Sustainable tea production through agroecological management practices in Vietnam – A review

Abstract

Tea is one of the most important crops in Vietnam, as both an export and domestic commodity. In Vietnam, tea farming has been dominated by conventional management practices for decades. The continuity of this approach has led to a number of issues arising. These range from serious soil degradation, low economic efficiency, poor tea quality and environmental contamination. Recently, there has been a growing conversion from conventional tea farming to agroecological tea management practices. To date, limited studies have been conducted to determine the viability of this conversion in Vietnam, particularly regarding technical aspects. Focusing on aspects of soil health, tea productivity and quality, here we highlight the benefits and challenges of conventional tea production system and provide a comprehensive evaluation of potential advantages agroecological tea management practices could have for Vietnam. The outcomes of this review are an informative resource for tea producers, tea production management authorities and other relevant organizations; enabling more informed decisions regarding the management methods, policies and programs to promote agroecological tea management in Vietnam and other tea producing nations.

Keywords Agroecological management and conventional management · Sustainable development · Soil health · Tea quality · Vietnam

1. Introduction

Tea (*Camellia synesis* Kotze) is one of the oldest beverages in the world. In 2017, global tea production amounted to nearly 6 million, of which 2.1 million tonnes were exported worldwide (Tuan 2018; Voora et al. 2019). In the same year, the global tea market was valued at approximately USD 50 billion. This economic sector is projected to grow by from 4.5 to 5.3 percent annually to reach USD 73 billion in 2023. Globally, the top five tea producing countries in 2017 were China, India, Kenya, Sri Lanka and Vietnam, while the top five tea exporters were Kenya, India, Sri Lanka, Argentina and Vietnam (FAO 2018; International Institute for Sustainable Development 2018). In 2016, globally the total area of registered organic tea was around 542,000 hectares (ha), which was 13,2% of the total global tea production area (Willer and Lernoud 2019).

Vietnam has been cultivating tea for thousands of years. In Vietnam, tea is one of the most important cropped plants, both for domestic consumption as well as export. The current area of tea plantations in Vietnamese is around 130,000 ha, with the total production volume of fresh tea leaves being over 1 million tonnes (Bui and Nguyen 2020; Doanh et al. 2018). Tea is mainly grown in the Northern mountainous and Central Highland provinces. It plays an essential role in providing a livelihood and economic sustainability for these regions (Cong Bien et al. 2018; Doanh et al. 2018). The tea industry employs around 1.5 million people. Since 2010, the annual economic contribution of tea exports has been over USD 200 million per annum (GSO 2020a; Hong and Yabe 2015; Van Ho et al. 2019).

Tea cultivation in Vietnam has been dominated by conventional management practices. The applications of chemical fertilizers and pesticide have long been a tradition of tea growers to improve tea productivity, reduce pest and disease damage and maintain soil fertility (Doanh et al. 2018; Phong et al. 2015a). Common tea production practices also include mono-cropping and cultivation of tea on steep sloping land (MARD 2016; Toan and Phuong 2014). Combined, these "conventional" management practices have resulted in soil degradation and erosion, reduced tea productivity and quality, and led to increasing concerns as to environmental problems and human health impacts (Hong and Yabe 2015; Van Ho et al. 2019). Although the production and export volume of Vietnamese tea over the last two decades has consistently increased, due to the low-quality, Vietnamese tea products have been mainly exported to lower-value markets such as Taiwan, Pakistan, Iran, Indonesia and Russia (Doanh et al. 2018; Van Ho et al. 2019).

Vietnamese tea export prices have been consistently lower than the world average. From 2012 to 2019, despite rapid growth in the Vietnamese tea export volume and the markets, Vietnamese tea price per kg was 35-40% below the world average pricing (GSO 2020a; Khoi et al. 2015). The main reason for the reduced price, is the high proportion of chemical residues, which results in limited market access due to non-compliance with international regulations such as those of the European Union (Doanh et al. 2018; MARD 2017). In addition, poor post-harvesting technology and lack of branding development further exacerbate the poor market price (Khoi et al. 2015). Over the past decade, there has been an increasing demand for tea quality standards such as pesticide residues limits, hygiene and contaminants of the international market, and Vietnam recently has joined numerous international trade agreements such as the Trans-Pacific Partnership (TPP) and the Regional Comprehensive Economic Partnership (RCEP). Subsequently, Vietnamese tea producers could lose not only the international markets but also their home market to other exporters such as China and India without improvements in tea quality and safety (Xiong 2017).

The quest for sustainable tea production and higher quality is driving an increasing conversion from conventional tea farming practices to organic-based methods; where non-chemical pest and disease management practices are used (Ha 2014a; Hong and Yabe 2015; Van Ho et al. 2019). This transformation in tea management practices has been driven by the growing interest in high quality and economic efficiency of tea production, and an increased awareness of the harmful effects of agrochemicals on human health and the environment (Doanh et al. 2018; Ha 2014a). In addition, supporting policies and programs from the Vietnamese Government and international agencies are also playing an essential part in promoting the conversion and convincing the Vietnamese tea producers to implement more agroecological practices (Ha 2014a; Van Ho et al. 2019).

Agroecology is the application of natural ecological system processes and concepts for optimizing the interactions between humans, plants, animals and the environment, whilst also considering the social aspects to ensure a fair and sustainable food system (FAO 2020). Agroecology can play a vital role in supporting food production, nutrition improvement and food security while restoring the ecosystem services and biodiversity, which are important to sustainable agriculture (Chappell and LaValle 2011; FAO 2020). In addition, agroecology provides a practical way for restoring soil quality depleted by conventional management practices (Altieri et al. 2020).

For tea production, numerous studies conducted outside of Vietnam have indicated the beneficial impacts of agroecological management practices such as using organic fertilizers (Li et al. 2015; Lin et al. 2019), biofertilizers (Nepolean et al. 2012;

Roychowdhury et al. 2014; Xu et al. 2014), biopesticides (Nakai 2014; Roychowdhury et al. 2014), mulching, intercropping (Jianlong et al. 2008; Sun et al. 2011; Zhang et al. 2017) and integrated pest and disease management strategies (Mamun and Ahmed 2011; Shrestha and Thapa 2015). These practices can result in soil health improvement (biological, chemical and physical properties), reduce agrochemical input and chemical residues in soil and on tea leaves. Ultimately, agroecological tea production practices can mitigate the negative effects of chemical uses on the environment while maintaining tea productivity and quality. In Vietnam, the benefits of agroecological tea management, assessing profitability and social and policy aspects have been investigated to a limited degree (Doanh et al. 2018; Duc and Goto 2019; Van Ho et al. 2019). Previous studies have also examined the impacts of mulching and biofertilizers on soil quality (Cu and Thu 2014a, b) but to our knowledge, there has not been any study investigating the effects of other agroecological practices such as organic fertilizers, intercropping or non-pesticide pest and disease management.

Based on this, our review will (1) determine the challenges and positive impacts of conventional tea management systems in Vietnam, and (2) evaluate the potential benefits of agroecological tea management practices on soil health, tea quality, and then (3) recommend the most suitable management and supporting policies for enhancing and sustaining tea production without negative impacts on the soil and its environment.

2. Tea plantations in Vietnam

Tea plants belong to the Theraceae family and are native to East Asia. However, these perennial plants have now been cultivated all around the world, in tropical and sub-tropical areas (Meegahakumbura et al. 2018). In Vietnam, there are two main kinds of tea plants: wild tea and the domesticated cultivars. The wild tea is referred to as Shan tea, which is mainly grown in the Northern high mountainous provinces (above 1000 m) such as Ha Giang, Lai Chau, Yen Bai, Lao Cai and Dien Bien (Hatvala 2018). Wild tea can reach 15 meters in height and have the distinctiveness of growing, cultivation and processing in comparison with the domesticated tea varieties (Intellectual Property Office of Vietnam 2018). The domesticated tea varieties are small woody plants or evergreen bushes, with pointed and fragrant leaves. Both these kinds of tea plants are cultivated in 28 out of 64 provinces in Vietnam, and the five largest tea producers in the nation are Thai Nguyen, Ha Giang, Phu Tho, Lam Dong and Tuyen Quang provinces (GSO 2020b). Of these five provinces, four are in the North while Lam Dong is in the Central Highland (Fig. 1).

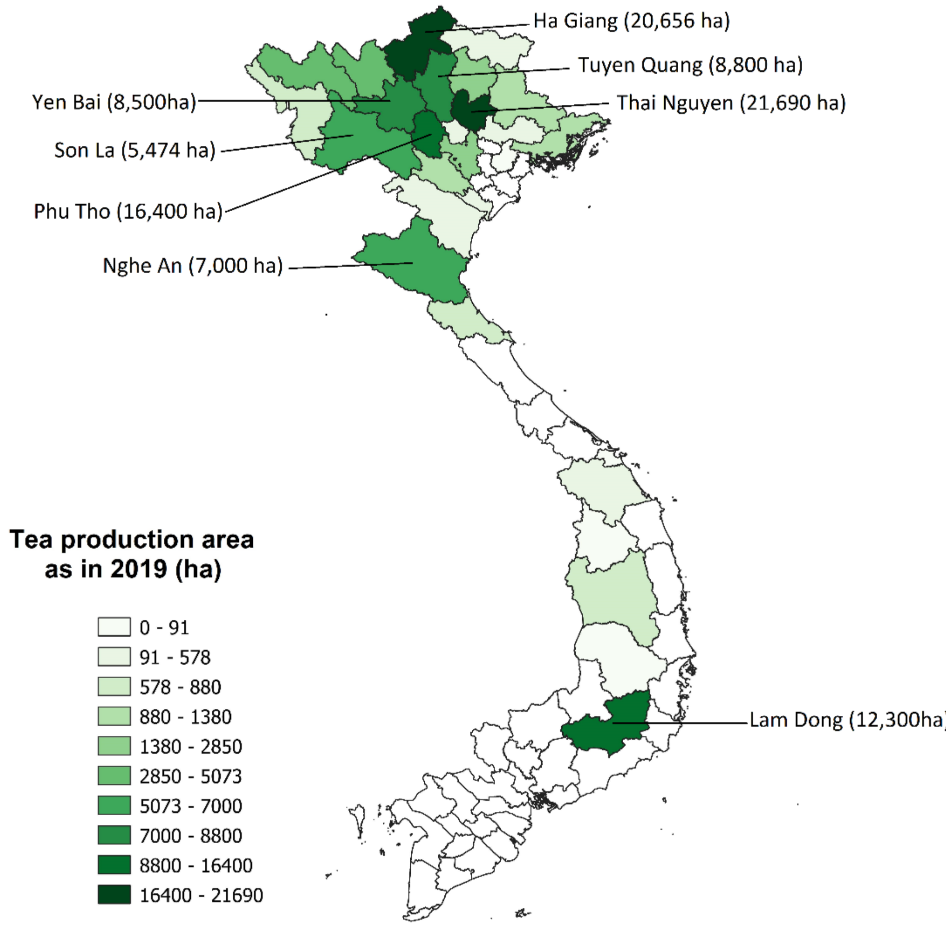

Fig. 1 Distribution of tea plantations in Vietnam in 2019. Data was soured from GSO (2020b), Ha Giang government (2019) and Thai Nguyen government (2019).

Since the Doi Moi policy - a transformation that aimed to gradually improve the economic efficiency towards 'a socialist market economy under state guidance' (Beresford 2008), tea production has contributed significantly to economic development and social sustainability of the country; especially in rural regions where livelihood for farmers has been limited (Khoi et al. 2015). Vietnam was one of the seven largest tea exporters worldwide from 2010 – 2019 (top five from 2010- 2017) and in return, exports of tea products contributed around USD 200 million annually to the country's economic revenue (Van Ho et al. 2019; GSO 2020a). It is also forecasted that Vietnam will remain as one of the top five tea producers and exporters globally, and become the second largest green tea exporter after China by 2027; with projected export volumes of around 148,500 tonnes (FAO 2018). The tea industry in Vietnam provides employment to more than 400,000 small households in rural regions and 600 industrial tea processing companies. Annually, around 1.5 million jobs are created by tea production, processing and other related fields of the tea value chain such as trading and services (Doanh et al. 2018;

Hong and Yabe 2015). Aside from its economic and social importance, tea also plays a critical role in Vietnamese culture, as it has been used as a daily beverage in every part of the country for centuries (Wenner 2011).

3. Soil health and conventional tea management

3.1. Soil health and tea soil in Vietnam

Since the concept for soil quality was introduced in early 1990s, numerous revisions have been proposed (Bünemann et al. 2018; Karlen et al. 1997) and the term 'soil health' is now more frequently used than 'soil quality' (Bonfante et al. 2019). Simply, soil heath can be defined as the capability of a soil to provide ecosystem services (Williams et al. 2020). From an agricultural perspective, soil health refers to the capacity of soil to support crop productivity (Mursec 2011). Soil health is now acknowledged to consider all the soil feature indicators including soil physical, chemical and biological properties (Allen et al. 2011; Arias et al. 2005; Cardoso et al. 2013). In recent decades, agricultural soil has been seriously degraded by human interventions (Mursec 2011; Shah et al. 2019). Conventional agricultural practices such as agrochemical applications and mechanical tillage have led to significant soil heath degradation, including reduced soil biodiversity (Alori et al. 2020). For tea farming industry, long-term conventional tea cultivation has been considered as the main driver of severe soil acidification, soil nutrient imbalance and nutrient leaching in tea plantations (Li et al. 2016; Yan et al. 2020).

In Vietnam, the requirements for soil characteristics used for tea plantations were issued by the Ministry of Agriculture and Rural Development (MARD) under the Technical procedure for Tea production: 10TCN446:2001 (Chung 2013). This technical document lists soil features for optimizing tea growing and productivity: a well-drained soil with a pH (KCl) of 4 - 6, soil depth and organic matter of at least 50 cm and 2% respectively, and soil slope of less than 25 degrees were recommended. However, in Vietnam tea is grown in 28 distinct provinces where soil characteristics, climatic and topography vary significantly, and for many areas the soil physical and chemical properties do not meet the MARD requirements. For instance, about 60% of tea producing districts of Phu Tho province typically grow tea in soil containing less than 2% of organic matter, and on steep sloping land (slope >25 degrees) (MARD 2016; Tea Research and Development Center 2015). In addition, tea plants need an adequate amount of both macronutrients (nitrogen, phosphorus and potassium) and micronutrients (zinc, boron and aluminum) for optimal growth and productivity (Hajiboland, 2017).

3.2. Conventional tea management practices in Vietnam

Intensive use of agrochemicals are the common practices of tea growers worldwide (Sitienei et al. 2013; Wu et al. 2016; Xie et al. 2020). Among the chemical fertilizers, nitrogen (N) is widely used to ensure high tea productivity. In Japan, tea fields are amended with the N application rate of more than 1000 kg/ha/year (Abe et al. 2006; Zou et al. 2014). In China, the N application rate can reach 1200 kg/ha/year. This amount far exceeds the actual uptake of N by tea plants (Wu et al. 2016; Yan et al. 2020). Vietnamese tea farmers traditionally apply mineral fertilizers either multiple times after each harvest or 1- 2 times a year during rainy seasons, after tea pruning. The rate of fertilization application varies widely between provinces or regions and is based predominantly on individual farmer decision and their experiences. The recommended application rate of fertilization for tea cultivation in Vietnam is 300 kg N + 150 kg P_2O_5 + 150 kg K_2O per ha. However, tea growers generally exceed the recommendation of the manufacturers to ensure a satisfying tea growth, yield and soil nutrient loss replacement (Hong 2016; Huu Chien et al. 2019). Since 2000, Vietnam has imported 3.5 - 4.5 million tonnes of inorganic fertilizers per annual, with Vietnamese farmers spending on average around USD 5 billion per annual on fertilizers (Toan et al. 2019).

Around 50 different pests and insect species are known to cause damage to parts of the tea trees, especially to young tea leaves and tea buds, resulting in significant tea yield losses (Tu 2019). In 2015, more than 71,000 ha of tea plants were damaged by tea pest, such as *Empoasca flavescent* (green leafhopper), *Helopeltis theivora* (tea mosquito bug), *Physothrips setiventris* (tea thrips) and *Oligonychus coffeae* (red spider mite) (MARD 2016). In addition, leaf and stem diseases have been commonly found in most of tea plantations (Hung and Tao 2006) while root diseases causing by fungal species such as *Poria hypolateritia* (black root rot) and *Poria hypolateria* (red root rot) are among the most destructive tea diseases in Vietnam (Phong et al. 2015b). Tea yield losses caused by pest and diseases ranged from 10 to 15% in average but can be up to 100% in severe conditions (Phong et al. 2015b; Shrestha and Thapa 2015).

To reduce the incidence of these pests and diseases, widespread application of pesticides and fungicides have been the dominant practice. Vietnamese tea farmers use an estimated amount of 128 liters of pesticides per ha annually (Hong and Yabe 2016). Apart from chemical pesticides, in recent years alternatives practices such as biological pest management (alcohols, local herbs, light trap and manual removal) and biopesticides have also been applied to protect tea fields (Thu 2016; Tu 2019) (Table 1). However, the proportion of farms using non-chemical pest and disease management methods is still very low compared to chemical use (NOMAFSI 2015; Thu 2016). In 2019, the market value of biopesticides was estimated at USD 31 million. This equates to only 3% the total value of plant protection market in Vietnam (Mordor intelligence 2019).

Table 1 Summaries of the most common tea pest and diseases and its control methods in Vietnam. Data was retrieved from MARD (2001), Hung and Tao (2006), Thu (2016), Tu (2019) and other unpublished data.

Common name	**Scientific names**	**Classification**	**Chemical pesticides (*)** *(Active ingredients)*	**Biopesticides (**)** *(Active ingredients)*	**Other non-pesticide methods (**)**
Blister blight	*Exobasidium vexans*	Leaf disease	Imibenconazole	Abamectin; bacillus bacteria, yeast	Alcohols, botanicals, host plant resistant, pruning
White blight	*Phyllosticta theafilia*	Leaf disease	Imibenconazole	Abamectin; lactic acid bacteria, yeast	Alcohols, botanicals, host plant resistant, pruning
Horsehair blight	*Marasmis equimis*	Leaf disease	Mancozeb 80%	Abamectin; bacillus, yeast	Alcohols, host plant resistant, pruning, botanicals
Grey blight	*Pestalotiopis thea*	Leaf disease	Chlorothalonil; Difenoconazole,	Abamectin; bacillus bacteria	Alcohols, host plant resistant, pruning, botanicals
Damping off	*Ustilina vulagrin*	Root disease	Mancozeb + Metalaxyl	*Trichoderma* spp. *Bacillus* spp.	Manual removal, host plant resistant
Black root rot	*Rossellinia arcuna*	Root disease	Fosetyl aluminium, Phosphorus acid	*Trichoderma* spp. *Actinomycetes* spp.	Manual removal, host plant resistant
Red root rot	*Poria hypolateria*	Root disease	Mancozeb 80%	*Trichoderma* spp. *Chaetomium* spp.	Manual removal, host plant resistant

Brown root rot	*Fomes noxius*	Root disease	Fosetyl aluminium, Phosphorus acid	*Trichoderma* spp. *Chaetomium* spp.	Manual removal, host plant resistant
Green leafhopper	*Empoasca flavescen)*	Tea pest	Bup rofezin; Cartap	*Beauveria bassiana;* Abamectin;	Plucking, predators, field sanitation
Tea mosquito bug	*Helopeltis theivora*	Tea pest	Bup rofezin; Etofenprox	*Beauveria bassiana* Matrine; Isoparafin	Plucking, predators; botanicals, field sanitation, light trap
Tea thrips	*Physothrips setiventris*	Tea pest	Etofenprox	Abamectin; Isoparafin; Azadirachtin	Plucking, predators; botanicals, field sanitation, light trap
Leafroller	*Gracillaria theivora*	Tea pest	Emanectin Benzoat	Abamectin; Matrine; Azadirachtin	Plucking, predators, field sanitation
Red spider mite	*Oligonychus coffeae*	Tea pest	Acrinathrin; Propagite	Matrine; Azadirachtin; Isoparafin	Plucking, light trap, predators

Note: While the chemical pesticides (*) are commonly used in conventional tea management practices, biopesticides and other non- pesticide methods (**) are the main pest and disease control methods in agroecological tea farming in Vietnam.

3.3. Agrochemical overuse and its effects on soil health

For tea and most other plant crops produced in Vietnam, conventional agriculture employing intensive usage of chemical fertilizers has been considered as one of the main causes of soil health degradation (Kundu et al. 2016; Suhag 2016; Sultana et al. 2014). This farming approach brings about economic efficiency due to cheap inputs and high productivity in the short term but results in the degradation of soils and leads to reduced tea productivity in the long run (Doanh et al. 2018). Long-term use of mineral fertilizers in tea cultivation can result in problematic soil acidification. Chong et al. (2008) found that long-term conventional tea cultivation resulted in soil pH of 3.38 compared to 4.16 of organically managed tea soil. Likewise, 70% of studied conventional tea fields that applied intensive calcium cyanamide ($CaCN_2$) had soil pH values below 4.0, of which 9% were below 3.0 (Oh et al. 2006). Lin et al. (2019) argued that excessive chemical usage in tea cultivation resulted in nutrient imbalance and increased heavy metal levels in soil which exacerbates soil acidification. Using only compound fertilizers in conventional tea production resulted in the highest loss of soil fertility and degradation compared to the combination of organic manure and mulching; indicated by the decreases of soil health indicators such as wet stable aggregates, soil organic matter, soil organic carbon and the increases of soil bulk density and soil penetration resistance (Yüksek 2009). High levels of heavy metals (Cu, Ni, Zn, Hg, As, Cd, Cr and Pb) and pesticide residues (imidacloprid, β-Hexachlorocyclohexane, permethrin) were also recorded in tea plantations subjected to continual over application of agrochemicals (He et al. 2020). Likewise, various pesticide residues such as Ethion (47,75 ppb), Chlorpyriphos (177,75 ppb); Heptachlor (115,05 ppb) and Dicofol (187,70 ppb), were detected in soils of conventional tea plantations in India. Comparatively, in soils from organic tea plantations, levels of the aforementioned heavy metal contaminants and residual agrochemicals were all below the detection levels (Bishnu et al. 2009).

Although there is no study on the effects of heavy pesticide applications on tea plantations in Vietnam to date, investigations on other crops in Vietnam and other countries showed that long-term pesticide use can have negative impact on soil quality properties. A 10-year study conducted from 2002-2013 on vegetable production in Vietnam concluded that about 80% of pesticides have been used incorrectly. This has resulted in increased production cost and environmental pollution (Hoi et al. 2016). Residues of many pesticides including dichlorodiphenyltrichloroethane (DDT), dicofol and isoprothiolane have been found in soil samples from the Red River Delta of Northern Vietnam (Nishina et al. 2010). The World Bank warned that land and soil pollution in Vietnam, caused mainly by fertilizer application and pesticide residues from farming activities, is a significant emerging problem (Nguyen 2017). Burrows and Edwards (2002) showed that increased pesticide use negatively affected microbial activity and diversity of nematode and earthworms. A reduction in

the populations of fungal, actinomycete and protozoal populations due to the applications of Edosulfan and Pyrethroid was also found (Kalia and Gosal 2011). Similarly, fungicides (Bavistin and Dithane M-45) and carbendazim led to an extensive reduction of many soil fungi species in first 20 days, such as *Penicillium* spp, *Mucor racemosus* and *Aspergillus ruber* (Aggarwal et al. 2005). Heavy uses of chlorpyriphos, carbendazim, 2,4-D and carbofuron in paddy fields resulted in a significant decrease of soil bacterial populations and soil microbial biomass (Arora et al. 2019). Similar findings on the negative effects of pesticide applications on soil organisms were also reported by Lo (2010), Kalia and Gosal (2011), and Arora and Sahni (2016).

3.4. Soil erosion

Aside from soil and vegetation characteristics, inappropriate farming practices such as mono cropping, over ploughing, burning or clearing out plant residues and pesticide applications have been considered as the main causes of soil erosion in Northern Vietnam (Alam 2014; Vezina et al. 2006). Soil erosion is a major cause of soil degradation in Vietnam; affecting about 40% of Vietnam's total land surface area (Ha et al. 2012; Phuong et al. 2014). As 80% of tea plantations in Vietnam are grown in high rainfall, mountainous regions on steep sloping land (Doanh et al. 2018), soil erosion is a constant and difficult challenge. Studies on the effects of slopes on soil erosion rates in Northern Vietnam have indicated that soil loss occurs at a rate of 96 tonnes/ha/year at a 3 degree slope, 211 tonnes/ha/year at an 8 degree slope and can reach 305 tonnes/ha/year at a slope of 15 degrees (Nguyen and Pham 2018).

Tea seedlings are commonly grown at a recommended spacing of 100 cm by 60 cm and this leaves a large area of soil open to surface erosion, especially during the crop establishment period when tea canopy is not yet closed. Sahoo et al. (2016) showed that rainfall runoff observed in tea fields without soil conservation measures in the establishment years ranged from 30 to 35%. Similarly, Zhang et al. (2003) estimated that soil loss by erosion from tea plantations in China could be up to 4,000 tonnes/km^2/year. Soil erosion leads to soil organic matter and nutrient losses, reduced soil water holding capacity, exposure of subsoil with high acidity and poor fertility, thus resulting in soil health degradation (Lal et al. 2018; Zheng et al. 2010).

3.5. Environmental and human health concerns

To date, the effects of extensive pesticide applications in tea cultivation with negative consequences on the environment and health of Vietnamese tea farmers and consumers have not been clear. Scientific investigations carried out in other

farming activities have indicated a strong alarming signal to this concern. The study of Dasgupta et al. (2007), investigated the levels of agrochemicals and pesticides on 190 rice farmers in the Mekong Delta region of Vietnam. The results from this study showed a high prevalence of pesticide poisoning by organophosphate and carbamate exposure with over 35% of test subjects experiencing acute pesticide poisoning (Dasgupta et al. 2007). At national level, more than 3,000 cases of pesticide poisoning were recorded by the Ministry of Health, causing more than 100 deaths in Vietnam just in the first half of 2011 (Dang et al. 2017). Research on tea plantations from other Asian and African countries also concluded that intensive usage of pesticides and fungicides puts the health of tea growers and consumers at risk (Hajiboland 2017). Using the modified QuEChERS method, a recent study conducted in China found 102 different pesticide residues in tea leaves (Huang et al. 2019). Likewise, Feng et al. (2015) found 198 out of 232 harvested tea samples of green tea, oolong tea and black tea were contaminated with pesticide residues, and the residue levels in 39 samples were exceeding the maximum residue limits of the European Union. Globally, pesticide poisoning is a public health issue, which has been responsible for around 300,000 deaths worldwide every year (Sabarwal et al. 2018).

3.6. Advantages of conventional tea management method

Comparative analyses as to the benefits of conventional tea farming in Vietnam versus other cultivation alternatives is largely undocumented. Studies conducted in other tea growing nations have indicated this farming method could have some positive benefits in comparison with organic and other tea management methods. Intensive applications of chemical fertilizers generally increase tea yield, compared to the yields from plants grown solely supplemented with organic fertilizers (Das et al. 2016; Yang et al. 2012). Many agrochemicals such as fertilizers and pesticides commonly used by conventional tea farmers are typically cheaper and more readily available, especially in the remote and mountainous regions of Vietnam (Doanh et al. 2018). In addition, conventional tea producers also do not need to seek for certifications. Tea producers that adopt agroecological management strategies must meet the criteria of compliance watchdogs, including organic, VietGAP and the Rainforest Alliance. Demonstrating compliance can be both costly and time consuming (Ha 2014a; Van Ho et al. 2019). Finally, conventional farming practices typically have lower labor input requirements, which is an advantage that convinces many tea growers to stick with the conventional management approach (Doanh et al. 2018; Quiao et al. 2016).

4. Agroecological management practices for sustainable tea development - A promising approach

4.1. Agroecological tea production in Vietnam

Traditionally in Vietnam, agroecological practices such as manure and plant residue applications, intercropping, mulching and agroforestry have been utilized in a range of cropping systems including maize, vegetables, forests and fruits (Dzung et al. 2013; Grosjean et al. 2016; Nguyen and Pham 2018). In recent years, other farming management systems and practices including organic agriculture, VietGAP standards, integrated pest and/or disease management (IPM or IDM), biofertilizers and biopesticides use have been promoted – mainly in rice, vegetable, fruit, tea and coffee plantations (Doanh et al. 2018; Duc and Goto 2019). The VietGAP refers to a voluntary standard package providing the criteria and requirements for safe and sustainable agriculture production, enhanced by certification and auditing processes (Nicetic et al. 2016; Van Ho et al. 2019). To be certified, VietGAP adopters must record all practices on their farms, from field selection, to production, harvest and processing. VietGAP products also need to meet the pesticide limits (Nicetic et al. 2016). In addition to VietGAP standard, organic farming also has received increasing attention. In 2010, there were 21,300 ha of certified organic agricultural land in Vietnam, accounting for about 2% of total agriculture land areas (Nghia et al. 2016). By 2016, this had grown to 77.000 ha (Suharyono 2018).

In the tea production sector, there has also been increased interest and implementation of agroecological management practices in recent years; in form of organic and other cultivation methods (Doanh et al. 2018; Ha 2014a). In 2019, the provinces with largest certified VietGAP and organic tea areas are Ha Giang, Phu Tho and Thai Nguyen with nearly 7,000 4,100 and 1,600 ha of tea plantations respectively (Ha Giang Government 2019; Thai Nguyen Government 2019). Other agroecological practices such as intercropping with legumes in the establishment years (1-3 years old), incorporation of shade trees, organic mulching, terraces and mini terraces have been also practiced, either separately or in combination (NOMAFSI 2015). Currently, the proportion of certified VietGAP and organic tea areas is still very small compared to the total area of tea production (Thai Nguyen Government 2019). However, this figure is expected to rapidly grow in the next few years as many tea producers are currently adopting VietGAP and organic management practices (Ha Giang Government 2019; Thai Nguyen Government 2019). At a national level, more than 52,000 ha of tea plantations were proposed to meet the VietGAP standard by 2020, accounting for around 42% of the total tea plantations in the country (Thu 2016).

4.2. Potential advantages of agroecological tea cultivation

4.2.1. Soil physical and chemical properties

The influence of agroecological tea management on soil physical properties has been well documented. A study conducted in tea fields in Vietnam showed that tea residue mulches application used in combination with biofertilizers containing various beneficial microorganisms (*Bacillus* spp., *Lactobacillus* spp., *Streptomyces* spp., *Saccharomyces* spp.) resulted in a significant decrease of soil bulk density and an enhancement to soil moisture content (Cu and Thu 2014b). Likewise, using the fern *Gleichenia linearis* as mulch improved soil moisture when applied at a rate of 25 tonnes/ha (Cu and Thu 2014a). Sun et al. (2011) argued that straw and plastic mulches increase soil water content and water use efficiency, while Peng et al. (2006) indicated that straw mulches and intercropping with legumes stabilizes tea plantation temperatures, reducing the deleterious impact of high temperatures and daily temperature fluctuations of soils. Organic fertilizers such as sheep manure significantly improved soil porosity, soil bulk density and particle density (Chepkorir et al. 2018).

In tea cultivation, organic fertilizer application such as sheep manure significantly reduced soil acidification and improved soil N content (Chepkorir et al. 2018; Li et al. 2018). Studies have shown that phosphate solubilizing bacteria (PSB) and arbuscular mycorrhizal fungi (AMF) can convert nutritionally important elements from unusable to usable forms (Roychowdhury et al. 2014; Sabaiporn et al. 2020). Phosphate solubilizing bacteria such as *Bacillus* spp. and *Pseudomonas* spp. were shown to increase P availability to tea plants by converting P from insoluble to soluble forms to increase its availability resulting in increased plant growth (Gebrewold 2018). Mulching practices and intercropping with soybean resulted in a significant reduction of exchangeable aluminum (Al) content, weed occurrence, disease and pest incidences, but increases of soil pH, organic matter content and N content (Jianlong et al. 2008). Organic mulches (straw, chopped grass, legumes) have been shown to significantly increase soil organic matter and soil N status (Sun et al. 2011); soil organic carbon, soil pH, available P, and total N content (De Silva 2007). After adding tea pruning mulches and biofertilizers (*Bacillus* spp., *Lactobacillus* spp., *Streptomyces* spp., *Saccharomyces* spp.) to soils of tea plantations a significant increase in soil organic matter content, concentration of exchangeable cations (Al^{3+}, Ca^{2+} and Mg^{2+}) and a decrease of soil acidification was observed (Cu and Thu 2014b).

4.2.2. Soil biological properties

Agroecological tea management practices such as organic fertilizers, biofertilizer application and mulching are known to improve soil biological diversity and structure (Bishnu et al. 2009; Roychowdhury et al. 2014). The application of tea pruning mulch over soil surface as a single practice or combined with biofertilizers significantly increased the number of bacteria by up to ~1734,6%, actinomyces by ~319% and fungi by ~24,5% compared with non-mulch and biofertilizer treatments (Cu and Thu 2014b). A similar study done in China indicated that long-term application of rape cake and sheep manure significantly increased the abundance of many bacteria such as Burkholderiales, Streptomycetales, Acidobacteriales, Nitrospirales, Solibacterales and Gemmatimonadales (Lin et al. 2019). Such increases of soil microbial abundance are important for tea plants, as an enhanced soil microbiome can incorporate potentially beneficial bacteria that enhance plant growth and productivity. For instance, *Nitrospira* spp. play a role in the nitrification processes of the N cycle (Koch et al. 2015; Lücker et al. 2010); *Burkholderia* spp. can improve plant growth as well as inhibit pathogen growth (Wu et al. 2016); and *Streptomycetales* spp. could help to mitigate plant diseases as they are able to produce various bioactive metabolites, such as antibiotics, anti-inflammatory and antimicrobial enzymes (Kinkel et al. 2012; Lyu et al. 2017). Gu et al. (2019) compared chemical fertilizers and organic manure (cow and pig manure) combined with commercial organic fertilizers in tea plantations. Outcomes from Gu et al. (2019) study showed significant increases in the relative abundance of soil microorganism groups that were able to perform chemoheterotrophy (29%), N fixation (41%), fermentation (110%), and aerobic nitrite oxidation (557%) in the organic fertilizer treatments. Other studies focusing on mulching practices in tea gardens also indicated that organic mulch materials such as chopped grass and straw all increase microbial biomass carbon, population of beneficial fungi, bacteria and mycorrhiza (De Silva 2007).

At present, the impacts of agroecological tea management practices on soil microbial diversity and community structure are largely undocumented in Vietnam, but they have been well studied in other countries such as in China. Qiu et al. (2014) illustrated that organic manure application resulted in the highest microbial diversity in soils compared to NPK treatment only. Similarly, sheep manure was shown to mitigate soil acidification, enhance the diversity and abundance of soil microbes, as well as improve the overall microbial community structure in soils of tea plantations (Li et al. 2018). In terms of soil fauna, a study in China showed that organic tea cultivation led to an increase in common species diversity, species richness and trophic diversity of nematodes in both soil surface and subsurface layers in comparison with conventional tea farming (Li et al. 2014)

4.2.3. Tea quality, productivity, production cost and market development

Agroecological management practices have the potential to be more beneficial for tea quality than conventional management approaches by reducing or eliminating the agrochemical uses, thus reducing pesticide residues, as well as improving other tea quality indexes such as amino acid and water extract content (Birch et al. 2011; Reddy 2017). Some studies have indicated that organic fertilizers produced from animal manure and vinegar residues can significantly improve tea quality indicators (amino acids, water extract content and caffeine content) and reduce the heavy metal contents such as arsenic and cadmium in tea leaves as compared with mineral fertilizer applications (Li et al. 2015; Li et al. 2016). Likewise, the application of biofertilizers containing *Paenibacillus polymyxa* produced from effluent generated during sweet potato starch production, resulted in increased levels of tea polyphenol and water extract content by 10.4% and 6.3% respectively (Xu et al. 2014). The beneficial outcomes from other forms of agroecological cultivation on tea quality have also been reported such as mulching (Sun et al. 2011; Yüksek 2009), intercropping (Jianlong et al. 2008; Sedaghathoor and Janatpoor 2012), non-chemical pest and disease managements (Mamun and Ahmed 2011; Shrestha and Thapa 2015).

Compared to conventional fertilizer usage, the application of sole organic fertilizers and biofertilizers generally resulted in lower tea yields, especially in the transition period although the differences are not always significant (Doanh et al. 2018; Haorongbam et al. 2014; Lin et al. 2012). However, combining organic fertilization and biofertilizers could lead to higher tea productivity compared with chemical fertilizers, particularly in the long run (Haorongbam et al. 2014; Lin et al. 2012). Despite organic manure and biofertilizer have lower levels of nutrients than mineral fertilizers, the presence of growth promoting compounds such as enzymes, hormones, organic matter, as well as a higher microbial activity and functional diversity, could make them essential for the improving soil fertility and productivity (Haorongbam et al. 2014). To obtain optimal tea productivity and reduce the harmful effects of intensive mineral fertilizer usage, a combination of organic fertilizer with proper proportion of chemical fertilizers has been widely recommended (Lin et al. 2012; Qiu et al. 2014; Xie et al. 2019).

A higher income is one of the main driving factors for the conversion from conventional management to agroecological tea practices. Recent studies indicated that organic tea adopters could earn a better net income than their conventional counterparts (Deka and Goswami 2021; Doanh et al. 2018). Although implementation of agroecological tea strategies generally requires extra investments for labor, relevant certifications and pests and diseases control, agroecological tea adopters typically invest less on agrochemicals (Bui and Nguyen 2020; Doanh et al. 2018; Qiao et al. 2016). In addition,

agroecological tea products can be sold with higher prices as tea consumers seek for tea with a better quality (Bui and Nguyen 2020; Doanh et al. 2018). All these factors contribute to a significant higher net income, especially in long-term agroecological managed fields.

In 2015, approximately 75,000 tonnes of registered organic tea were produced worldwide, valued at around USD 765 million. It is forecast that organic tea will experience a rapid growth of 6-13% per year due to the increasing demand for a chemical-free tea beverage by consumers (Hajra 2017). In 2017, the global tea market was valued at approximately USD 50 billion. It is further predicted this economic sector is projected to grow by around 5.3% annually to reach USD 73 billion in 2024 (Statista 2020). As one of the leading tea producers and exporters in the world, this market growth creates a great opportunity for the Vietnamese tea industry to expand their international market and improve the international market share of high-quality tea export. The beneficial impacts of agroecological tea management practices on aspects of soil health, tea quality and productivity are summarized in Table 2.

Table 2 Summary the benefits of some agroecological management practices on tea soil properties, tea quality and productivity.

Agroecological practices	Materials	Beneficial effects	References
Organic fertilizers	• Rape cake and sheep manure	• Increase soil pH, the relative abundance of various bacteria; significantly increase the amino acid content but reduced the contents of Cadmium (Cd), Lead (Pb) and Arsenic (As) in tea leaves.	Lin et al. (2019)
	• Commercial farmyard manure made from chicken manure	• Resulted in the greatest levels of soil organic matter, total N, total P, N available, K available; richest soil bacterial community diversity compared to only chemical fertilizers and half chemical plus half organic manure applications.	Qiu et al. (2014)
	• Vinegar residue	• Significantly increase alkali-hydro N, available P and available K compared to chemical fertilizers and tea quality indexes (tea amino acid, caffeine, water extract and polyphenols)	Li et al. (2015)
Biofertilizers	• Phosphate-solubilizing bacteria (PSB), arbuscular mycorrhizal fungi (AMF) and tea residues	• Retain soil fertility and nutrient quality, mobilize nutritionally important elements from unusable to usable forms; enrich soil microorganisms, increase tea yield, and reduced chemical fertilizer usage.	Roychowdhury et al. (2014)
	• *Paenibacillus polymyxa* produced from wastewater from the sweet potato starch industry	• Tea yield, level of tea polyphenol and water extract content were significantly increased by an average of 16.7%, 10.4% and 6.3% respectively.	Xu et al. (2014)
	• Nitrogen fixing *Azospirillum*, phosphate solubilizing bacteria and AMF fungi	• Increase tea soil fertility, reduce tea disease and chemical fertilizers.	Nepolean et al. (2012)

Biopesticides	• Insect-pathogenic fungus *Metarhizium anisopliae*	• Significantly reduce the incidence of adult *Aedes aegypti* and *Aedes albopictus* mosquitoes.	Roychowdhury et al. (2014)
	• Doubled stranded viruses of Baculovirade family	• Successfully control *Adoxophyes honmai* and *Homona magnanima* species.	Nakai (2014)
	• *Aspergillus niger, Azospirillum brasilense, Bacillus subtilis, Beauveria bassiana, Trichoderma harzianum, T. viride and Verticillium lecanii.*	*A. niger* and *T. harzianum* are the most compatible microbe in relation with commonly used pesticides in tea (Azadirachtin; Dicofol; Phosalone; Clothianidin; Deltamethrin etc.), suggesting that there may be some compatible agrochemicals that can be utilized in combination with the biopesticides.	Dutta et al. (2016)
Mulching	• Straw mulches	• Result in an increase of soil water content and water use efficiency, significantly increase soil organic matter, available N, nitrate N, and ammonium N and tea yield (12-13%).	Sun et al. (2011)
	• Chopped grass (*Brachia decumbens*); legume (*Calliandra calothyrsus*)	• Improve soil pH, soil organic and microbial biomass carbon, soil CEC, plant available P, and total N contents. Grass and legume mulches increase the population of positive microorganisms (bacteria, fungi, and mycorrhiza).	De Silva (2007)
	• Straw mulch and white clover as living mulch	• Straw and white clover enhance the stability of soil temperature in the same layer, decreases daily temperature difference and the emergence of harmful high temperature.	Peng et al. (2006)
	• Soybean (*Glycine max)*	• Significantly improve soil nutrient by reducing exchangeable Al content, increasing soil pH and organic matter, total N content and available N; reduce weed occurrence, disease and pest incidences.	Jianlong et al. (2008)

Intercropping	• Aromatic plants (*Cassia tora, Leonurus artemisia, Medicago sativa* and *Mentha haplocalyx)*	• Reduce the population of tea green leafhoppers, increase the natural enemies of tea pests such as spiders, coccinellids, lacewings, and parasitoids.	Zhang et al. (2017)
Integrated Pest/Disease Management (IPM/IDM)	• IPM-FFS (Farmers Field School). IPM relied on local communities	• Enhance safe tea production and improve tea farmers' income.	Shrestha and Thapa (2015)
	• IPM (light traps, heat treatment, manual removal, planting of rehabilitation and trap crops, pruning)	• Significantly reduce the incidence of common tea pests such as termites, mosquitos, aphids, caterpillars, spiders and so on; reduce chemical uses, pesticide residues and improve tea quality.	Mamun and Ahmed (2011)

4.2.4. Soil erosion reduction

Several agroecological management practices were found to effectively reduce soil erosion as well as improve water retention capacity of tea soil. Sahoo et al. (2016) indicated that cover crops, vegetative barriers, and contour staggered trenches significantly reduced rainwater runoff by 15-20% in the first two years of tea plantations. Similarly, Thushari (2018) suggested that shade tree planting is an effective solution to mitigate soil erosion in tea soil as they prevent rainwater from directly contacting on the ground and reduce rainwater speed. Vetiver grass (*Vetiveria zizanioides* L) also offers an effective break, reducing water runoff and preventing soil erosion in tea plantations on slopes (Haridas 2001).

Practices such as intercropping, mulching, growing grass hedgerows, mini-terraces not only for tea but other plants like coffee, rubber and other annual crops in the Northern Vietnam significantly reduced soil erosion and water runoff (NOMAFSI 2016). Organic manure (buffalo manure), vermicompost, earthworms (*Eisenia andre*), and compost uses in maize plantations in Northern Vietnam resulted in a significant reduction of runoff water, soil loss and leachate properties, in comparison with only chemical fertilizer treatments (Doan et al. 2015). The lowest amount of soil loss was recorded in the vermicompost treatments (0.3 kg/m^2), followed by compost (0.4 kg/m^2), organic manure (1.1 kg/m^2) and the chemical fertilizer (1.4 kg/m^2) (Doan et al. 2015). In comparison with traditional practices, the application of mulching and terraces in the Northern mountainous areas of Vietnam significantly reduced soil loss by ~90.3% and ~93.9%, respectively (Nguyen and Pham 2018). As 70% of Vietnam's tea production occurs on sloping land, of which 50% slope more than 20 degrees (Tien 2015), appropriate agricultural practices to reduce soil erosion and water loss is playing a key solution to restore and improve soil health (Lal Rattan 2015; Nguyen and Pham 2018).

4.2.5. Challenges and how to encourage agroecological tea management strategy

Despite rapid growth over the last few years, agroecological tea farming still accounts for only a small percentage of tea plantations in Vietnam. First, poor technical assistance, unavailability of inputs required for agroecological practices such as biofertilizers, biopesticides or organic fertilizer, small scale production and lack of understanding of long-term benefits of agroecological tea farming have been identified as the main limiting factors (Doanh et al. 2018; Tuan 2019; Van Ho et al. 2019). Furthermore, limited market information and linkages, especially that involve international markets such as legislation and standards regarding food safety and quality has been a great barrier with

a majority of Vietnamese tea stakeholders (Ha 2014a; Thang and Hoa 2015). Moreover, the third-party certification processes of organic and VietGAP tea products are costly and time-consuming, preventing conventional tea farmers from adopting these cultivation methods (Ha 2014a; Van Ho et al. 2019). Finally, difficulty in accessing affordable credit for enhancing technology adoption and investing in the establishment period of agroecological tea production is also influencing tea producer decisions, especially in low-income small households (Doanh et al. 2018).

To promote agroecological tea farming, central and provincial governments must provide both technical and non-technical supporting policies and programs. For the technical aspects, the governments and other relevant stakeholders should provide better extension services and organize relevant training to farmers, including on-farm trials to allow farmers to learn from each other and understand the benefits of this management implementation (Doanh et al. 2018; Tuan 2019). Furthermore, encouraging the commercialization of agrochemical alternatives would make these organic or biological inputs easily accessible to tea producers, even in remote areas (Ha 2014a; Van Ho et al. 2019). Improving market information and access to affordable credit are important priorities to support low-income tea farmers and encourage them to change their management practices towards agroecological managed fields. As a result, tea exporters would also invest more in high technology and advanced innovations to improve tea quality and productivity such as branding, post harvesting and marketing (Doanh et al. 2018 Thang and Hoa, 2015).

5. Conclusion

Tea production has played a crucial role in the economic growth and social sustainability in Vietnam, especially in providing employments for poor people in rural areas. Despite a consistent growth of production volume over the last few decades, long-term conventional tea farming in Vietnam has been encountering many problems, including soil degradation and erosion, low tea quality and productivity and increased human health and environmental pollution concerns. As a result, there has been a rapid conversion from conventional tea farming to agroecological tea management practices such as using organic fertilizers and biofertilizers, mulching and intercropping as well as IPM and IDM. However, to date, the effects of these management practices on soil health and tea quality in Vietnam are poorly understood. This study is the first comprehensive review showing how agroecological tea management practices can improve soil physical, chemical and biological properties; eliminate the concerns of chemical hazards on human health and the environment; as well as improve tea quality indicators, including amino acid, catechin and reduce the chemical residues in tea products. Increasing demand of global market on high-quality tea products will allow agroecological tea producers to expand their production areas and export volume.

Funding

This work was supported by Deakin University and Alliance of Bioversity International and International Center for Tropical Agriculture (CIAT), Asia Hub, Common Microbial Biotechnology Platform (CMBP), Hanoi, Vietnam.

Conflicts of Interest

The authors declare no conflict of interest.

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