Summary of Dissertation

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Dissertation Title	Soil fertility and its correlation with green-tea elemental and functional components in a special tea-production area around Cong River in Thai Nguyen province, Vietnam ベトナム国タイグエン省コン川沿いの特産茶葉生産地における土壌肥沃度とその茶葉成分への影響に関する研究		

Introduction. In Vietnam, green tea is one of the most favorite beverage and tea production plays an important role in the national agricultural sectors. Tan Cuong commune in Thai Nguyen province is considered as the core center of tea production with special tea quality. The evaluation of tea products by the stakeholders varied within the commune, which is usually higher for the tea leaves produced around the riverside of Cong River than those away from. It could be assumed that such difference in tea evaluation may result from the differences in soil environments due to topographic or other conditions in the commune.

Meanwhile, it is believed that increasing N uptake from soil brings about the increase both in the yield and quality of tea plants, particularly the content of Theanine, which is determinant for the “umami” and fragrance of tea infusion. Because of this, excessive N fertilizer is applied, which may cause excessive soil acidification, the leaching loss of nutrient elements, and water pollution. However, the information on tea garden soils has been quite limited in Vietnam. The purposes of this study are to investigate the soils in terms of the distance from Cong River and to correlate the soil factors with the contents of elemental components and functional components in tea leaves including Theanine as well as Catechins (polyphenols; responsible for bitter and astringent taste with a function of antioxidant effect) in order to develop appropriate, environmental-friendly soil management schemes for tea production.

Materials and methods: The study area was located in the flood plain of Cong River in Tan Cuong. The terrain was composed of back marsh lowland with interspersing rows of the current natural dike and, followed by river terraces away from the river. Tea gardens were located on the lowlands adjacent to the river and on the previous dikes or hill slopes.

Three transect lines (A, B, and C) were installed perpendicularly to the river, each on which four study sites were established. They were coded as A1 to A4, B1 to B4, and C1 to C4. For comparison, four forested patches adjacent to the tea gardens on transect B (BF1, BF2, BF3, and BF4) were selected. In addition, three tea gardens were studied in Song Cau (S1, S2, and S3) which was considered as the inferior tea production area.

For pedological characterization, soil profiles were described at B1 to B4 and S1 and soil samples were collected from each pedological horizon for general physicochemical analysis, clay mineral composition, Al, Fe and Si oxide-hydroxides, and total element contents. To assess soil fertility, soil samples were collected at the depth of 0-10 cm and 20-30 cm in all study sites and analyzed for general physicochemical properties and DTPA-extractable contents of Mn, Fe, Cu, and Zn. Undisturbed soil samples were collected at the depths of 0-10 cm and 20-30 cm in B1 to B3, BF1, BF3, and S1 sites to assess soil physical properties. At B1 to B4, soil solution was weekly collected at 20 cm depth and its chemistry was analyzed. Meanwhile, tea leaf samples were collected for the total element analysis. For tea infusion by boiling water, the contents of total elements and the concentrations functional components (Theanine, Catechins, total polyphenols, and antioxidant activity) were determined.

Pedological characteristics. Although all soils were strongly acidic throughout the profile with high contents of exchangeable Al, pedological characteristics varied, depending on physiological location of tea gardens and soil disturbance: the B1 and BF1 soils at the riverside were classified as Typic Ustipsaments. They were deep, sandy-textured, and predominated by quartz and kaolin minerals in the clay fraction. Meanwhile, the B2 to B4 and BF3 soils far from the river were Typic Dystrustepts while the S1 soil was Typic Paleustults. These soils were relatively shallow, fine-textured with 2:1 clay minerals as well as kaolin minerals. The $(Fe_d\text{-}Fe_o)/Fe_t$ ratio was the lowest in B1 and BF1 sites and the highest in S1 site. These results indicated that the former soils were supplied as sediments upon flooding while the latter were intrinsic in relatively moderate-weathered status. The analysis of total element contents supports these views. In addition, the influences of soil disturbance were observed in the soil profiles and properties in B2 and B4 sites.

Soil fertility. The soils showed strongly acidic nature with the average pH(H_2O) of 3.7 at the surface and 3.9 at the subsurface. The ECEC was low, and dominated by exchangeable Al. In spite of such acidic condition, a relatively large saturation of exchangeable Ca, K, and Mg on the ECEC was found in the surface soils. The level of available P was high, occasionally exceeding 1000 and 500 mg kg^{-1} at the surface and subsurface, respectively. Nitrification was not restricted, and a portion of NH_4-N applied as fertilizers was converted to NO_3-N in the surface soils to move down to deeper layers.

Three determinant factors of soil properties and fertility were identified: the first is the distance from the river for which soil texture classes varied from sandy loam close to the river to light clay far from the river. Physical properties were related to soil texture and also depended on the distance from the river. Influences on these properties by soil compaction were found at the riverside site. In addition, the exposure of subsurface soils due to severe disturbance was found in the farthest site from the river. The second was the garden age for which the levels of T-C and T-N were correlated with increasing age, suggesting that the addition of plant residue and manure replenished soil organic matter pools after the establishment of tea gardens. Lastly, fertilizer management practices principally determined the levels of the exchangeable bases, available P, and mineral N. However, a significant portion of these nutrients was likely to exist in water soluble forms without adsorption onto soils. Chemistry of soil solution also revealed that a lot of acids and nutrients were leached down and lost from soils.

Tea quality evaluation. The contents of mineral elements in tea leaves and tea infusion were in a harmless range for consumers. Regarding to the functional components, tea quality in the riverside sites was superior both in Theanine and total polyphenol contents of tea infusion, compared with those on the previous dikes and Song Cau, which corresponded to the market evaluation. Therefore, it is supposed that the increasing Theanine content could contribute to rising the market prices of tea products. The correlation analysis between mineral elements in tea leaves and functional components in the infusion revealed that the elements N, P, K, and Zn taken-up by tea plants could enhance the synthesis and accumulation of Theanine while the increasing Ca, Mg, and Al could lead to those of polyphenols including Catechins.

Important soil factors affecting tea quality. The multiple regression analysis revealed that pH, EC, and exchangeable Mg in the surface soils and potentially available Zn in the subsurface soils had significant effects on the levels of total polyphenols, Catechins, and antioxidant activity in tea infusion. The enhancement of the synthesis of phenolic compounds as a defensive substance may induced by the soil conditions with strongly acidic nature, a relatively high content of exchangeable Mg and the deficiency of Zn, which may result in more bitter taste of tea products. The obvious case was the higher contents of total polyphenols and Catechins of tea infusions from Song Cau due to the combination of negative effects of these soil factors. In contrast, judging from the positive correlations between the Theanine content in tea infusion and total contents of N, P, K, and Zn in tea leaves and negative correlations between those contents in the tea leaves and clay contents of the soils, it is suggested that the availability of these elements are crucial to building up the umami taste and fragrance. This is the case of higher contents of Theanine of tea infusions at the tea gardens at the riverside (A1, B1, and C1 sites) with the coarse-textured soils, which could allow readily uptake of fertilizer nutrients as water-soluble forms. Thus, according to the soil and tea-leave analysis, soil managements to increase the availability of N, P, K, and Zn and reduce exchangeable Mg under moderately acidic condition are required to improve tea quality through enhancing the synthesis of Theanine and retarding that of polyphenols.

As the conclusion, the management replacing the current system depending on chemical fertilizer is recommended for the enhancement of tea quality through environmentally-friendly tea production. Firstly, the application of green manure of tea pruning materials is essential to increase the contents of soil organic matter (humic substance, especially) with the aim at improving CEC promoting soil aggregate formation. The second is the improvement of soil chemical aspects with appropriate alleviation of soil acidity as well as balanced nutrient composition to stimulate the synthesis of Theanine. For this, although expanding use of handmade organic manure by households is important, the connection between tea production and organic fertilizer factory should be established to facilitate the supply of organic fertilizer with sufficient quantity and modified quality with balanced nutrient composition. In addition to such organic manure, biochar technique should be tested and optimized for tea production.