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Review

Feasibility of Tea/Tree Intercropping Plantations on Soil Ecological Service Function in China

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Abstract: In order to explore whether tea/tree intercropping plantations have positive effects on soil ecosystem services functions, the possible effects of intercropping cultivation of 151 different tea and other species' intercropping setups were summarized and analyzed in terms of three aspects of soil ecological service functions (supply services, support services, and regulating services). An ArcGIS map was plotted to show the distribution of existing intercropping plantations in China up to June 2021. Furthermore, it was concluded that 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.

Keywords: intercropping tea plantations; soil; ecological service function; water-retention capacity; environmental conditions; sustainability; monoculture tea gardens

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1. Introduction

The rapid development of human science and technology and the economy has come at the expense of natural resources, and there has been a conflict between the conservation of the natural world and social development over the past decades [1]. Fortunately, the awareness of this problem and appeals to the public to value natural resources have increased exponentially. "Sustainable development" is based on summarizing the positive and negative experiences and lessons of the relationship between development and the environment [2]. The Sustainable Development Goals of the UN are designed to ensure a better future for both nature and humans. The 15th of the 17 targets, Life on Land, is aimed at the protection, restoration, and promotion of the sustainable use of terrestrial ecosystems, the sustainable management of forests, and halting and reversing land degradation [3]. Agroforestry is a land use management strategy that integrates trees or shrubs around crops or pastureland and provides ecosystem services and environmental benefits in many aspects [4]. These include increasing carbon sequestration [5,6], enhancing biodiversity conservation [7,8], developing soil enrichment capacity [9], improving air and water quality [10], and improving microclimates and hydrology [11].

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 (scientific names and common names in this review are listed in Appendix A.1 Table A1, and there are also some species intercropping with tea trees but not mentioned in the article that are listed in Supplemental Materials Table S3). 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 [12]. 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 [12].

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 [13]. These four cropping methods are the most common intercropping practices, and all can contribute critically to ecosystem services [14]. The ecosystem service function refers to the natural environment and utility formed and maintained by the ecosystem and ecological process [15]. These systems provide food, medicine, and other raw materials for human production and living, and create and maintain the Earth's life support system [16,17]. 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 [18]. The intercropping of tea plants with other tree species may facilitate plant growth, enhance nutrient cycling, and bolster disease resistance [19]. 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 [20]. Additionally, due to the nitrogen-fixing capabilities of rattail grass (*Vulpia myuros*), the soil environment can be ameliorated, ultimately leading to increased tea yields [21,22].

With various intercropping tea plantation patterns competing with each other, there is no complete overview that can fully reflect the current status of ecological tea plantations in China. For example, the current distribution of intercropping tea gardens in China is unclear, including the number and location of various types of intercropping plantations. Additionally, there is no systematic summary for the extent of the impact of intercropping tea gardens on soil ecological service functions. In order to investigate the impact of intercropping tea plantations on soil ecological service functions, this review will summarize several aspects of the systematic division of the "Millennium Ecosystem Assessment". The "Millennium Ecosystem Assessment" defines ecosystem services as the benefits that humans can derive from ecosystems, where ecosystem services are classified into four categories: provisioning services, regulating services, supporting services, and cultural services [23]. Soil ecosystem service functions are not only reflected in agricultural and forestry production, but the carbon, N, water, and biological reservoirs in soils also make a significant contribution to the sustainability of the planet [24]. The Food and Agriculture Organization of the United Nations (FAO) redefined and clarified ecosystem services and their relationships to soil function when organizing the World Soil Resources Status Report [25]. Specifically, from these four aspects, in the supply service the soil maintains water and supplies plants for growth, provides habitats for soil animals as well as birds, and is a diverse source of biomass. In the regulating service, the soil has a nutrient cycling function and a sediment regulation function that filters and buffers water. In support services, the accumulation, storage, and transformation of organic matter in the soil supports nutrient cycling and increases soil fertility. The cultural services are oriented to the preservation of monuments and ancient records, which are not mentioned in this paper, which rather focuses on the first three.

This review will fill these knowledge gaps and provide a comprehensive overview of the current ecological intercropping tea plantations in China. It aims to provide a systematic review of all types of intercropping tea gardens in China. I will summarize the types and numbers of intercropping tea gardens that are predominantly present in various locations, and create maps to show these data. I will organize selected documents to confirm whether intercropped tea gardens have a greater ability to adjust soil ecological service function than monoculture tea gardens. I will analyze soil ecological functions in intercropping tea plantations from three aspects: supply services, support services, and regulation services. I will also use the results of the analysis to identify knowledge gaps and suggest future research priorities.

2. Materials and Methods

The preliminary scoping search was conducted in May and June 2021 using Web of Science Core Collection, UBC Library, and Elsevier Science Direct abstracts. These three databases cover the more authoritative articles and books available in agriculture and forestry. The coverage of these articles is extensive and up-to-date, especially Web of Science. This citation service indexes an average of about 65 million pieces annually and was once described as the most significant accessible citation database [26]. The leading search terms reviewed were identified as “agroforestry”, “soil ecosystem service function”, “intercropping tea garden”, “sustainability”, and “China”. These main terms were used as the basis for the preliminary scoping research.

The main term combined with the Boolean operator “AND” produced 179 search results (Table 1, and Supplementary Data are available in Table S1). Therefore, the main term, “intercropping tea garden”, was replaced with specific terms such as “tea grass compound type” and “tea fruit compound type”, and the search was repeated. In order to improve specificity, the various compound tea plantation terms were combined into search strings, and the experiment obtained approximately 10,069 search results. Search results identified by all databases were exported to Zotero, and 985 duplicates were eliminated before filtering duplicates. Since Zotero can set up multiple tags and a multi-level table of contents, it is beneficial for this type of large-scale review. In contrast, individual literature management software can only set two levels. Additionally, when using Zotero it is easy to cite and update the cited literature, cite many formats, and directly download the format I need. After selecting 398 articles without any duplicates, including journal articles, research articles, and book chapters related to this topic, the remaining citations went through the screening process explained below (with the inclusion/exclusion criteria as a guide, criteria available in Appendix A.2). After reading and selecting according to content and the criteria, there were 223 papers that formed the basis of this review.

Table 1. Main terms that were used to search for the results documents in the Web of Science Core Collection, UBC Library, and Elsevier Science Direct abstracts. (* means that the word is substitutable in different search terms or may have different derivatives in different search terms, for example, "soil enhanc*" may be "soil enhance" or "soil enhancement".)

Main Terms	Expanded Terms
1. Agroforestry	Agroforestry OR agroforest* OR “agro-forest*”
2. Soil ecosystem service function	Soil OR “soil regulat*” OR “soil enhanc*” OR “soil protect*” OR “soil fertility” OR “soil quality”OR “soil nutrient*” OR “soil stabiliz*” OR “plant nutri*” OR “nutrient cycling” OR decompos* OR “nitrogen cycling” OR “nitrogen fix*” OR “nitrogen captur*” OR “atmosphere* nitrogen fix*” OR “atmosphere* N* fix*” OR “atmosphere* nitrogen captur*” OR “atmosphere* N* captur*” OR erosion control OR “erosion control” OR “water retention”
3. Intercropping tea garden	compound ecological tea garden* OR “intercrop*” OR “intercrop* tea garden*” OR “intercrop* tea plantation*” OR “compound ecological tea plantation *”
3a.	tea grass compound* OR “tea grass compound plantation*” OR “tea grass compound garden*” OR “tea herb compound plantation*” OR “tea herb compound garden*” OR “grass intercrop* tea plantation*” OR “grass intercrop* tea garden*” OR “grass intercrop* tea*” OR “herb intercrop* tea plantation*” OR “herb intercrop* tea garden*” OR “herb intercrop* tea*”

Table 1. *Cont.*

Main Terms	Expanded Terms
3b.	tea fruit compound* OR "tea fruit compound plantation*" OR "tea fruit compound garden*" OR "fruit intercrop* tea plantation*" OR "fruit intercrop* tea*" OR "fruit intercrop* tea garden*"
3c.	tea forest compound* OR "tea forest* compound plantation*" OR "tea forest* compound garden*" OR "tea* tree* compound plantation*" OR "tea* tree* compound garden*" OR "forest* intercrop* tea plantation*" OR "forest* intercrop* tea garden*" OR "forest* intercrop* tea*" OR "tree* intercrop* tea plantation*" OR "tree* intercrop* tea garden*" OR "tree* intercrop* tea*"
3d.	tea fungus compound* OR "tea fung* compound plantation*" OR "tea fung* compound garden*" OR "fung* intercrop* tea plantation*" OR "fung* intercrop* tea*" OR "fung* intercrop* tea garden*"
4. Sustainability	"sustainab*" OR "biodivers* enrich*" OR "biodivers* increas*" OR "environment* conserv*" OR "conserv* manag*"
5. China	"China" OR "PRC"

3. Results

3.1. What Are Those Intercropping Tea Plantations?

Under the analysis based on those 223 articles, Figure 1 (Supplementary Data can be found in Tables S2, S4 and S5) represents the categories of intercropping tea plantations in China. As I mentioned in the introduction, 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.

In this review, 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. Additionally, grain–tea intercropping can increase grain yield and quality while improving the environment. Tea–grass intercropping also increases biodiversity, improves the microclimate of tea plantations, and reduces the incidence of pests. It can also increase the diversity of soil microorganisms and improve land utilization and the productivity of tea plantations.

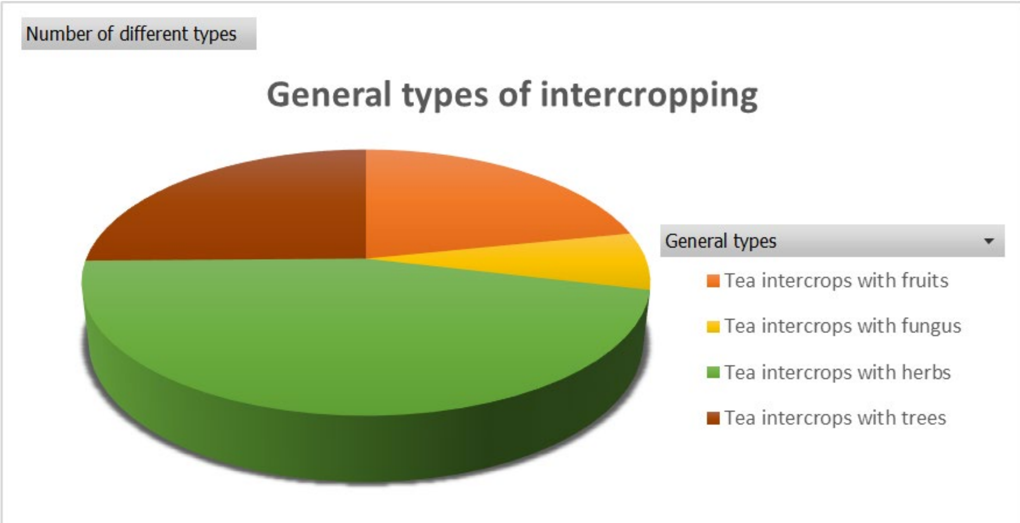

Figure 1. The proportions of each type of tea tree intercropping with other plants or fungi in China until June 2021.

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.

In this study, we identified 277 tea–herb intercropping tea plantations, 131 tea–fruit intercropping tea plantations, 42 tea–mushroom intercropping tea plantations, and 152 tea–forest intercropping tea plantations (Figure 1).

Through the analysis, a total of 151 different types of intercropping patterns were involved in this study. Tea trees can be intercropped with a particular plant alone, or they may be intercropped with a variety of plants to create a more complex ecological system.

For example, red pepper (*Capsicum annuum*) can be intercropped with tea alone, or with cedar (*Cunninghamia lanceolata*) and camphor (*Cinnamomum camphora*).

3.2. Where Are Those Tea Plantations?

Figure 2 is a map created by ArcGIS Map on the basis of the database I collected (Supplementary Data can be found in Tables S2, S6 and S7). ArcGIS Map has powerful map making, spatial analysis, spatial data building and other functions, and existing data can be built on a high-quality base map. As we can see above, most of the composite ecological tea plantations are stacked up tightly in the lower right corner of the map, which is the southeast of China, such as in Fujian Province, Jiangsu Province, and Zhejiang Province. A few are located in central and southwest China, such as in Yunnan Province. Due to the different intercropping patterns, the temperature and environmental conditions required for growth will vary. According to Figure 3 (Supplementary Data can be found in Tables S8–S10), it is quite coincidental that most of them prefer a subtropical monsoon climate, and most of China has a subtropical monsoon climate. In our literature review, more than 80% of the study locations of the articles covered were located in subtropical monsoon climates (Figure 4). Others were in temperate monsoon climates, tropical monsoon climates, subtropical mountain climates, subtropical island climates, and the more unusual Xishuangbanna region, which has a climate that changes from year to year depending on the time of year. To be more specific, Xishuangbanna has an Indian Ocean tropical southwest monsoon climate from May to October, and a subtropical rapids climate from November to April.

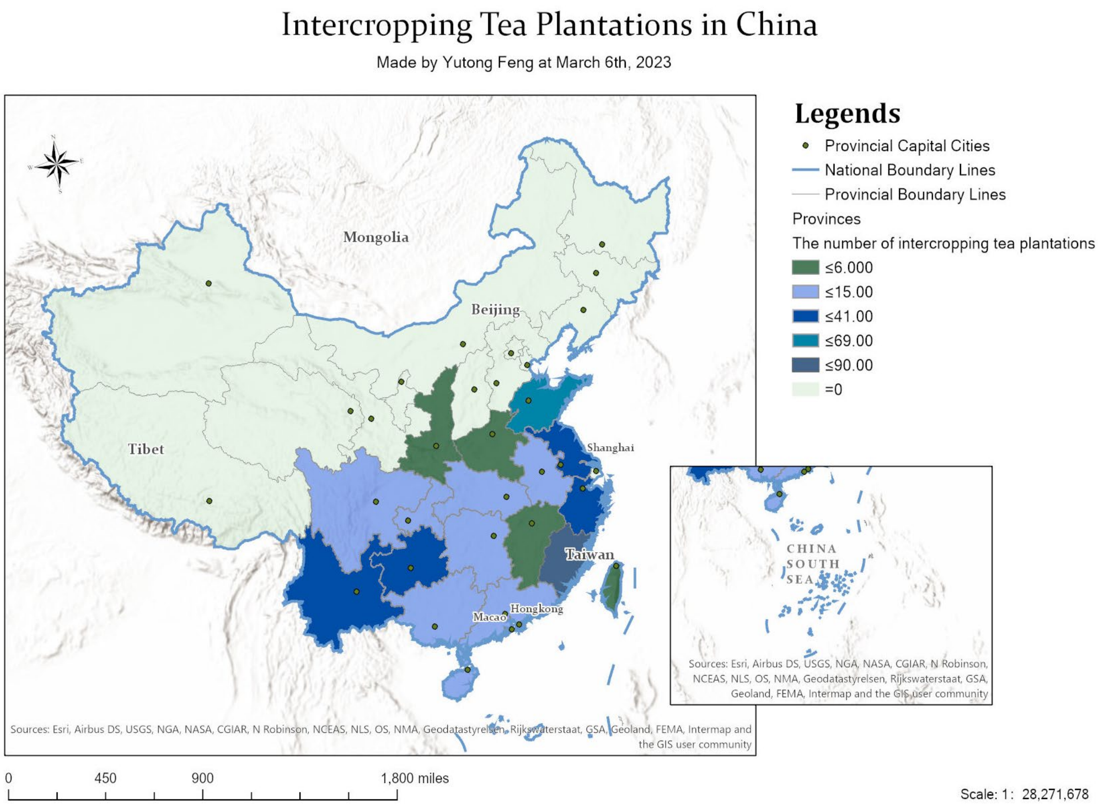

Figure 2. A map showing the distributions of all types of intercropping tea plantations in China up to June 2021.

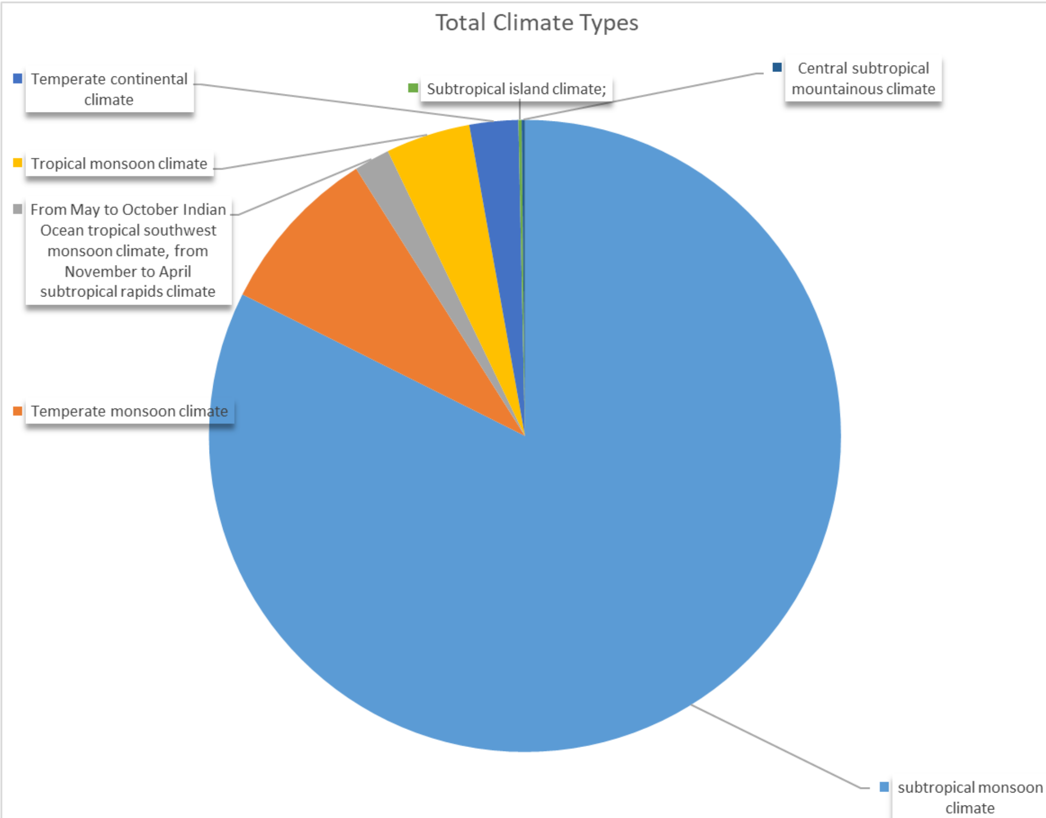

Figure 3. The proportion of different climate types in China based on intercropping tea plantations.

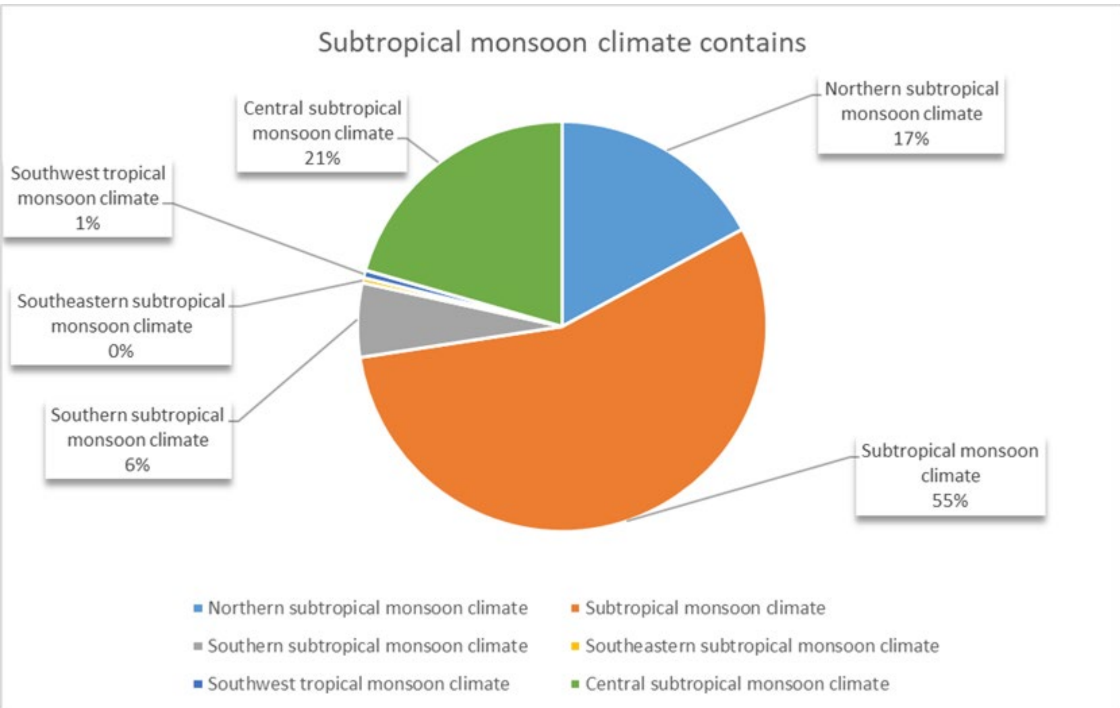

Figure 4. Specific proportions of subtropical monsoon climates of intercropping tea plantations in China.

4. Discussion

4.1. 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 [27]. 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 [28,29]. 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% [30]. 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 [31,32]. 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% [31]. 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 [33]. 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 [34]. 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 [35]. 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 [36,37]. 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. Wu et al. [36] also indicated that this water movement in the plant community could increase the nutrient utilization of the plants, thus benefiting their growth. The mechanism of the groundwater resource sharing model in intercropping systems can better regulate the water use and circulation in the soil, resulting in a significant increase in the soil water holding capacity [36]. These results reaffirm that tea and rubber trees are successful intercropping species in terms of water use.

4.2. 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. [38] 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 [38]. 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 [39,40]. 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. [41] 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 [41]. In the same paper, the authors also pointed out that the long-term intercropping of aromatic plants could increase the content of organic matter, total N, alkali-hydrolysable N, fast-acting P, and fast-acting K in the soil, and could optimize the soil environment for tea tree growth. The data showed that the organic matter content reached 2.66% in the intercropping of annual phlox and 2.46% in common soapwort, exceeding the control group by 77.3% and 64.0%, respectively. The organic content of wrinkled giant hyssop and tea intercropping types, which had the lowest relative organic content, was also higher than the control group by 16.8% in the 0 to 10 cm soil layer [41]. The same effect also happened in tea trees intercropped with Jasmine (*Jasminum sambac*), where the organic matter, total N, total P and hydrolyzed N contents of the tea tree were higher than those of the latter [42]. For the legumes mentioned above, soybean intercropping with tea is also a good choice. Experiments showed that soybean intercropping had a significant effect on soil improvement in tea plantations, with a significant increase in soil pH and a significant decrease in exchangeable Al content. Soil organic matter, alkaline N, fast-acting K and exchangeable Ca and Mg were significantly higher than those in monoculture tea plantations, while fast-acting P was not significantly lower, indicating that these soybeans could improve the fertility level of tea plantations [43].

From the above, it can be seen that intercropping tea with different plants leads to different changes in the soil's organic substances and metal ions. Such changes may be an increase or decrease in chemical content, or an increase or decrease in the plant's ability to absorb them. However, an increase in these changes is not necessarily an absolute benefit, nor is a decrease necessarily harmful. The analysis needs to be tailored to the needs of different intercropped tea gardens. In most cases, however, the advantages of intercropping over regular tea plantations outweigh the disadvantages. It is therefore advisable to carry out a small-scale experimental simulation each time an intercropping model is designed. This will not only give an idea of the specific impact of the intercropped plant, but will also give a chance to reduce the unknown economic losses.

4.3. Regulating Services

4.3.1. Impacts on Microorganisms' Activities and Energy Transformation

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 [44]. 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 [45]. 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 [46]. In Lin et al.'s [46] experiment, there were five experimental groups and one control group, namely: no fertilizer treatment (CK), full chemical fertilizer treatment (NPK, annual application: N 102.90 kg/hm^2, P_2O_5 33.90 kg/hm^2, K_2O 33.90 kg/hm^2), half chemical fertilizer and half organic fertilizer (NPKO, annual application: half chemical fertilizer—N 51.45 kg/hm^2, P_2O_5 16.95 kg/hm^2, K_2O 16.95 kg/hm^2; half organic fertilizer—5716.50 kg/hm^2), full organic fertilizer (O, annual application: 11433.00 kg/hm^2 per year), full chemical fertilizer and leguminous green manure (NPKL, annual application: N 102.90 kg/hm^2, P_2O_5 33.90 kg/hm^2, K_2O 33.90 kg/hm^2 per year), and half chemical fertilizer plus half organic fertilizer plus leguminous green manure (NPKOL, annual application: half chemical fertilizer—N 51.45 kg/hm^2, P_2O_5 16.95 kg/hm^2, K_2O 16.95 kg/hm^2 per year). There were no significant differences in the number of culturable microorganisms between the CK and NPK treatments (NPKO, O, NPKL, NPKOL). However, the numbers of culturable bacteria, actinomycetes, and fungi in the NPKO, O, NPKL, and NPKOL treatments showed significant increases, which ranged from 255.3% to 455.3% for bacteria, 172.1% to 286.0% for actinomycetes, and 60.8% to 190.2% for fungi, respectively [46]. Lin also indicated that the activity of converting enzymes significantly rose due to the stimulation of plant root growth and microorganism multiplication by overseeding leguminous forage with N fixation. Consequently, more converting enzymes were secreted by both plant roots and microorganisms [46]. In addition, Li Yanchun's experiment intercropped tea trees with red Lingzhi (*Ganoderma lucidum*) and applied high-throughput sequencing technology to analyze and compare the changes in soil bacterial communities between intercropped red Lingzhi tea plantations and monocultures. Compared with the monoculture tea plantation, the relative abundance of proteobacteria in the soil of intercropped Ganoderma tea plantations increased significantly by 21.18%. In comparison, the relative abundance of *Acidobacteria* and *Gemmatimonadetes* decreased significantly by 15.09% and 53.52%. At the genus level, the intercropped Ganoderma treatment significantly increased the relative abundance of the beneficial soil microflora, *Burkholderia*, *Sphingomonas*, and *Dyella* [47].

Moreover, tea plants grown in acidic soils are strongly dependent on arbuscular mycorrhizal fungi (AMF) [48]. This is because AMF changes the pH value of the tea tree soil, thus allowing the roots to better absorb nutrients. Additionally, it has been proved that some strains of soil AMF improve plant growth, root development, and nutrient absorption in tea plants [49]. When tea plants intercrop with AMF, AMF could stimulate the development of root morphology, which enhances the ability to absorb water and nutrients in plants [50]. This change can be positive or negative. The fact is that Sun and Tang [51] reported that inoculation with arbuscular mycorrhizal fungi II (*Funneliformis mosseae*) and Arbuscular mycorrhizal fungi IV (*Glomus intraradices*) decreased root-hair incidence in Sorghum bicolor. However, Orfanoudakis et al. [52] discovered that inoculation with arbuscular mycorrhizal fungi III (*Gigaspora rosea*) resulted in an increase in the total number of root hairs but a substantial reduction in the root-hair density of European alder (*Alnus glutinosa*). There were also differences in the effects on roots caused by different AMF strains. Whether it is a reduction in root incidence or a reduction in the total number of root hairs, it is not possible to conclude that AMF intercropping will necessarily have a positive impact on tea trees. Returning to the previous hypothesis, I still believe that simulation experiments are necessary before implementing intercropping in tea plantations. There are not enough data to suggest that inoculation with a particular strain of AMF causes a specific impact, which creates a considerable challenge in assessing the sustainability of this inoculation trial. There is still much uncertainty due to the complexity of the soil environment, and more experiments are awaited to explore the possibilities of intercropping tea trees and fungi.

4.3.2. Regulating Environment Conditions

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 [49,53,54]. 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 [27]. 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 [55]. 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 [56,57]. According to Sun et al. [58], 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 [59], improve land utilization, increase the early income of tea trees, and promote economic development [60]. For example, the soil water content of both yellow camphor trees (*Cinnamomum pathenoxylum*) and mountain pepper (*Litsea cubeba*) intercropped with tea, respectively, was higher than that of the pure tea plantation soil. It is beneficial to reduce the soil volume, increase soil permeability, relieve the acidification intensity of pure tea tree soil, and improve tea quality [61]. Additionally, it is also pointed out in the same article [61] that the soil is more compact and less permeable when cedar and tea are intercropped. In contrast, the soils of the intercropping pattern of the yellow camphor tree and mountain pepper with tea, respectively, were relatively looser, thus improving the soil's aeration and water storage capacity. However, excessive canopy shading can lead to competition between intercrop roots for water and fertilizer uptake in the soil, which may reduce tea yields. For example, when tea and chestnut (*Castanea mollissima*) are intercropped, there is a strong relationship between tea yield and intercrop density. If the density is too low, the ecological benefits are not obvious, the yield is low, and the quality is close to that of a monoculture tea plantation. If the density is too high, the competition between species will be enhanced. Excessive shading by the chestnut canopy and competition for water and fertilizer uptake by the root system will reduce the tea yield. Considering the effect of intercropping on tea quality and chestnut harvest, the density of intercropping should not be lower than 150 plants/hm^2 [62]. Therefore, the density of each plant in the intercropping system is important, as it depends on the location and the interplanting species. When intercropping Ginkgo trees in Taishan tea plantations, the degree of density (the ratio of the vertical projection of the canopy to the whole forest area) should be controlled at 0.4 for good tea quality. When intercropping chestnuts in tea plantations, the degree of density should be controlled at 0.3 for good tea quality [63]. Additionally, this confirmed that different intercropping modes will have various influences on soil ecosystem services.

4.4. Intercropping Tea Plantations vs. Monoculture Tea Plantations

As the evidence suggests, each planting method has its own advantages and disadvantages (Table 2). 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.

Table 2. The comparison between Monoculture Tea Plantations and Intercropping Tea Plantations.

Aspects	Monoculture Tea Plantations	Intercropping Tea Plantations
Use of water	Higher water consumption	Lower water consumption
Biodiversity	Scarcity of biodiversity	Abundant biodiversity
Resistance to natural disaster	Low resistance to natural disasters	High resistance to natural disasters
Soil conditions	Soil erosion, soil acidification, soil deterioration	Increased soil fertility, increased soil water content, and mitigation of acidification
Cost	Less labor and cost	More labor and cost
Planting requirements	Low planting requirements, requiring little expertise	High implantation requirements and complex expertise required
Is success guaranteed?	Long history and high credibility	Each type of intercropping tea plantation requires pre-experiments to confirm whether the desired objectives can be achieved, which is time-consuming.
Financial benefits	Fundamental income	Valuable fruits and wood materials, the raw material for organic tea.

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 [64]. In contrast, the excellence of monoculture tea plantations over intercropping tea plantations is more focused on humans.

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. Nonetheless, owing to the prevailing global warming and climate change, tea plants encounter difficulties in sustaining their survival at specific altitudes or maintaining a stable habitat. At some point, the past systems will no longer apply, and new systems will be born. In a sense, intercropping tea plantations are the “products” of the new era that can be adapted to the future ecological environment.

5. Conclusions

There are 151 different intercropping systems in this review, distributed in different areas of China. From a macroscopic point of view, intercropping tea plantations can regulate temperature and humidity in the environment [28], improve the micro-environment in the tea plantation [65], and promote the even distribution of root systems in the space, thus reducing the competition of crops for space [66]. Intercropping tea plantations could also improve the water conditions in the soil. The differences in soil hydraulic properties in different regions of the rubber tree–tea agroforestry system lead to the spatial distribution of surface water and groundwater [35], and improve the water availability of different root plants. Better infiltration and better preferential flow under tea trees have the potential to reduce runoff generation and erosion risks, facilitate groundwater recharge, and increase water storage, thereby offsetting interception and transpiration losses from crop intercropping and rubber trees, thereby contributing to water resource management.

The effect of the agroforestry complex cropping pattern on improving the functional services of the ecosystem is clearly significant. Through intercropping with different plants, tea trees will have different degrees of impact on the organic matter and microbial community of the soil. This effect may be positive or negative, depending on the specific type of intercropping. If there is no nutrient competition between the two parties, then in most cases tea trees will receive positive feedback [41]. Therefore, intercropping tea plantations need to be designed according to the conditions of the target tea plantation. For example, N fixation by legume forages stimulates plant root growth and substantially improves soil conditions by increasing the number and diversity of bacteria, fungi, and actinomycetes in them, thus increasing soil microbial diversity [46]. Similarly, the increase in plant species leads to an increase in biodiversity. Complex ecological niches can provide more efficient ecosystem service functions. For example, intercropped tea plantations can have higher carbon storage potential as well as photosynthetic efficiency, etc. The moderate shade also provides tea plants with suitable space for survival, which can regulate carbon and N metabolism and promote bud sprouting and growth [67]. Excessive shade, on the other hand, can lead to a reduction in the photosynthetic rate and a reduction in splash erosion potential. Therefore, when tea trees are intercropped with different plants, different spacing should be maintained to ensure that all plants can grow properly. It should be noted that not only the difference in intercropping species, but also the influence of climate in the planting area should be taken into consideration.

In short, intercropping tea plantations have a very broad prospect and deep potential.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13061548/s1, Table S1: Searching results of different databases after using the main terms combined with the Boolean operator “AND” or “OR”; Table S2: Summary of candidate papers and their details, including intercropping types, general types, number of intercropping tea plantations, locations, climates, advantages, and sustainability.; Table S3: Scientific names that occur in the candidate papers; Table S4: Details of different tea/tree intercropping types; Table S5: General types of intercropping; Table S6: Details of intercropping tea plantations’ locations; Table S7: Specific numbers of intercropping tea plantations in each province; Table S8: Climate types of intercropping tea plantations in China; Table S9: Different climate types of intercropping tea plantations in China based on Table S8; Table S10: Specific categories of subtropical monsoon climates of intercropping tea plantations in China.

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Data Availability Statement: The data presented in this study are available in the Supplementary Materials.

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Appendix A

Appendix A.1. Glossary

Table A1. The scientific names and common names of those plants that appear in this review.

Scientific Name	Common Name
Agastache rugosa *Ageratum conyzoides* *Alnus glutinosa*	Wrinkled giant hyssop Billygoat weed European alder
Camellia sinensis L.	Tea tree
Capsicum annuum L. *Castanea mollissima* *Chamaecrista rotundifolia* *Cinnamomum camphora*	Red pepper Chestnut Round-leaf cassia Camphor tree
Cinnamomum pathenoxylum *Citrus reticulata* Blanco	Yellow camphor tree Tangerine
Claroideoglomus etunicatum	Arbuscular mycorrhizal fungi (AMF) I
Cunninghamia lanceolata	Cedar
Dianthus barbatus	Sweet William
Diospyros kaki	Persimmon tree
Ectropis obliqua (Prout)	Tea geometrid
Eriobotrya japonica	Loquat
Funneliformis mosseae	Arbuscular mycorrhizal fungi (AMF) II
Ganoderma lucidum	Red Lingzhi
Gentiana rigescens	Gentiana
Gigaspora rosea	Arbuscular mycorrhizal fungi (AMF) III
Ginkgo biloba L.	Ginkgo tree
Glomus intraradices	Arbuscular mycorrhizal fungi (AMF) IV
Glycine max	Soybean

Table A1. *Cont.*

Scientific Name	Common Name
Jasminum sambac	Jasmine
Litsea cubeba	Mountain pepper
Lolium perenne L.	Perennial rye-grass
Lucuma nervosa	Canistel
Malus pumila	Apple tree
Medicago sativa	Alfalfa
Myrica rubra	Waxberry
Phlox drummondii	Annual phlox
Pisum sativum	Pea
Prunus americana	North American plums
Salvia japonica	Common sage
Saponaria officinalis	Common soapwort
Solanum tuberosum	Potato
Stropharia yunnanesis	Yunnan roundheads mushroom
Trifolium repens	White clover
Vicia faba	Broad bean
Vicia glabrescens	Smooth vetch
Vigna radiata	Mung bean
Vulpia myuros	Rattail grass
Zea mays	Corn

Appendix A.2. Criteria

a. Study exclusion/inclusion criteria

If the research met the criteria outlined below, it was included in the review:

- Related research topics: including research on the cultivation mode of intercropping tea gardens. Research must be conducted in China.
- Relevant research methods/design: The research uses relevant, transparent, and repeatable quantitative or suitable qualitative methods.
- Comparators of related research: with and without the correlation comparison between the intercropping tea garden and the monoculture tea garden.
- Relevant research results: The research measures and reports relevant results. These results show that the existence of intercropping tea gardens has obvious positive, negative or neutral effects on the function of the soil ecosystem in the tea garden.

The first stage of inclusion/exclusion only requires filtering the relevance of the article based on the title. The abstracts of the remaining articles will be read, while fewer articles will be evaluated through the full text. The same researcher will be responsible for the entire screening phase. The researcher will record the research screening process and list all articles excluded at each stage in accordance with the requirements of the systematic review guidelines. This will be provided as a supplement to the full text. We realized that the term "ecological tea garden" was proposed in the scientific literature in 1986. However, we admit that we have conducted research on what we now think of as ecological tea gardens. We will include all relevant studies dating back to 1950. The search will be conducted in English and Chinese. The decision is based on research feasibility in terms of available time and resources. For the same reason, we will include research published in English and Chinese.

b. Exclusion criteria

If the study does not meet the inclusion criteria or focuses on one or more of the following, it will be excluded from this review:

- Research compound/general ecological tea gardens in China;
- Exploratory research, conceptual framework, methodological papers;
- Published research on the benefits of intercropping tea gardens for soil ecological service functions without (re)representing the original data;
- Research on whether the intercropping tea garden is sustainable or whether there is research on biodiversity;
- The absence of links/data on the role of forests and trees, research on ecosystem services and the provision of services in agricultural systems.

c. Potential effect modifiers and reasons for heterogeneity

The following are variables that may affect the results of the relevant research, so they will be recorded and reported in the comprehensive review:

- Intercropping tea garden types: tea herb compound type, tea fruit compound type, tea forest compound type, tea fungus compound type;
- Inconsistency in the altitude and climate of the tea area studied;
- Inconsistency in the implementation time of compound cultivation technology.

The above is a preliminary list that the researchers intend to revise to determine further causes of heterogeneity during the review process.

d. Study quality assessment

The assessment of the quality of the research will not be part of the exclusion/inclusion criteria, meaning that all articles that pass the full text selection will be included in the preliminary review. The quality of the research will also be assessed for the meta-analysis. If the study provides the relevant sample mean, sample size, standard deviation and/or standard error, etc., the study is considered suitable for meta-analysis. During the quality assessment period, research will be divided into three categories: (1) quality less than acceptable; (2) acceptable quality; and (3) high quality of learning. Studies classified as less than acceptable (1) will be excluded from the meta-analysis. The evaluation of the quality of the research is based on:

- Trial time;
- Perfect experimental setup and analysis;
- Containing suitable control treatments;
- Taking into account the degree of accidental environmental pollution;
- Quality of the samples of the experimental units (randomness and representativeness);
- Numbers of copies, etc.

If the research is very interesting but does not provide enough data, the reviewer documented intercropping types, but quoted their conclusions carefully, and only if they had related data and results. If no additional information was available, the study was excluded from the meta-analysis.

e. Data extraction strategy

The following information was recorded for all included studies/publications:

- Title;
- Author(s);
- Journal;
- Publication date;
- Study location;
- Type of tea plantations (type of tea–herb connection, type of tea–fruit connection, type of connection of tea–forest, type of connection of tea–fungus);
- Classification of climatic regions;

- The nature of the examined function of the soil ecosystem;
- Methodology (quantitative experiment, farmer's field test, participatory experiment);
- Type of investigation (main investigation, review, or meta-analysis);
- Main landscape environment (e.g., the tree species in the tea forest compound type);
- Types of results and effects (increased soil fertility, increased tea production).

Some of these articles were from researchers at local agricultural bureaus, forestry bureaus, or tea research institutes. These document reports recorded the effects of local tea/other species intercropping over the last few decades. Most of them met the above criteria, but some of the experimental results were more biased towards the benefits for the local economy. As for these reports, their intercropping patterns were documented, but their conclusions were quoted carefully, and only if they had related data and results.

An artificial intercropping tea garden ecosystem uses the tea tree's shade-tolerant property to create an ecosystem of three layers or two layers, of forest canopy and a ground cover layer with plants of different heights, canopies, and root depths. This artificial community enables the full use of light, ground power, nutrients, water, and energy. Different taxa of organisms can also reproduce in a more suitable environment, thus bringing out the best biological and ecological effects and economic benefits. Intercropping planting mode is not perfect. However, all in all, after collecting information on tea plantations in so many locations, it could be concluded that the advantages of ecological composite tea gardens outweigh the disadvantages.

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