Tea/Tree Intercropping Plantations on Soil Ecological Service Function

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The benefits of intercropping tea plantations exceeded those of monocropping tea plantations in terms of soil ecosystem service functions, such as water retention capacity, mineral contents, effects on energy transformation, and regulating environmental conditions. Intercropping tea plantations were more sustainable than regular tea plantations because of the different degrees of variability and benefits in all three aspects mentioned above. However, tea and tree intercropping plantations often require careful planning and preliminary experimentation to determine the type of intercropping that will have positive impacts, especially in the long term.

intercropping tea plantations | soil | ecological service function | water-retention capacity | environmental conditions | sustainability

1. Introduction

In the scope of agroforestry, ecological tea gardens, more precisely intercropping tea gardens, are a very important and significant component. In the tea (*Camellia sinensis* L.) and other species' intercropping gardens, the key is the cultivation of tea and other tree and plant species. Tea garden intercropping is a planting mode in which tea is the main crop, and one or more trees and other crops are planted in the same tea garden using the gaps between tea rows to form an artificial vertical composite ecological tea garden. It makes full use of different spaces and soil layers on the same land, so that different plants and tea intercrop [1]. Conducting reasonable intercropping can regulate the light, temperature, water, and atmospheric conditions of tea plantations, improve the soil environment, enhance soil fertility, increase the biodiversity in the ecosystem of tea plantations, maintain the ecological balance of tea plantations, and make all ecological factors change in a direction favorable to the growth of tea trees. It can improve the land use value of tea plantations, and produce comprehensive benefits for ecological, economic, and social aspects [1].

Based on different combinations, intercropping tea gardens have been classified into four types: tea–tree intercropping, tea–fruit intercropping, tea–herb intercropping, and tea–fungi intercropping [2]. These four cropping methods are the most common intercropping practices, and all can contribute critically to ecosystem services [3]. The ecosystem service function refers to the natural environment and utility formed and maintained by the ecosystem and ecological process [4]. These systems provide food, medicine, and other raw materials for human production and living, and create and maintain the Earth's life support system [5][6]. Tea–tree intercropping systems, an agroforestry system that integrates tea trees with other tree species, are helpful and have considerable ecological profits. For example, when intercropping tea trees and cedar trees, they can be arranged into a network of a protective forest belt around the tea garden to regulate the microclimate of the tea garden and enhance the ability of tea trees to resist catastrophic weather [7]. The intercropping of tea plants with other tree species may facilitate plant growth, enhance nutrient cycling, and bolster disease resistance [8]. When tea trees are intercropped with Gentiana (*G. rigescens*), the tea trees can promote the growth condition of the root length of Gentiana, and Gentiana can increase the yield of tea [9]. Additionally, due to the nitrogen-fixing capabilities of rattail grass (*Vulpia myuros*), the soil environment can be ameliorated, ultimately leading to increased tea yields [10][11].

2. Tea/Tree Intercropping Plantations on Soil Ecological Service Function

Intercropping Tea Plantations

There are four main types of intercropping models according to the types of tea plantations. They are tea herb intercropping mode, tea fruit intercropping mode, tea forest intercropping mode, and tea fungus intercropping mode. In addition, they also include tea intercropping with an agriculture (field crops, vegetables) model, tea intercrops with a forests and agriculture model, tea intercrops with a forests, edible mushrooms, and agriculture (herbs) model, etc.

The tea forest composite planting mode (which refers to the tea trees' composite planting mode) refers to the appropriate over-planting of high-rise (tree type), fast-growing, and productive tree species and economic tree species between or outside the rows of tea plantations to form a multi-species and multi-level composite three-dimensional structure, such as with conifer and rubber trees. The advantage is to use the growth characteristics of tea trees and different tree species to establish a scientific and reasonable combination form of a three-dimensional structure. This could create an ideal regional microclimate, and create a natural environment suitable for tea tree growth, which can meet the ecological habit requirements of tea trees. It could also improve the utilization of soil, solar energy, and biological energy, enrich biological diversity, enhance system stability and output function, protect the ecological environment, and improve tea quality.

In the intercropping of different fruit trees in the tea garden (tea–fruit composite planting mode), using the root system of tea trees and fruit trees, the tree postures in the spatial distribution are not at the same level of height combination. Fruits include waxberry (*Myrica rubra*), North American plums (*Prunus americana*), apples (*Malus pumila*), and others. They could improve the microclimate environment of the tea garden, could efficiently integrate the use of water, soil, light, heat, and air in the tea garden, and could improve land utilization and light energy utilization. Fruit trees' canopies are conducive to resisting the damage of excessive direct sunlight on tea trees, reducing the evaporation and transpiration of tea plantations, increasing the air humidity, and improving the environmental conditions of tea plantations. At the same time, tea–fruit intercropping enriches the biological community of tea plantations and provides a suitable habitat for natural enemies of tea tree pests. Moreover, it gives full play to their natural control of pests, significantly reducing the main pests of tea trees, thus contributing to improving tea quality.

In the tea–grass complex planting model, grass not only stands for natural grasses, but also for some green manure crops. Therefore, a more detailed division can be made between herbaceous tea plantations and grain–tea intercropping tea plantations. The herbaceous tea plantations include aromatic plants (billygoat weed (*Ageratum conyzoides*), alfalfa (*Medicago sativa*), etc.), leguminous green manure plants (white clover (*Trifolium repens*) and soybean (*Glycine max*)), and natural grasses. The rest of the tea plantations are intercropped with grains, such as perennial rye-grass (*Lolium perenne*), corn (*Zea mays*), potato (*Solanum tuberosum*), and edible legumes (broad bean (*Vicia faba*), smooth vetch (*Vicia glabrescens*), mung bean (*Vigna radiata*), etc.). Aromatic plants or green manure crops can be planted between the rows of the tea plantation and between the terrace walls, or the ground can be artificially covered with straw and other plant material between the rows of the tea plantation, forming a two-layered structure of tea–grass (fertilizer). The advantage is that this increases the coverage of the topsoil layer, improving the soil structure and making full use of the space in the tea garden to increase the carbon sink capacity. It also improves the soil organic matter and N content, thus increasing the soil fertility level. It inhibits the growth of weeds and saves costs.

If the composite cropping pattern includes mushrooms, it will be classified in this broad category. Tea tree and fungus species, by the principle of symbiosis and mutual benefit, artificially create conditions, through the tea–(forest)–optimal fungus combination, three-dimensional cultivation, to produce a compound income of a multi-species, multi-level, multi-functional, multi-benefit, high-efficiency, high-quality, sustainable, and stable composite planting model. Its characteristics include the development of three-dimensional planting, which improves the ecological environment of tea plantations, as well as fertilizing the soil of tea plantations. It also improves the water retention of soil and tea plantations' moisture retention capacity, increases the output and income of tea plantations, improves the quality and yield of tea, saves labor by reducing expenditures, and improves the comprehensive benefits of tea plantations. Fungi include Yunnan roundheads mushrooms (*Stropharia yunnanesis*), Ganoderma, arbuscular mycorrhizal fungi (AMF) I (*Claroideoglomus etunicatum*), and others.

Supply Services—Maintaining Fundamental Water-Holding Capacity

An intercropping plantation is able to improve soil water holding capacity. In particular, the double-layer canopy space structure intercepts rainfall twice, reduces the direct scouring of rainwater on the soil surface, reduces surface runoff, helps maintain the physical structure of the soil surface, and is conducive to the protection of soil and water and soil fertility [12]. For example, expanding the planting area of eggfruit (*Lucuma nervosa*) through inter-planting tea trees has a positive effect on preventing soil erosion and the spread of stone desertification in mountainous areas, and is also conducive to the development of eggfruit industrialization [13][14]. Tea trees intercropped with broad bean and pea (*Pisum sativum*) can not only reduce the evapotranspiration of the topsoil, but also, due to the tea tree intercropping, increase the organic matter content of the soil—the organic matter content of broad bean in an intercropping tea plantation increased 13.5% and the organic matter content of pea in an intercropping tea plantation increased 14%. When tea trees intercrop with perennial rye-grass and pea, it promotes the formation of the soil aggregate structure, enhances the water holding capacity of the soil, avoids the loss of water from the topsoil, and thus improves the soil water content. For example, the soil water content of perennial rye-grass intercropped with tea plantations increased by 2.8%, and the soil water content of pea intercropped with tea plantations increased by 0.47% [15]. Intercropping white clover can effectively delay and shorten drought times by increasing the water content of the soil surface layer during high temperature periods of drought. In addition, it reduces the impact of drought on tea tree growth, which is a good biological measure for water conservation and moisture preservation in the drought defense technology system of tea trees in subtropical hills [16][17]. The experiment showed that the effect of intercropping white clover in different soil depths on water content control was different. The average water content of intercropping white clover in a 0–20 cm soil layer was significantly higher than that of monoculture tea plantations in all months of the year, which increased by 7.14% [16]. Due to the vigorous growth of tea trees, the evaporation of water increased, which led to the deeper root distribution of tea trees (the main root distribution was 0–50 cm, which was larger than that of 0–40 cm in monoculture) and a greater consumption of deep soil water. This increased soil water utilization [18]. Complex ecosystems artificially combine multiple species and increase the number of beneficial organisms of the tea tree system, and have good ecological control functions against a catastrophic climate [19]. In a rubber-tea plantation, the complementary vertical water use pattern of rubber tree trees and tea trees reduces the competition for water and nutrients, a common phenomenon in efficient agroforestry complex systems [20]. It also allows the root distributions to complement each other, as the roots can find and avoid neighboring roots, creating spatial segregation in the soil. This phenomenon is referred to as hydroecological niche separation [21][22]. The rubber tree trees absorb water evenly from each row on the slope. This water use pattern ensures a synergistic hydraulic redistribution in this agroforestry complex system.

Support Services—Effects on Mineral Elements in Soil

Under intercropping patterns, the relative changes in the content of various metal ions and other biochemical components in the soil may have different effects on the intercrop. Such effects may act on the nutrient cycling process of the intercrop, or may directly affect the soil fertility, thus accelerating or weakening the growth capacity of the plants. For example, an experiment by Dong Minghui et al. [23] in Suzhou was conducted in the famous Dongting Mountain Biluochun tea area. This experiment used the flame photometric method and atomic absorption to characterize soil nutrients in five tea–fruit intercropping types of tea plantations in the region. It included tea and loquats (*Eriobotrya japonica*) intercropping, tea and waxberry intercropping, tea and tangerines (*Citrus reticulata*) intercropping, tea and Ginkgo tree (*Ginkgo biloba*) intercropping, and monoculture tea plantations. The results showed that tea–fruit intercropping significantly increased the contents of organic matter, fast-acting P, fast-acting K, and alkali-hydrolysable N [23]. At the same time, the soil pH varied according to the type of intercropped fruit trees. It also effectively increased the organic matter content of tea tree soil, which helped to increase the content of soil organic matter and available nutrients such as N, P and K elements [24][25]. However, when tea trees are intercropped with different plants at different times, the effects on the production of chemistry substances in tea leaves are not the same. A study by Wang et al. [26] found that intercropping aromatic plants in tea plantations for a short period would cause competition with tea trees for nutrients. When tea trees were intercropped with wrinkled giant hyssop (*Agastache rugosa*), common sage (*Salvia japonica*), sweet William (*Dianthus barbatus*), annual phlox (*Phlox drummondii*), and common soapwort (*Saponaria officinalis*), respectively, the effects of different intercrops on the soil organic matter were inconsistent. Except for annual phlox, the other intercropping types' effects on soil organic matter content in different soil layers were lower than that in monoculture tea plantations. It was particularly pronounced in the topsoil layer. This may be due to the rapid growth of intercrops, forming nutrient competition with tea trees in the early stages [26].

Regulating Services

Microorganisms are active participants and promoters of soil formation and soil fertility. Additionally, they regulate material cycling, energy conversion, and information transfer between biological, soil and environmental systems. The humic acid they decompose and transform plays an important role in maintaining stable soil functions. It indicates that tea trees and soybean intercropping can improve the growth of inter-root soil microorganisms, which may be due to the intercropping crop's root interactions, making root secretions more abundant [27]. The intercropping of leguminous green manure and tea trees can also improve the abundance and diversity of inter-rooted soil microbial communities. The species and content of phospholipid fatty acid biomarkers of tea tree inter-rooted microorganisms increased by 94.18% and 2.49%, respectively. Leguminous green manure can effectively improve soil fertility and promote the metabolic activity of inter-root microorganisms on nutrients in tea plantations, which is of practical significance to enhance the economic and ecological benefits of tea plantations [28]. Similarly, scientists discovered that when round-leaf cassia (*Chamaecrista rotundifolia*) was treated with fertilizer, the three major groups of microbial populations in the soil, namely bacteria, actinomycetes, and fungi, exhibited varying degrees of increase [29].

Intercropping modes improve the soil environment in directions such as soil temperature, PH, and the humidity of tea trees, effectively improving the self-regulating ability of the associated biological community of tea trees [30][31][32]. Zhu Haiyan et al. (2005) studied tea–persimmon (*Diospyros kaki*) intercropping tea plantations in Hubei Province. The results showed that after intercropping, the pH values of both inter- and non-inter-root soils of tea trees were 0.2 units higher than those of pure tea plantations [12]. Soil acidification has become a constraint for high yield tea, as the percentage of tea plantations with a pH below 5.0 is about 70% in China [33]. From the measured results, the pH value of soils in both systems was lower than 5.0. However, after intercropping, the pH value of soils increased, and soil acidification was improved to some extent, thus providing a better growing environment for tea plant growth. Intercropping patterns also improve the capability of the soil nutrient supply [34][35]. According to Sun et al. [36], an average of one shade plant per 12 m^2 tree and 1 hm^2 of leaf litter can add 5 t of organic matter to the soil, which is equivalent to 77 kg of N per hectare. This shows that the inter-planting of tea plantations with forest trees can promote the circulation of nutrients in tea plantations and increase soil organic matter. It could also enhance the ability of the soil to maintain and supply nutrients [37], improve land utilization, increase the early income of tea trees, and promote economic development [38].

Intercropping Tea Plantations vs. Monoculture Tea Plantations

As the evidence suggests, each planting method has its own advantages and disadvantages. However, it is clear that the advantages of agroforestry intercropping far outweigh the disadvantages. Meanwhile, the advantages of agroforestry intercropping also outweigh those of monoculture tea orchards. By comparison, the water consumption of ordinary monoculture tea plantations is much greater than that of intercropping tea plantations. Since intercropping tea gardens have a high soil water content and low evaporation, they can save water loss.

Moreover, the former possesses a scarcity of ecological diversity that is far less resilient to natural disasters than the latter. Due to the complex ecological environment and the rich biodiversity of intercropping tea plantations, the resistance to intercropping tea plantations is generally extremely high. Even in a disaster that may lead to the extinction of some species, such as large-scale forest fires or floods, other species will still survive. In contrast, monoculture tea plantations may be considerably more susceptible to complete devastation in the face of such adversities. Long-term monoculture tea plantations can lead to high acidity and reduced local soil fertility, resulting in soil erosion. However, the interaction between species in intercropping tea plantations can increase the permeability of the soil, alleviate the acidification intensity of the soil, and improve the quality of tea leaves.

Furthermore, it significantly impacts the diversity of fungi and bacteria in the soil microenvironment. Monoculture tea plantations may attract similar pest or weed species due to a single species. Long-term monoculturing can lead to pest and weed resistance, and the chemicals can also cause irreversible damage to the soil. However, intercropping tea plantations can significantly increase the species richness and community diversity of arthropod communities and increase the proportion of predatory and parasitic natural enemies in the total number of individuals of tea tree canopy species. Pest and disease control is achieved through biological control [39].

On the one hand, the professional knowledge tea cultivators need for monoculture tea plantations is less than that needed for intercropping tea gardens due to its single species. On the other hand, monoculture tea plantations require far less labor and material resources than intercropping tea plantations. The cultivation plan is the same every year, and only handling equipment for the tea plant is needed. A simple process can save considerable costs for the tea factory. An additional point to mention is that monoculture tea plantations have been around for thousands of years, and tea cultivators have already worked out how to obtain higher yields from their local tea trees. A specialized system has been derived for a long time under a fixed climate and location.

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