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The Introduction of Worms into Tea Gardens: Ecological Practice of Soil Improvement and Tea Quality Improvement

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Abstract: Under the background of sustainable agricultural development and ecological protection, tea gardens are faced with problems of soil degradation, ecological imbalance, and quality improvement. The model of "worm entering tea garden" came into being. Studies have shown that earthworms can improve soil, promote the growth of tea trees, improve tea yield and quality, and maintain ecological balance, provide a basis for green production and sustainable development, and provide new ideas for solving problems in tea gardens and exploring agricultural ecological models, promote win-win economic and ecological benefits, and promote high-quality development.

Keywords: Earthworm into tea garden; Soil improvement; Ecological balance; Tea quality; Sustainable development

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1. Ecological characteristics of earthworm

1.1. Biological characteristics of earthworms

The earthworm is a key soil organism whose biological traits play a crucial role in maintaining ecological balance. These creatures are primarily active during the daytime and retreat underground at night. They inhabit soils rich in moisture and organic material, deriving nourishment from both organic debris and microorganisms present in the soil. Earthworms exhibit diverse reproductive strategies, encompassing both sexual and asexual methods [1]. For instance, the "Daping No. 2" species can generate offspring via cocoon production when conditions are favorable. Environmental elements, such as nutrient levels in the substrate, can substantially influence their reproductive success. Moreover, earthworms demonstrate remarkable adaptability, thriving across various soil types. However, their population density and overall biomass are frequently linked to the soil's physicochemical characteristics. Research indicates that factors like the carbon-to-nitrogen ratio, pH levels, and heavy metal concentrations in the soil significantly impact the growth and reproduction of earthworms [2].

1.2. Ecological functions of earthworms

Earthworm plays an indispensable role in the soil ecosystem. Its ecological functions are mainly reflected in the decomposition of organic matter, soil aeration, and nutrient cycling. Through these functions, earthworms not only promote soil health and fertility but also create a more suitable environment for plant growth. Studies have shown that earthworms convert complex organic matter into nutrient-rich small molecule compounds through feeding and excretion activities, a process that significantly increases the amount of available nutrients in the soil.

Earthworms not only influence soil physical characteristics but also contribute significantly to nutrient cycling. By transporting minerals from deeper soil layers to the surface, they redistribute these nutrients throughout the soil via their excretions. This activity enhances the nutrient content of the topsoil and supports sustained soil productivity over time [3]. Notably, in specific agricultural ecosystems, like tea plantations, the presence of earthworms has been linked to notable improvements in both tea yield and quality.

The active involvement of earthworms in soil processes follows a dynamic sequence, beginning with the ingestion of organic material, followed by decomposition and transformation, tunneling and aeration activities, and concluding with the release of nutrients. These stages are interconnected and occur progressively. In the context of tea garden management, this process plays a crucial role in fostering a healthy soil microecosystem. Research indicates that using earthworm castings as an amendment in tea gardens can effectively decrease soil bulk density while enhancing both water retention and organic matter levels, thereby indirectly supporting the growth and development of tea plants [4]. Consequently, integrating earthworms into agricultural practices or employing earthworm composting techniques represents a key approach for advancing modern tea garden management.

2. The theoretical basis of the introduction of worms into tea gardens

2.1. The effect of earthworms on soil improvement

Earthworms are crucial for enhancing soil quality in tea gardens, contributing significantly to overall soil improvement through physical, chemical, and biological mechanisms. Their activities improve soil structure by increasing porosity, which enhances aeration and drainage capabilities. This physical enhancement creates a looser environment for tea plant roots to grow while boosting the soil's water retention capacity, ensuring sufficient hydration for tea plants even during dry periods [5]. Simultaneously, as earthworms break down organic matter, they release numerous nutrients essential for tea plant growth and metabolism, such as available nitrogen, phosphorus, and potassium. Furthermore, earthworm activity stimulates the soil microbial community, encouraging the proliferation of beneficial bacteria. This process accelerates the decomposition and humification of organic materials, fostering a healthier soil ecosystem.

Moreover, the activities of earthworms exert a multi-faceted influence on the soil within tea gardens. Specifically, enhancements in the physical characteristics of the soil serve as a precursor to changes in its chemical and biological attributes. For instance, an increase in soil porosity not only boosts aeration but also creates additional space for microbial proliferation. In turn, this thriving microbial population accelerates the decomposition of organic matter, establishing a beneficial cycle. Importantly, earthworm activity can also diminish the concentration of heavy metals—such as copper, zinc, and chromium—in tea garden soils, thereby decreasing the likelihood of tea plants absorbing harmful substances. This characteristic is especially crucial for enhancing tea quality, given that heavy metal residues represent a significant factor impacting tea safety [6].

2.2. Effects of earthworms on tea quality

The impact of earthworm activity on tea quality is evident through its substantial influence on the chemical makeup and sensory characteristics of tea. Research indicates that earthworms enhance the physical and chemical attributes of soil via their biological processes, which in turn indirectly impact the growth and metabolic functions of tea plants, altering key chemical constituents of tea. For instance, in tea gardens enriched by earthworm activity, the concentration of tea polyphenols initially rises before stabilizing, a phenomenon closely tied to the organic material and microbial communities derived from earthworm castings. Furthermore, amino acid levels, crucial for tea's freshness, also rise in soils with active earthworm populations, particularly during the spring tea harvest season, increasing by 10%–15% [7]. Additionally, earthworm activity fosters the buildup of volatile aroma precursors in the soil, which are subsequently absorbed and metabolized by tea plants to produce the distinctive aromatic compounds found in tea.

The line chart in **Figure 1** shows the dynamic effects of earthworm treatment on the chemical composition of tea, in which tea polyphenols, amino acids and aroma components all showed varying degrees of increase. This change not only reflects the effect of earthworm on soil nutrient cycling, but also provides a scientific basis for the improvement of tea quality. From the perspective of sensory quality, earthworm activity improved the flavor coordination and aroma intensity of tea, making it more in line with the evaluation criteria of high-end tea.

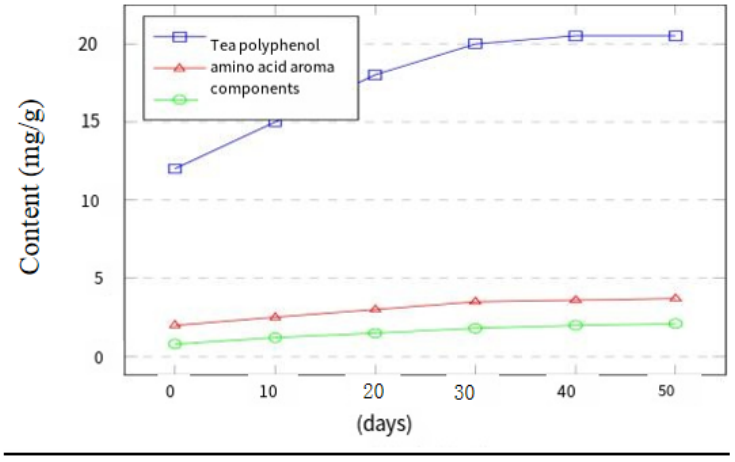

Figure 1. Dynamic effects of earthworm treatment on the chemical composition of tea

Further analysis showed that the effect of earthworm activity on tea quality was spatiotemporal and heterogeneous. The effect of earthworm activity was different in different seasons and types of tea plantations. To better understand this phenomenon, the following mind map summarizes the multilayered relationship between earthworm activity and tea quality.

Through the analysis in **Figure 2**, it can be seen that earthworm activities not only directly improve the ecological conditions of the soil in the tea garden but also enhance the intrinsic quality of tea through complex biogeochemical processes. This finding provides new ideas for optimizing tea plantation management practices while also highlighting the important role of earthworms in sustainable agriculture.

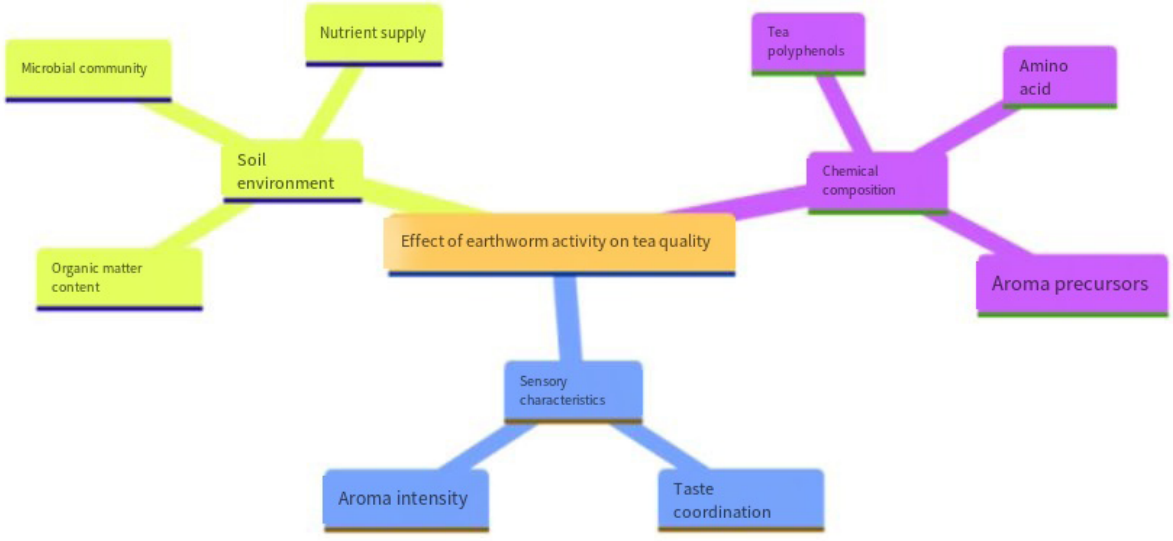

Figure 2. The multilevel relationship between earthworm activity and tea quality

3. Practical application of earthworms in tea gardens

3.1. Methods of introducing earthworms into tea gardens

Introducing earthworms into tea gardens represents an ecological agricultural method that can substantially enhance soil quality and facilitate the growth of tea plants. By carefully selecting appropriate earthworm species, optimizing their placement density, and implementing scientific management practices, both the productivity and sustainability of tea plantations can be greatly enhanced. When choosing earthworm species, it is advisable to focus on those with high adaptability and exceptional capabilities in decomposing organic waste, such as Eisenia fetida and Pheretima guillelmi [8]. These earthworms are not only capable of rapidly acclimating to the tea garden soil environment but also contribute to improving soil structure while enhancing aeration and water retention through their activities.

The density of delivery is one of the key factors determining the effect of earthworm introduction. Studies have shown that 100–200 adult earthworms per square meter in tea plantations is an ideal range. This density can ensure the reproduction and survival of earthworms and will not lead to the intensification of resource competition or the deterioration of the soil environment due to high density. In addition, when placing should be as far as possible to choose cloudy days or evening time to reduce the damage caused by direct sunlight to earthworms and to ensure that earthworms can quickly adapt to the new environment.

Regarding management practices, consistently monitoring soil moisture, temperature, and pH levels is crucial. Since earthworms are highly sensitive to environmental changes, maintaining soil that is adequately moist yet not excessively waterlogged is essential. Additionally, it is vital to refrain from using highly toxic pesticides that could be lethal to earthworms [9]. Furthermore, the proper addition of organic materials, such as straw or cow manure, can provide a sufficient food supply for earthworms while also enhancing soil fertility. Experience has demonstrated that integrating tea gardens with straw mulching techniques not only promotes the growth and reproduction of earthworms but also suppresses weed growth and boosts soil hydration.

To sum up, the scientific and reasonable introduction of earthworms can not only significantly improve the

soil quality of the tea garden but also create a superior growing environment for tea trees, to realize the double improvement of tea yield and quality.

3.2. Application effect of earthworms in tea garden management

From the viewpoint of soil enhancement, earthworm activity contributes to increased soil permeability, facilitates water infiltration, and enhances aeration, thereby improving soil conditions. Earthworm castings, serving as an excellent source of organic fertilizer, are abundant in essential nutrients like nitrogen, phosphorus, and potassium, which can substantially boost soil fertility. Additionally, the actions of earthworms can expedite the breakdown of organic materials, support the diversification of soil microbial populations, and consequently establish a more robust soil ecosystem. Such transformations offer superior growth environments for the root systems of tea plants, aiding in nutrient uptake and strengthening their resilience against stress factors.

In terms of pest management, the existence of earthworms can play a role in indirectly minimizing pest populations within tea gardens [10]. For instance, the actions of earthworms stimulate the proliferation of advantageous microorganisms in the soil, which helps suppress the development of specific disease-causing agents. Moreover, by enhancing the soil conditions, earthworms contribute to the robustness of tea plants, thereby lessening the likelihood of pest infestations and diseases. While certain pesticides may negatively impact earthworms, the appropriate application of organic farming methods can successfully mitigate such issues [11].

The use of earthworms also showed positive results in terms of tea yield and quality. The study found that tea plantations using worm manure or worm composting technology generally had higher tea yields than those under traditional management. Additionally, the soil modified by earthworms increased the content of key components such as amino acids and tea polyphenols, thereby improving the taste and aroma of tea. This quality improvement not only meets consumers' demand for high-quality tea but also brings higher economic benefits to tea farmers.

The contribution of earthworms to the management of tea plantations mainly focuses on soil improvement (40%), pest control (35%), and the improvement of tea yield and quality (25%). The combined effect of these three aspects makes earthworms one of the important tools for the ecological management of tea gardens.

Further analysis shows that the application effect of earthworm is closely related to its ecological environment. For example, in the mode of mixed raising native chickens in an organic tea garden, earthworms and other organisms jointly build an efficient ecological circulation system. This model not only improves the economic benefits of the tea garden but also enhances the stability of the ecosystem. In addition, by-products such as humus and microbial metabolites produced during the composting process of earthworms can also provide additional nutrient support for tea plants.

4. The economic and ecological benefits of earthworms entering the tea garden

4.1. Economic benefit analysis

The economic impact assessment of introducing earthworms into tea gardens must take into account various factors, including cost expenditure, enhancement of tea output, and elevation of market value. Research indicates that incorporating earthworms into tea gardens can enhance soil structure and fertility while substantially boosting tea production and quality through their biological functions. In real-world applications, the method of earthworm composting has been demonstrated to be a highly effective and eco-friendly approach for transforming organic waste into premium organic fertilizer. This transformation not only mitigates environmental contamination but

also supplies essential nutrients to tea plants, thereby stimulating their growth.

In order to more intuitively show the economic benefits brought by the introduction of worms into the tea garden, the following table details the relevant economic indicators (**Table 1**).

Table 1. Economic benefits of worms entering tea plantations

Projects	Cost (yuan/mu)	Increased production (kg/ mu)	Increase market value (%)	Net income growth (yuan/mu)
Initial investment	500	-	-	-
Annual maintenance	200	15	10	1,200
Long-term benefits	-	30	20	3,000

From the table above, it is evident that while there was a certain expense involved in the early stages of introducing earthworms, as these earthworms began to impact soil enhancement positively, tea production witnessed a substantial increase. Additionally, due to improvements in quality, market prices also rose. It is projected that under standard management practices, each mu of tea plantation could generate an extra net profit of approximately 1,200 yuan annually. In the long term, this amount has the potential to exceed 3,000 yuan.

In addition, it is worth noting that in addition to direct economic benefits, the adoption of worm farming can also help build a more sustainable agroecosystem. For example, it helps reduce the use of chemical fertilizers, reducing pressure on the environment while also attracting more beneficial insects, creating a virtuous cycle. Therefore, in the long run, promoting the vermis model in tea plantations is of great significance for achieving the goal of high-quality development of China's tea industry.

4.2. Ecological benefit analysis

The ecological benefit analysis of vermiculture in tea plantations is a key perspective to understand its importance in sustainable agriculture. Earthworm activity can significantly improve soil health, especially in the special ecosystem of tea plantations, not only in terms of physical structure improvement but also in terms of biodiversity and carbon sink capacity. Studies have shown that earthworms can significantly improve soil microbial activity, such as increasing the number of bacteria, fungi, and actinomyces, by breaking down organic matter and promoting nutrient cycling. This change further optimizes soil enzyme activity, such as catalase, urease, and alkaline phosphatase, thus providing a better growing environment for tea plants.

5. Conclusion and prospect

The application of earthworms in tea gardens was systematically analyzed to reveal its multiple contributions to the sustainable development of agriculture. Studies have shown that earthworms and their metabolite, worm castings, can significantly improve the physical, chemical, and biological properties of soil in tea plantations. Specifically, earthworm activity not only increased soil organic matter content and nutrient availability but also enhanced the diversity and activity of microbial communities. These changes provide a better growing environment for tea plants, thereby improving tea yield and quality. In addition, the application of earthworm composting technology effectively solves the problem of waste disposal in tea gardens and realizes the recycling of resources.

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