SOIL SOLUTION CHEMISTRY UNDER TEA GARDEN IN TAN CUONG COMMUNE OF THAI NGUYEN PROVINCE, VIETNAM

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ABSTRACT

The objective of this study is to investigate soil solution chemistry under tea gardens at the alluvial plain of Cong River in Tan Cuong commune, Thai Nguyen province, Vietnam. The study area is the core area for high-quality tea production. Four tea gardens in a transect line established perpendicularly with the river were selected as study sites. Soil solution samples were collected at the depth of 20 cm by using porous cups. The results of the present study are well agreed with those of our previous studies that the nitrification of ammonium fertilizers applied in tea cultivation still occur although the existence of strongly acidic condition and nitrification-derived NO_3^- is the dominant counter anion for leaching loss of base cations. The differences in precipitation between rainy and dry seasons and farming practices in terms of fertilization were responsible for the variation in the volume and chemical properties of the soil solution collected. Annually, soil nutrients have been added through fertilization at the end of dry season but rapidly solubilized and leached down by higher precipitation in the rainy season, especially in coarse-texture soil with high content of kaolin clay mineral adjacent to the river.

HÓA TÍNH CỦA DUNG DỊCH ĐẤT DƯỚI CÁC VƯỜN CHÈ TRÊN ĐỊA BÀN XÃ TÂN CƯƠNG THUỘC TỈNH THÁI NGUYÊN, VIỆT NAM

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TÓM TẮT

Mục tiêu của nghiên cứu này là tìm hiểu đặc tính hóa học của dung dịch đất dưới các vườn chè chịu ảnh hưởng của bồi tụ bởi sông Công trên địa bàn xã Tân Cương, tỉnh Thái Nguyên, Việt Nam. Khu vực nghiên cứu là vùng sản xuất chè đặc sản và chất lượng cao. Bốn vườn chè trên một đường thẳng vuông góc với dòng chảy của sông Công được chọn làm các điểm nghiên cứu. Mẫu dung dịch đất được lấy ở độ sâu 20 cm bằng ống hút chân không. Kết quả của nghiên cứu này đồng thuận với các kết quả trước đây của chúng tôi đó là quá trình nitrate hóa phân amoni bón cho cây chè vẫn xảy ra trong môi trường axit mạnh, ion NO_3^- phát sinh từ quá trình đó trở thành anion đối kháng chính gây nên hiện tượng rửa trôi cation kiềm trong đất. Sự khác biệt về lượng mưa giữa mùa mưa và mùa khô và phương thức bón phân là nguyên nhân dẫn đến sự thay đổi về thể tích và tính chất hóa học của dung dịch đất thu thập được. Hàng năm, các chất dinh dưỡng trong đất được bổ sung thông qua việc bón phân vào cuối mùa khô nhưng nhanh chóng bị hòa tan và rửa trôi do lượng mưa lớn vào mùa mưa, đặc biệt là ở đất có kết cấu thô nhẹ với hàm lượng khoáng sét cao ở gần sông.

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1. Introduction

Tea, a product made up from leaf and bud of the plant *Camellia sinensis*, is the most widely consumed beverage in the world. Vietnam is a developing country of Southeast Asia, of which economy mainly bases on agriculture. In the country, tea production plays an important role in the agricultural sector with 13th ranking for the export value among agricultural products and Vietnamese tea export was ranked 8th in the world in 2020 [1]. However, there has been the variation in tea quality revealed through marketing prices among production areas of which the highest based-price quality of tea has been recognized in Tan Cuong commune, a special tea production located in the Northern mountainous region.

Because tea plants prefer NH_4^+ to NO_3^- [2]-[4], NH_4^+ fertilizer application such as urea or ammonium sulfate is believed to increase both yield and quality of tea through improving the development of plant root and the accumulation of free amino acids in tea leaves [5]. A number of studies have characterized the impacts of overuse fertilizer in tea cultivation on soil physicochemical properties as well as soil acidification [6], [7]. In acidification process, the lowering pH decreases the net negative charges and the concomitant reduction in exchangeable Ca, K, Mg contents to be adsorbed onto soils in tea gardens [8]. The increasing exchangeable Al competes for cation exchange sites of soils with exchangeable K, Ca, and Mg, enhancing the release of the latter to soil solution. Thus, leaching loss of basic cations increases with the NO_3^- and SO_4^{2-} derived from the fertilizer as the counter anions [9].

Recently, a study on tea soils in Tan Cuong commune have indicated that the soils used for tea cultivation in the commune are varied with different soil types, formation conditions, and pedogenesis [10]. The investigation on soil physicochemical properties supposed that significant portion of some nutrients was likely to exist in water soluble forms without adsorption onto soils [11]. Although environmental problems related to soil nutrient leaching loss under intensive tea cultivation are now concerned in Vietnam, there was no study on the chemistry of soil solutions sampled directly from the fields so far. Because monitoring soil solution chemistry can provide indicators of environmental pollution and suction cups are easy to install and operate and have a low capital cost [12]-[15], the technique has been applied effectively for many crops including tea cultivation [16]-[18].

Since the indispensability of assessing quantitatively soil solution chemistry under tea gardens contributes to improve the efficiency of nutrient management and develop a sustainable agriculture in Vietnam, the objective of this study is to investigate the concentrations of macro nutrients (N, P, K, Na, and Mg) and some other basic parameters (pH and EC) of extracted soil solution as well as estimate the leaching loss of such nutrients under tea gardens.

2. Materials and Methods

2.1. Study area and site

The study area was located in the flood plain of the Cong River flowing eastward. The terrain is composed of back marsh lowlands with interspersing rows of the current natural dike and the previous dikes, followed by river terraces away from the river. The previous dikes are not connective. The topography is flat in the lowland and rises to several ten-meter heights in elevation with gentle slopes of 5 to 15° due to the dikes and terraces. Tea gardens are located on the lowlands adjacent to the river and on the slope lands while the other lowlands away from the river are used for paddy cultivation.

According to the preliminary information from the commune office, tea quality based on the farm-gate shipping price was higher at tea gardens close to the riverside than those away from, suggesting that such a gradient in tea quality may correlate with the difference in the terrain and soils within the alluvial plain. Therefore, three transect lines (A, B, and C) were established from the recent alluvial terrace at the riverside toward previous terraces with undulating landform.

This study was conducted for four tea gardens located on the middle transect line (B1 to B4) in Tan Cuong commune with increasing distance from the river. In terms of topography, B1 and the adjacent forested patch (FB1) are closed to the river with a flat terrain while B2 and B3 sites are on the previous dikes with gently undulating landform. In B4, according to the owner, there has been severe soil disturbance with the removal of surface soils.

2.2. Soil solution sampling and analysis

Soil solution was weekly sampled at the study sites by using a porous-cup method from March 2017 to February 2018. At each site, three suction cups were installed at the depth of 20 cm. pH, EC, NO_3^-, and NH_4^+ were immediately measured in the sites by the pH meter (B-71X, Horiba), the electrical conductivity meter (B-771, Horiba), the nitrate ion meter (B-74X, Horiba), and the solution test kit (simple pack, Sibata), respectively. The remained solution was frozen until analysis. Except for concentration of Al^{3+} determined with inductively coupled plasma atomic emission spectrometry (ICP-AES; ICPS 7510, Shimadzu), those of other ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, and $H_2PO_4^-$) were determined by ion analyzer (IA-300, TOA-DKK).

2.3. Data analysis

The correlations between soil solution volume and monthly precipitation were conducted using SPSS 22.0.

3. Results and discussions

3.1. Soil solution properties

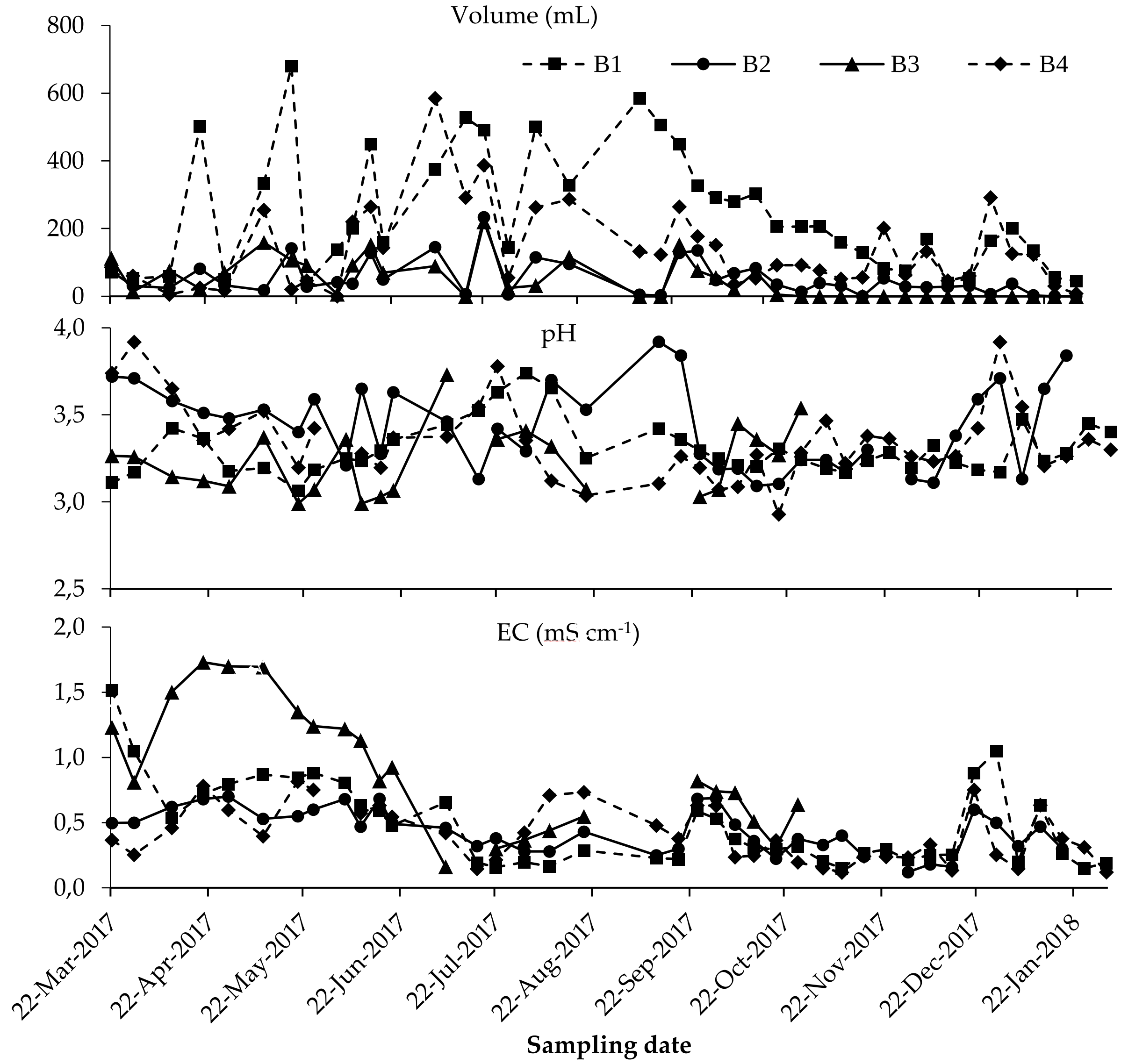
Table 1 gives the volume-weighted average with the range (minimum – maximum values) of soil solution chemistry in each sampling site on Transect B in Tan Cuong commune. It should be noted that soil solution sampling in B3 site was terminated after November 2017 due to earth excavation. In spite of relatively wide variation, the volume tended to be higher in B1 and B4 sites than in B2 and B3 sites. The EC and total concentrations of cations and anions in B3 site were higher than those in other sites. The solution was extremely acidic with pH ranging from 2.9 to 3.9, which tended to be lower in B1 and B3 sites than in B2 and B4 sites. Among cations, Al^{3+} was the dominant cation species, of which concentration in B3 site, in particular, was very higher than those in other sites. Meanwhile, NO_3^- ion was the predominant species of anions and its concentration considerably exceeded that of NH_4^+. B3 site showed higher concentration of NO_3^- among the sites. The concentration of $H_2PO_4^-$ was negligibly detected compared with base cations, SO_4^2, and Cl^-.

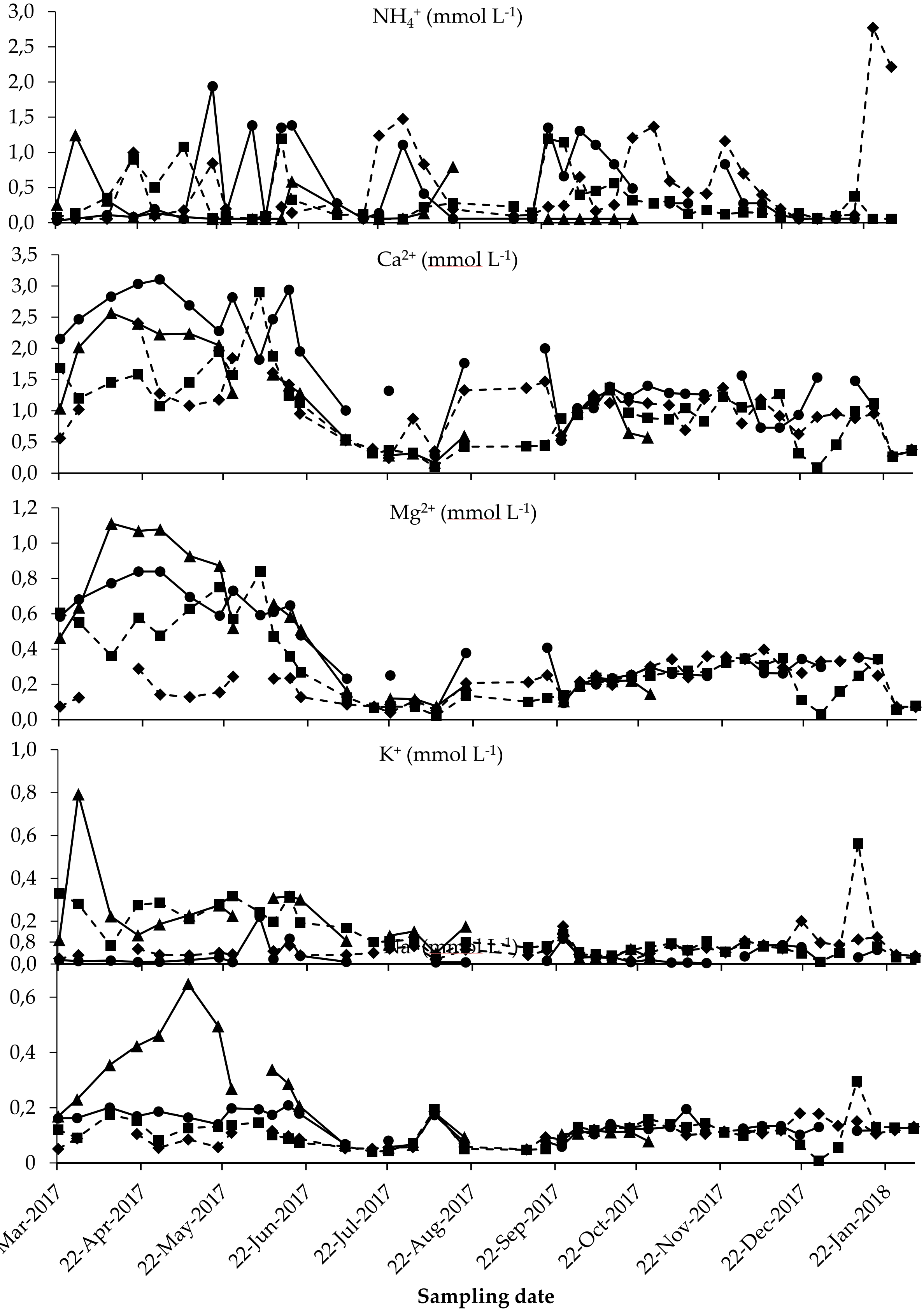
Table 1. *Weighted averages of chemical properties of soil solutions under tea gardens in Tan Cuong commune*

		Average (minimum – maximum)							
		B1		B2		B3		B4	
Vol	mL	244	(39 - 680)	56	(3 - 233)	80	(5 - 220)	138	(5 - 585)
pH		3.3	(3.1 - 3.7)	3.4	(3.1 - 3.9)	3.2	(3.0 - 3.7)	3.4	(2.9 - 3.9)
EC	mS cm^{-1}	0.48	(0.15 - 1.52)	0.44	(0.12 - 0.70)	0.91	(0.16 - 1.73)	0.41	(0.12 - 0.82)
NH_4^+	mmol L^{-1}	0.31	(0.06 - 1.19)	0.47	(0.03 - 1.94)	0.20	(0.06 - 1.25)	0.53	(0.06 - 2.77)
Ca^{2+}	mmol L^{-1}	0.98	(0.09 - 2.90)	1.68	(0.28 - 3.10)	1.24	(0.17 - 2.57)	1.01	(0.24 - 2.40)
Mg^{2+}	mmol L^{-1}	0.29	(0.02 - 0.84)	0.41	(0.06 - 0.84)	0.46	(0.08 - 1.11)	0.21	(0.04 - 0.40)
K^+	mmol L^{-1}	0.14	(0.01 - 0.56)	0.04	(0.01 - 0.22)	0.18	(0.03 - 0.79)	0.07	(0.02 - 0.20)
Na^+	mmol L^{-1}	0.11	(0.01 - 0.30)	0.14	(0.06 - 0.21)	0.23	(0.06 - 0.65)	0.10	(0.05 - 0.19)
Al^{3+}	mmol L^{-1}	1.51	(0.00 - 8.24)	0.80	(0.00 - 1.68)	4.27	(0.00 - 11.9)	1.13	(0.00 - 2.88)
H^+	mmol L^{-1}	0.52	(0.18 - 0.86)	0.43	(0.12 - 0.81)	0.64	(0.19 - 1.02)	0.50	(0.12 - 1.18)
NO_3^-	mmol L^{-1}	4.18	(0.22 - 12.6)	4.21	(1.29 - 10.5)	7.55	(1.06 - 16.1)	4.33	(1.15 - 12.9)
SO_4^{2-}	mmol L^{-1}	0.32	(0.01 - 1.10)	0.50	(0.11 - 4.70)	0.55	(0.11 - 1.09)	0.16	(0.02 - 0.76)
Cl^-	mmol L^{-1}	0.35	(0.02 - 1.12)	0.27	(0.05 - 0.52)	0.55	(0.05 - 1.51)	0.24	(0.04 - 0.50)
$H_2PO_4^-$	mmol L^{-1}	0.00	(0.00 - 0.01)	0.00	(0.00 - 0.06)	0.00	(0.00 - 0.02)	0.00	(0.00 - 0.00)

3.2. The variation of soil solution chemistry

Figure 1 depicts the changes in soil solution chemistry with each sampling date while Figure 2 compares the concentration of cations and anions as the volume-weighted averages during the rainy season (March to September) and during the dry season (October to February). The concentration of H^+ was calculated based on the pH value. The volumes of soil solutions collected during the rainy season tended to be higher with large fluctuation, compared with those during the dry season. The fluctuation in the volumes during the rainy season could be ascribed to the effects of rainfall in addition to regular watering throughout the year. The values of pH and EC and the ion concentrations exhibited larger fluctuation during the rainy season partially due to the dilution effect depending on the volume. However, as shown in Figures 1 and 2, the EC and the ion concentration except for NH_4^+ and Cl^- tended to be higher during the rainy season than during the dry season. Regarding to base cations, while the concentration of monovalent K^+ did not show a clear peak during the rainy season but tended to gradually decrease toward the end of the sampling duration (the end of the dry season), those of divalent Ca^{2+} and Mg^{2+} had one peak during the rainy season, exhibiting inverted U-shaped curve.





NH$_4^+$ (mmol L^{-1})
Ca^{2+} (mmol L^{-1})
Mg^{2+} (mmol L^{-1})
K$^+$ (mmol L^{-1})
22-Mar-2017
22-Apr-2017
22-May-2017
22-Jun-2017
22-Jul-2017
22-Aug-2017
22-Sep-2017
22-Oct-2017
22-Nov-2017
22-Dec-2017
22-Jan-2018
Sampling date

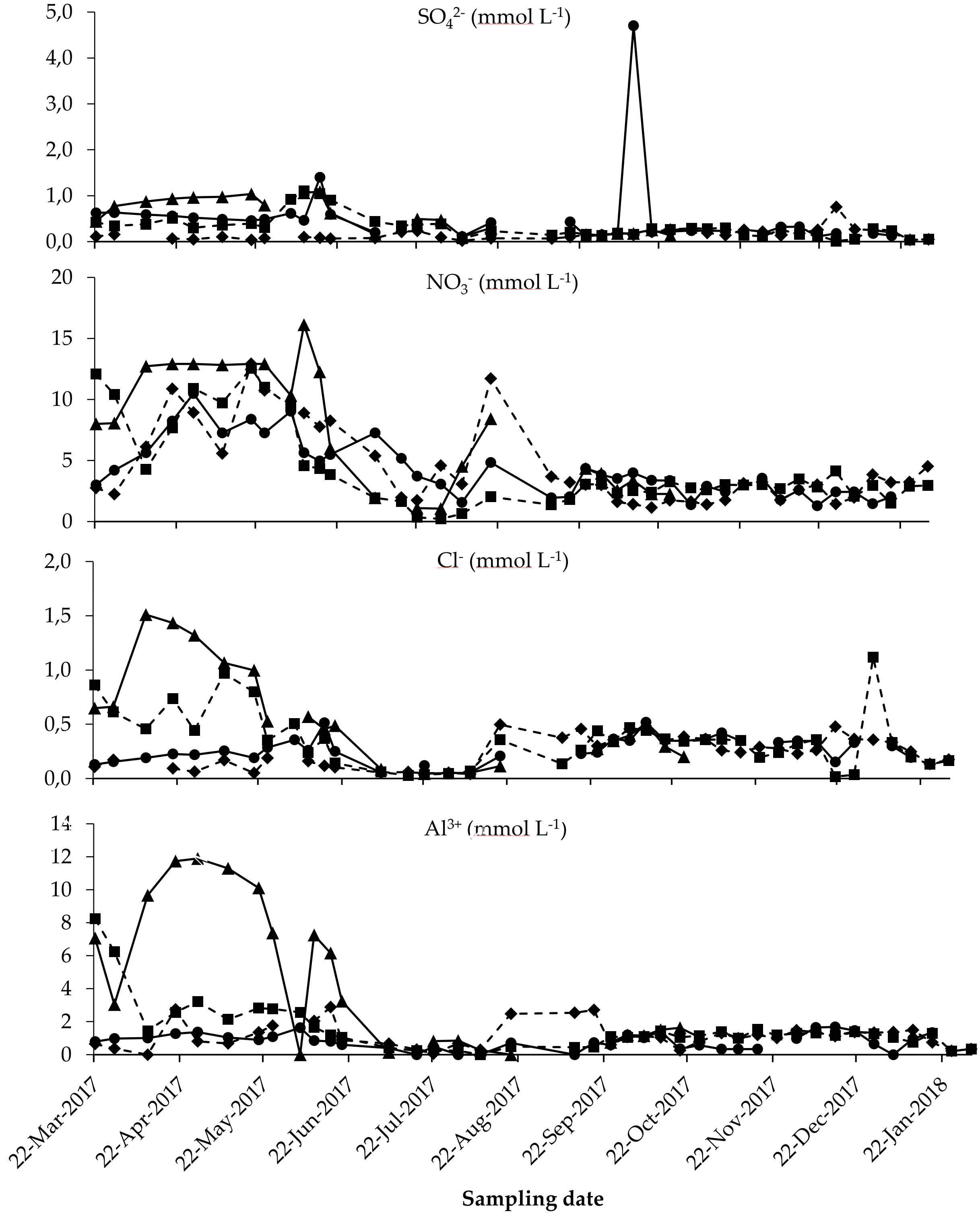


Figure 1. *Seasonal fluctuation of soil solution chemistry*

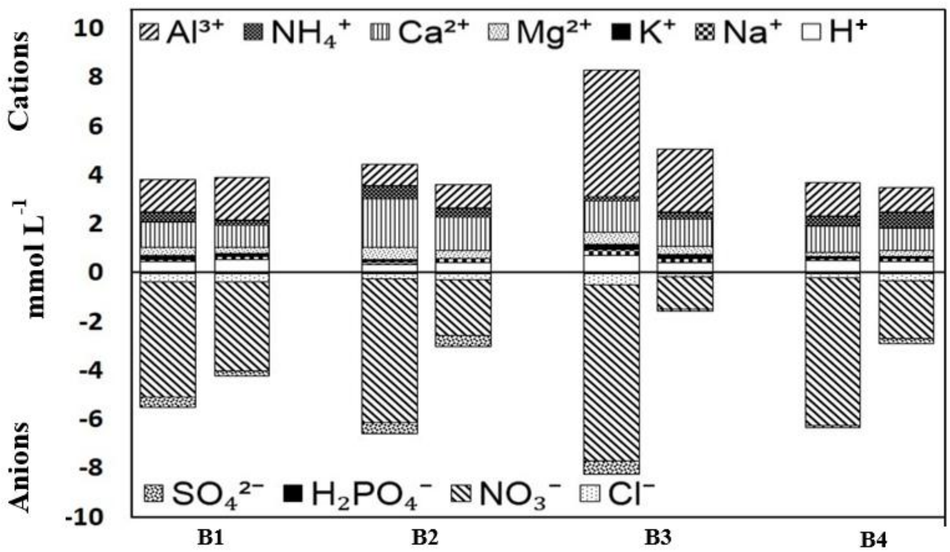


Figure 2. *Comparison of ion concentrations in soil solutions between two seasons at each sampling site. left: rainy season, right: dry season*

3.3. The leaching loss of nutrient from soils

The volumes of soil solution seemed to depend on precipitation, topography and ground condition: The monthly-sum of the soil solution volume positively correlated with monthly precipitation in Thai Nguyen province with r=0.59*, r=0.69*, and r=0.74** for B1, B2, and B4, respectively although the correlation coefficient in B3 was not significant with r=0.16. The larger fluctuation during the rainy season could be explained by the variation of precipitation. Then, the flat terrain without runoff water could be the reason for the higher volume in B1. In case of the higher volume in B4, the presence of rock outcrops [10] may guide rainwater toward the porous-cup installing point with relatively deep soils (>20 cm). Meanwhile, appreciable volumes were recorded during the dry season, which could be ascribed to regular watering throughout the year.

The conspicuous feature of soil solution chemistry is the low pH often dropping to around 3. Judging from higher NO_3^- concentration than NH_4^+, one important source of such high acidity seems the H^+ production through nitrification in spite of very acidic condition. Relatively lower pH and higher concentration of Al^{3+} in B3 site suggest that deprotonation from Al ion species also took place in this site where active Al was abundant as shown higher exchangeable Al and Al_o and dominant HIV mineralogy [10]. As well as SO_4^{2-} ion probably derived from ammonium sulfate, the NO_3^- derived from the nitrification of fertilized ammonium is the dominant counter anion for leaching loss of base cations. In spite of dilution effect which would be supposed more considerable with a larger volume of soil solution during the rainy season, the concentration of ions was higher during the rainy season than the dry season. In the tea production in Thai Nguyen province, fertilizers are applied usually at the beginning rainy season (early March). The change of ion concentration with time (Figure 2) indicates that the nutrients added as fertilizer would be rapidly lost through leaching: firstly, monovalent K^+, followed by divalent Ca^{2+} and Mg^{2+} with NO_3^- unless tea plants would uptake. This process might be exacerbated by the low nutrient retention capacity of coarse-textured soils close to the Cong River and kaolin mineral-dominated soils far from the river. The lower values of EC and ion concentrations from July to September indicated that the nutrients applied as fertilizers had been almost exhausted before the end of the rainy season, followed by apparent restoration due to small volumes of the soil solution during the dry season. These results well agreed with the findings on soil fertility shown by Hoang et al. (2019) [11].

Meanwhile, the concentration of P was very low in contrast to the high contents of available P at 20-30 cm determined with the Bray II method presented by Hoang et al. (2020) [10] and Hoang et al. (2019) [11]. One possible reason for this contradiction is the methodology of the available P. The solution of NH_4F is used to dissolve Al-bonded P, which is almost insoluble into usual soil solution. Therefore, it is suggested that the fertilizer P might be precipitated with Al (probably and Fe) and accumulated not only in 0-10 cm but also 20-30 cm soils. Taking into consideration P is the expensive resource over the world, further study should be conducted on soil P dynamics in tea gardens.

4. Conclusion

The present study investigated soil solution chemistry under tea gardens along the alluvial plain of Cong River in Tan Cuong commune, Thai Nguyen province, praised with the prime-quality tea production in Vietnam. There were variations with time in the amounts and chemical properties of soil solution. While the differences in the amounts of collected soil solution among tea gardens were affected by terrain and soil structure, those between rainy and dry seasons were explained by the variation in precipitation. In spite of strongly acidic conditions of both soil and soil solution, there was the occurrence of nitrification resulting in a higher NO_3^- concentration than NH_4^+ as well as an increase in H^+ concentration. It could be indicated that the nutrients added as fertilizer were rapidly lost through leaching, SO_4^{2-} and NO_3^- ions derived from the nitrification of fertilized ammonium are the dominant counter anions for leaching loss of base cations. In addition, heavier fertilization at the beginning rainy season (early March) was the reason explaining for the higher concentrations of ions during the rainy season than the dry season. The leaching loss of nutrients from soil is also exacerbated by soil texture and mineralogical components of the soils.

REFERENCES

[1] FAOSTAT, "Production quantity, export quantity and export value of tea of Vietnam in 2020," 2020. [Online]. Available: http://www.fao.org/faostat/en/?#data. [Accessed July 27, 2022]

[2] T. Hoshina, "Studies on absorption and utilization of fertilizer nitrogen in tea plants," *Bulletin of the National Research Institute of Tea*, vol. 20, pp. 1-89, 1985.

[3] K. Ishigaki, "Comparison between ammonium-nitrogen and nitrate-nitrogen on the effect of tea plant growth," *Japanese Agricultural Research Quaternary*, vol. 8, pp. 101-105, 1974.

[4] K. Ishigaki, "Studies on the nutritive characteristics of tea plant" (in Japanese), *Bulletin of the National Research Institute of Tea*, vol. 14, pp. 1-152, 1978.

[5] L. Ruan, K. Wei, L. Wang, H. Cheng, L. Wu, and H. Li, "Characteristics of Free Amino Acids (the Quality Chemical Components of Tea) under Spatial Heterogeneity of Different Nitrogen Forms in Tea (*Camellia sinensis*) Plants," *Molecules*, vol. 24, no. 3, pp. 1-9, 2019.

[6] D. Tong and R. Xu, "Effects of urea and $(NH_4)_2SO_4$ on nitrification and acidification of Ultisols from Southern China," *Journal of Environmental Sciences*, vol. 24, no. 4, pp. 682-689, 2012.

[7] D. Xue, H. Y. Yao, and C. Y. Huang, "Microbial biomass, N mineralization and nitrification, enzyme activities, and microbial community diversity in tea orchard soils," *Plant and Soil*, vol. 288, pp. 319-331, 2006.

[8] J. Y. Ruan, L. F. Ma, Y. Z. Shi, and F. S. Zhang, "Effect of litter incorporation and nitrogen fertilization on the contents of extractable aluminum in the rhizosphere soil of tea plant (Camellia sinensis (L.) O. Kuntze)," *Plant and Soil*, vol. 263, pp. 283-296, 2004.

[9] H. Ii, T. Hirata, H. Matsuo, M. Nishikawa, and N. Tase, "Surface water chemistry, particularly concentrations of NO_3^- and DO and ??15N values, near a tea plantation in Kyushu, Japan," *Journal of Hydrology*, vol. 202, no. 1, pp. 341-352, 1997.

[10] H. C. Hoang, D. V. Minh, K. Iwasaki, and S. Tanaka, "Soil Morphological, Mineralogical and Chemical Characteristics of Tea Gardens with High-Quality Leave Production in Thai Nguyen province, Vietnam," *Pedologist,* vol. 64, no. 1, pp. 3-13, 2020.

[11] H. C. Hoang, M. Tokuda, D. V. Minh, Y. Kang, K. Iwasaki, and S. Tanaka, "Soil physicochemical properties in a high-quality tea production area of Thai Nguyen province in northern region, Vietnam," *Soil Science and Plant Nutrition,* vol. 65, vol. 1, pp. 73-81, 2019.

[12] K. W. T. Goulding and C. P. Webster, "Methods for measuring nitrate leaching," *Aspects of Applied Biology,* vol. 30, pp. 63-70, 1992.

[13] E. A. Hansen and A. R. Harris, "Validity of soil water samples collected with porous ceramic cups," *Soil Science Society of America Journal*, vol. 39, pp. 528-536, 1975.

[14] E. I. Lord and M. A. Shepherd, "Developments in the use of porous ceramic cups for measuring nitrate leaching," *Journal of Soil Science,* vol. 44, pp. 435-449, 1993.

[15] C. P. Webster, M. A. Shepherd, K. W. T. Goulding, and E. Lord, "Comparisons of methods for measuring the leaching of mineral nitrogen from arable land," *Journal of Soil Science,* vol. 44, pp. 49-62, 1993.

[16] R. Poss, A. D. Noble, F. X. Dunin, and W. Reyenga, "Evaluation of ceramic cup samplers to measure nitrate leaching in the field," *European Journal of Soil Science,* vol. 46, pp. 667-674, 1995.

[17] T. A. Russo, K. Tully, C. Palm, and C. Neill, "Leaching losses from Kenyan maize cropland receiving different rates of nitrogen fertilizer," *Nutrient Cycling in Agroecosystems,* vol. 108, pp. 195-209, 2017.

[18] X. D. Yang, K. Nia, Y. Z. Shi, X. Y. Yi, Q. F. Zhang, L. Fang, L. F. Ma, and J. Ruan, "Effects of long-term nitrogen application on soil acidification and solution chemistry of a tea plantation in China," *Agriculture, Ecosystems and Environment,* vol. 252, pp. 74-82, 2018.