Agriculture, Ecosystems and Environment 254 (2018) 20–25

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Short communication

Tea planting affects soil acidification and nitrogen and phosphorus distribution in soil

Peng Yan, Chen Shen, Lichao Fan, Xin Li, Liping Zhang, Lan Zhang, Wenyan Han*

Key Laboratory of Tea Quality and Safety Control, Ministry of Agriculture, Tea Research Institute, Chinese Academy of Agricultural Sciences, Hangzhou, China

ARTICLE INFO

Keywords:
Tea garden
Soil acidification
N and P leaching risk

ABSTRACT

Land use change from natural forest to agricultural land often affects the properties of soil, resulting in various environmental problems. A field study was conducted to evaluate the effects of land use change from forest to tea cultivation on soil acidification as well as the nitrogen (N) and phosphorus (P) leaching risk. The soil acidification and nutrient concentrations in soil at a depth of 0–200 cm in two tea gardens with differing stand ages (10 and 100 years old), and three different fertilizer input levels (low-input, medium-input, and high-input), and in the forests adjacent to these tea gardens were measured at the Tea Research Institute of the Chinese Academy of Agricultural Sciences. Tea cultivation caused soil acidification throughout the 0–200 cm soil profile, and the lowest soil pH was observed in the 20–40 or 40–60 cm soil depth. Both nitrate (NO_3^-) and ammonia (NH_4^+) concentrations increased as the tea stand age and fertilizer input levels increased at the 0–90 cm soil depth. Compared to the forests, significantly higher concentrations of NO_3^- and NH_4^+ were observed in the 90–200 cm soil of the tea gardens, suggestive of a high risk of N leaching loss in the tea gardens. Longer tea cultivation times and higher input levels also increased the concentration of soil available P and $CaCl_2$-P at 0–90 cm soil depth, and a change point was observed in the relationship between soil available P and $CaCl_2$-P. Depending on the relationship between soil available P and soil $CaCl_2$-P, the soil $CaCl_2$-P concentration dramatically increased when soil available P surpassed 75.1 mg kg^{-1}. This study also indicated that soil acidification could occur in deep soil profiles as a result of tea cultivation and excessive fertilization; thus, there is a high risk of N and P leaching loss in tea gardens.

1. Introduction

Tea (*Camellia sinensis*) is a perennial evergreen plant taht is mainly distributed in tropical and subtropical areas. It is a major cash crop in many developing countries such as China, India, Kenya, and so forth. In 2014, the area devoted to tea cultivation totaled about 2.74 million ha in China; this area has been expanding rapidly because of the high economic value of the crop (Feng, 2015). Most high-quality tea is grown in the mountainous areas because of the special climate conditions and the growth characteristics of the tea; in turn, increasing numbers of mountain forests have been converted into tea gardens. It is therefore crucial to consider that soil chemical characteristics may be changed by tea cultivation because of the special biological characteristics of tea and agronomic management practices that accompany this crop.

Tea is a special crop that requires acidic soil and, in turn, acidifies the soil. It can uptake and accumulate large amounts of aluminum (Al) in the leaves, and the biogeochemical cycling of Al in tea leaves can cause soil acidification (Song and Liu, 1990; Ding and Huang, 1991). Moreover, tea prefers ammonium as a nutrient, and more NH_4^+-N fertilizer is often applied in tea gardens to increase the yield and quality of the tea (Ruan et al., 2000). Both the release of H^+ during the process of NH_4^+-N uptake from soil and the nitrification of NH_4^+ can accelerate soil acidification (Ruan et al., 2000, 2004). Han et al. (2002) reported that more than 40% of tea gardens had a soil pH around 4.0, 15% lower than the soil pH in a forest adjacent to the tea gardens. However, most of these studies were focused on the topsoil (0–20 cm), and there is little information on soil acidification at deeper soil depths. Notably, the downward movement of H^+ and NH_4^+ might lead to soil acidification in the subsurface soil.

In addition to soil acidification, other environmental problems, such as eutrophication, could be caused by tea cultivation. In general, tea production entails large input of chemical and organic fertilizers (Han et al., 2002). Based on an investigation of 434 farmers in the Zhejiang Province, China, the average rate of N fertilizer application was 521 kg ha^{-1}, far surpassing the required amount, 240 kg ha^{-1} (Ma

---

* Corresponding author.
E-mail address: hanwy@tricaas.com (W. Han).

https://doi.org/10.1016/j.agee.2017.11.015
Received 12 September 2017; Received in revised form 14 November 2017; Accepted 15 November 2017

et al., 2013). The concentrations of NO_3^- and NH_4^+ in the topsoil (0–20 cm) sometimes reach 30 and 15 mg kg^{-1}, respectively (Fan et al., 2015). Normally, mean precipitation is greater than 1500 mm, and heavy rainfall happens frequently in tea plantation areas. Under these conditions, high amounts of NO_3^- and NH_4^+ may leach from the root zone and cause eutrophication. Examining the distribution of NO_3^- and NH_4^+ in the soil profile might be useful for evaluating the potential of NO_3^- and NH_4^+ leaching risk in tea gardens.

At the same time, high concentrations of P have also been observed in some tea gardens because of high application rates of P fertilizer or organic fertilizer (Yang et al., 2013). Han et al. (2007) reported that topsoil available P concentrations were as high as 400 mg kg^{-1} in tea gardens with high productivities. An Olsen P value of 40 mg kg^{-1} has been considered a critical level for developing a risk of P leaching loss (Zhong et al., 2004). Previous studies have demonstrated that excessive Olsen P values above the critical P leaching level greatly increase the risk of P losses via erosion, overland flow, and leaching, which leads to the eutrophication of surface waters (Sharpley et al., 2000; McDowell and Sharpley, 2004; Aulakh et al., 2007). Therefore, the soil available P distribution in the soil profile can determine the critical level of available P above which $CaCl_2$-P increases. These are important factors when it comes to evaluating the P loss risk in tea gardens.

In this study, two tea gardens with different planting years, a young tea garden, about 10 years old, and an old tea garden, about 100 years old, were sampled and analyzed. Soil samples from three tea gardens with different fertilizer input levels (low, medium, and high input), and from the adjacent forest were also sampled and measured. The objectives of this study were to evaluate the effects of tea cultivation and agronomic management on (1) soil acidification in the vertical soil profile, (2) soil NO_3^- and NH_4^+ distribution in the 0–200 cm soil profile, and (3) soil available P and $CaCl_2$-P distribution at a soil depth of 0–200 cm and their relationship to each other.

2. Materials and methods

2.1. Field sites

The study area was located in Hangzhou City, Zhejiang Province, China, which is famous for producing Westlake Longjing tea. The environment of the experimental sites is characterized by a subtropical monsoon climate with four distinct seasons. The annual mean temperature is 17.0 °C, ranging from 1.7 °C in January to 33.0 °C in July, and the mean precipitation level is 1553 mm, with 74% of total rainfall occurring during the tea growing season from March to September. At the Tea Research Institute of the Chinese Academy of Agricultural Sciences, tea gardens of two different stand ages (10 and 100 years old) and the adjacent forest were used to analyze the effect of tea planting age on soil acidification and N and P leaching risk. Another three tea gardens with different fertilizer input levels (low, medium, and high-input), as well as the forest adjacent to the tea garden were sampled to analysis the affect of fertilizer input level on soil acidification and N and P leaching risk. The 10- and 100-year-old tea gardens and the adjacent forest were located at 120°5′E, 30°11′N, and the two study sites were located less than 0.5 km from each other (Fig. S1). The low-, medium-, high-input tea gardens and the adjacent forest were located at 120°10′E, 30°10′N, and were also located less than 0.5 km from each other (Fig. S2). *Longjing Quntizhong*" was cultivated in the old tea garden, and "*Longjing 43*" was cultivated in the other tea gardens. The soil is loamy clay with Anshan quartz-free porphyry parent material.

There were similar agronomic management approaches for the different-aged tea gardens. Normally, 2250 kg ha^{-1} of organic fertilizer (rape seed cake containing 45% organic C, 4.6% N, 0.9% P, and 1.2% K) or 1500 kg ha^{-1} of compound fertilizer (8.0% N, 6.0% P, and 3.4% K) is applied in the end of September or early in October. An additional 250 kg ha^{-1} N is dressed before and after the spring tea cropping in mid-February and May, respectively. N application for the three tea gardens with different input levels was 300, 600, and 900 kg ha^{-1}, over 3–4 split dressings, for the low-, medium-, and high-input tea gardens, respectively. Furthermore, 2250 kg ha^{-1} of organic fertilizer (rape seed cake) was applied to the high-input tea garden, and half that amount (1125 kg ha^{-1}) was applied to the medium-input tea garden; no organic fertilizer was applied to the low-input tea garden. The other agronomic management techniques for these tea gardens were similar for each garden and included pruning, tillage, weeding, and so on. Evergreen broad-leaf plants, including *Schima crenata korthals*, *Castanopsis sclerophylla*, and *Cinnamonum camphora*, dominated the adjacent forest. No fertilization was applied to the forest, except litter (approximately 10 Mg ha^{-1} $year^{-1}$).

2.2. Soil sampling and analysis

The area of each tea garden is greater than 300 m^2, and four plots of about 75 m^2 were set up in each tea garden (Fig. S1, S2). In October 2015, using a soil-drilling method, soil samples were taken from each plot at 10-cm increments to a depth of 20 cm, 20-cm increments to a depth of 60 cm, 30-cm increments to a depth of 150 cm, and 50-cm increments to a depth of 200 cm. Samples from at least ten points were homogenized from each plot to form a composite sample. Plant residues, roots, and stones were removed, and the soil samples were passed through a 5-mm sieve.

Samples were extracted with 0.1 mol L^{-1} KCl_2, and soil NO_3^- and NH_4^+ were measured in the extracts using continuous flow analysis (TRAACS 2000; Seal Analysis, Mequon, WS, USA) in the laboratory. Soil water content was measured after oven-drying at 105 °C. The other soil samples were air-dried and then passed through a 1-mm sieve for physicochemical analysis. The soil pH was measured using a combined glass electrode in a 1:1 (w:v) soil:distilled water mixture. Total soil N concentrations were determined using a Vario Max CN Analyzer (Elementar Analysensystem GmbH, Germany). Soil available P was extracted with Bray-1 (0.03 M NH_4F + 0.025 M HCl), and measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES, JAC IRIS/AP, Thermo Jarrell Ash Corporation, Franklin, USA). $CaCl_2$-P was measured using 0.01 mol L^{-1} $CaCl_2$ as an extract (2.5 g soil, 12.5 mL solution, 25 °C, shaken for 15 min) (Heckrath et al., 1995; Hesketh and Brookes, 2000). We also used the molybdate–ascorbic acid method for the colorimetric measurement of P.

2.3. Data analysis

Data from the different tea gardens and the forests were analyzed using one-way ANOVA at a 0.05 level of probability, followed by a *t*-test using SPSS v. 16.0 (SPSS Inc., Chicago, IL, USA). To ascertain the statistical relationship between soil available P and $CaCl_2$-P, we used the results of the soil available P and $CaCl_2$-P at each soil depth for all treatments. The two-segment linear Sigma plot model was used to analyze the relationship of available P and $CaCl_2$-P. The two-segment linear model is defined by Eqs. (1) and (2) as:

$$y_1 = a_1x + b_1 \quad x < T \tag{1}$$

$$y_2 = a_2x + b_2 \quad x \geq T \tag{2}$$

where a_1, b_1, a_2, and b_2 are the parameters, and T is the critical level for available P.

3. Results

3.1. Soil pH in the 0–200 cm profile

In this study, compared to the forest soil, significant decreases in the soil pH were observed in all of the tea garden soils throughout the 0–200 cm soil depth samples (Fig. 1). The average soil pH in the forest 0–200 cm soil depth samples was 4.00, which was 0.23, 0.52, 0.54,