for pesticides, ultimately enhancing tea leaf quality and ecological sustainability.

The flavor and quality of tea are closely intertwined with microbial diversity. Microbes can influence the chemical composition of tea leaves, affecting aroma compounds and enzyme activity. Consequently, adjusting the composition of rhizosphere microorganisms can lead to improvements in the taste and aroma of tea leaves.

5.2 Health and stability of ecosystems

Microorganisms play a crucial role in nutrient cycling within the soil, such as the decomposition of organic matter and nutrient release. They transform organic substances into nutrients available for plant uptake, thereby maintaining soil fertility (Tkacz et al., 2015). Microorganisms also contribute to the stability of soil structure, enhancing aeration and water retention capabilities.

The diversity of rhizosphere microbial communities contributes to maintaining ecological balance; they can suppress pathogen proliferation, reducing plant disease incidence. This ecological balance helps preserve the health and stability of soil ecosystems (Philippot et al., 2013). Microbes play a crucial role in soil ecosystem health and sustainability through mechanisms such as improving soil structure, reducing erosion, and safeguarding organic matter storage (Berg and Smalla, 2009). They help decrease soil erosion, maintain soil fertility, and mitigate the risk of soil impoverishment.

The association between the microbial diversity in the roots of Yunnan large-leaf tea trees and soil pH not only directly impacts tea yield and quality but also plays a crucial role in maintaining the health and stability of the soil ecosystem. Therefore, by implementing proper soil management and preserving microbial diversity, it is possible to achieve higher tea yields, improved tea quality, and a healthier soil ecosystem. This is of paramount importance for the sustainable development of the Yunnan tea industry.

6 Applications and Prospects

6.1 The role of soil microbes in sustainable agriculture

Soil microbes are integral components of soil ecosystems, and they have profound implications for the sustainability of agriculture (García-Fraile et al., 2015). In the future, soil microbes may play pivotal roles in agricultural environments, promoting the production of healthy foods, and aiding in pollution management, among other areas.

Based on a deep understanding of soil microbiota, researchers have begun developing microbial formulations aimed at improving nutrient uptake and plant growth (Jansson and Hofmockel, 2018). These bio-fertilizer and enhancers can reduce the reliance on chemical fertilizers, thus mitigating the environmental impact of agriculture.

Soil microbiota also play a pivotal role in organic farming. Organic agriculture harnesses the natural functions of soil microbiota to minimize the use of chemical pesticides and synthetic fertilizers, promoting the production of healthy and sustainable food. Soil microbiota can also aid in the degradation of organic and inorganic pollutants, purifying contaminated soils. This holds significant potential for soil remediation in agricultural and industrial areas.

6.2 Regulating soil pH for optimizing tea production potential

Regulating soil pH is one of the key factors in achieving high-quality tea production (Le et al., 2022). Based on the relationship between soil microbial diversity and soil pH, future agricultural management can become more precise. Farmers and agricultural experts can utilize information on microbial diversity to adjust soil pH to meet the requirements of tea plants at different growth stages.

Researchers are developing novel soil amendments that can alter soil pH by influencing soil microorganisms. These innovative methods hold the promise of increasing tea yield and quality. By managing soil pH more effectively, tea producers can establish sustainable tea cultivation practices. This will contribute to maintaining soil health, reducing the adverse environmental impacts of agriculture, and ensuring a stable tea supply for future generations.

7 Conclusion

This review delves into the association between the root microbiome diversity of Yunnan large-leaf tea trees and soil pH value, as well as its significance, unveiling the importance of this relationship for tea production and soil ecosystems.

Soil pH is one of the primary factors influencing the diversity of root microbiota in Yunnan large-leaf tea trees (Jiang et al., 2015). Under different soil pH conditions, there are significant differences in the composition and functionality of root microbial communities. Acidic soils typically support acid-tolerant microorganisms, whereas alkaline soils are enriched with alkaline-tolerant microorganisms. Microbial adaptation strategies to soil pH contribute to the maintenance of microbial diversity in the soil.

Microbial diversity has a direct impact on tea yield and quality. Some microbes enhance nutrient absorption and plant growth while suppressing soil pathogens, reducing the need for pesticides, thereby improving the eco-friendliness of tea production. Soil microbes also maintain the health and stability of soil ecosystems. They participate in nutrient cycling, inhibit soil pathogens, purify soil contaminants, and preserve soil fertility and structure.

By adjusting soil pH, agricultural producers can achieve higher yields and better quality tea while preserving soil health and sustainability. In the future, precise soil management and innovative soil amendments are expected to play a more significant role in tea production.

The association between the diversity of root microbiome in Yunnan large-leaf tea trees and soil pH holds significant importance for the sustainability of tea production and soil ecosystems. Gaining a deeper understanding of this association aids in optimizing agricultural practices, enhancing tea yield and quality, while also preserving soil health and ecological balance. With ongoing scientific research, we can anticipate the development of more innovative methods and strategies to support the sustainable growth of the Yunnan large-leaf tea industry.

Reference

Berg G., and Smalla K., 2009, Plant species and soil type cooperatively shape the structure and function of microbial communities in the rhizosphere, FEMS Microbiology Ecology, 68(1): 1-13.
https://doi.org/10.1111/j.1574-6941.2009.00654.x
PMid:19243436

Caporaso J.G., Lauber C.L., Walters W.A., et al., 2012, The ISME journal, 6(8): 1621-1624.
https://doi.org/10.1038/ismej.2012.8
PMid:22402401 PMCid:PMC3400413

Fierer N., 2017, Embracing the unknown: disentangling the complexities of the soil microbiome, Nature Reviews Microbiology, 15(10): 579-590.
https://doi.org/10.1038/nrmicro.2017.87
PMid:28824177

García-Fraile P., Menéndez E., and Rivas, R., 2015, Role of bacterial biofertilizers in agriculture and forestry. Aims Bioengineering, 2(3): 183-205.
https://doi.org/10.3934/bioeng.2015.3.183

He Y.C., Wang M.J., and Qin G.W., 2021, Study on bacterial diversity and its main environmental impact factors in rhizosphere soil of tea plant, Chaye Tongxun (Journal of Tea Communication), 48(1): 40-49.

Jansson J.K., and Hofmockel K.S., 2018, Soil microbiomes and climate change, Nature Reviews Microbiology, 16(1): 35-50.
https://doi.org/10.1038/s41579-019-0265-7
PMid:31586158

Jiang X., Hou X., Zhou X., Xin X., Wright A., and Jia Z., 2015, pH regulates key players of nitrification in paddy soils, Soil Biology and Biochemistry, 81: 9-16.
https://doi.org/10.1016/j.soilbio.2014.10.025

Jiang X., Wang X.H., Zheng W.Z., et al., 2021, Research on the differences in processing and roasting of various tea tree varieties in Yunnan for the quality of green tea, Nongye Yu Jishu (Agriculture and Technology), 41(15): 7.

Liu L., Yang R.J., Wang Q.M., Peng W.S., and Yan L., 2017, Research on epiphytic microbial communities on leaves of ancient tea trees (*Camellia sinensis* var. *assamica*) in Yunnan Province, China, Nongcun Shiyong Jishu, (2): 4.

Lauber C.L., Strickland M.S., Bradford M.A., and Fierer N., 2008, The influence of soil properties on the structure of bacterial and fungal communities across land-use types, Soil Biology and Biochemistry, 40(9): 2407-2415.
https://doi.org/10.1016/j.soilbio.2008.05.021

Lauber C.L., Hamady M., Knight R., and Fierer N., 2009, Soil pH as a predictor of soil bacterial community structure at the continental scale: a pyrosequencing-based assessment, Appl Environ Microbiol, 75(15): 5111-5120.
https://doi.org/10.1128/AEM.00335-09
PMid:19502440 PMCid:PMC2725504

Le V.S., Herrmann L., Hudek L., Nguyen T.B., Bräu L., and Lesueur D., 2022, How application of agricultural waste can enhance soil health in soils acidified by tea cultivation: a review. Environmental Chemistry Letters, 1-27.
https://doi.org/10.1007/s10311-021-01313-9

Lu K.Y., Zhang Y.F., Jia M., Gao L.R., Tian F., and Tang S.K., 2016, Bacteria distribution diversity in tea rhizospheric soil from different habitats at nannuo mountain based on 16S rRNA sequence analysis, Kunming Ligong Daxue Xuebao (Journal of Kunming University of Science and Technology (Natural Science Edition)), 41(2): 89-95.

Philippot L., Raaijmakers J.M., Lemanceau P., and Van Der Putten W.H., 2013, Going back to the roots: the microbial ecology of the rhizosphere, Nature Reviews Microbiology, 11(11): 789-799.
https://doi.org/10.1038/nrmicro3109
PMid:24056930

Philippot L., Spor A., Hénault C., et al., 2013, Loss in microbial diversity affects nitrogen cycling in soil, The ISME journal, 7(8): 1609-1619.
https://doi.org/10.1038/ismej.2013.34
PMid:23466702 PMCid:PMC3721106

Pii Y., Mimmo T., Tomasi N., Terzano R., Cesco S., and Crecchio C., 2015, Microbial interactions in the rhizosphere: beneficial influences of plant growth-promoting rhizobacteria on nutrient acquisition process. A review, Biology and fertility of soils, 51: 403-415.
https://doi.org/10.1007/s00374-015-0996-1

Rousk J., Brookes P.C., and Bååth E., 2009, Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization, Applied and Environmental Microbiology, 75(6): 1589-1596.
https://doi.org/10.1128/AEM.02775-08
PMid:19151179 PMCid:PMC2655475

Rousk J., Bååth E., Brookes P.C., et al., 2010, Soil bacterial and fungal communities across a pH gradient in an arable soil, The ISME journal, 4(10): 1340-1351.
https://doi.org/10.1038/ismej.2010.58
PMid:20445636

Shen C., Xiong J., Zhang H., et al., 2013, Soil pH drives the spatial distribution of bacterial communities along elevation on Changbai Mountain, Soil Biology and Biochemistry, 57: 204-211.
https://doi.org/10.1016/j.soilbio.2012.07.013

Smith S.E., and Read D.J., 2010, Mycorrhizal symbiosis. Academic press.

Tkacz A., Cheema J., Chandra G., Grant A., Poole P.S., 2015, Stability and succession of the rhizosphere microbiota depends upon plant type and soil composition, The ISME Journal, 9(11): 2349-2359.
https://doi.org/10.1038/ismej.2015.41
PMid:25909975 PMCid:PMC4611498