Assessment and mitigation of the environmental impacts of nitrogen fertilizer application in green tea fields

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Summary

Agricultural crops require a lot of nitrogen (N) for plant growth and are susceptible to N insufficiency. In the early 20th century, a method for artificially synthesizing ammonia (NH_3) from N_2 and molecular hydrogen (H_2) under high pressure and high temperature conditions was developed (the Haber-Bosch process), which has led to the amount of N that is applied through artificially synthesized fertilizers now being comparable to the amount that is naturally fixed. However, some of the N that is applied to agricultural lands in the form of fertilizers can readily leach out from the root zone, mainly in the form of nitrate-N (NO_3^--N), resulting in increased NO_3^--N concentrations in groundwater and eutrophication in surrounding water systems. In addition, nitrous oxide (N_2O) is emitted to the atmosphere, which is one of the major greenhouse gases and an ozone depleting substance.

Large amounts of N fertilizer have traditionally been used in the cultivation of tea (*Camellia sinensis* (L.)), as tea plants can store excess N as amino acid and a high content of free amino acids increases the trading price of Japanese green tea because this is one of the most important quality indexes. However, this heavy application of N fertilizer can have environmental impacts, such as increased levels of NO_3^--N in the surrounding water systems, acidification of the soil, and the emission of high levels of N_2O.

To address these issues, efforts have been made in recent years by farmers and concerned authorities to reduce the amounts of N fertilizer that are applied to tea fields in Japan, and to improve the soil and fertilizer management practices. However, little is known about how effective these approaches have been. Therefore, in the present study, I aimed to:

(a) Determine trends in water quality as a result of reduction in the use of N in tea fields.

(b) Determine the effects of environmental factors on N_2O emissions from tea field soils.

(c) Assess the mitigation effects of applying lime nitrogen and dicyandiamide (DCD) on N_2O emissions from tea field soils.

In Chapter 2, I assessed whether the reduction in N fertilizer use in an intensive tea-growing area in Shizuoka Prefecture has affected the water quality of the surrounding water systems. To do this, I applied the seasonal Mann-Kendall test, one of the most widely used non-parametric tests, to 10-year datasets of monthly pH and NO_3^--N concentrations at 16 sites, including drainages, springwater, groundwater, and streams. I found that there were significant downward trends in NO_3^--N concentrations at most sites, indicating that the efforts that have been made by farmers and concerned authorities to reduce the use of N fertilizer in tea fields have improved the NO_3^--N concentrations in water systems around the study area. However, I also observed significant downward trends in pH at 9 of the 16 sites, indicating that the water systems in this area have experienced increased acidification despite the reduction in N fertilizer use.

In Chapter 3, I evaluated the contributions of N_2O emissions from the soils between the rows and under the canopy of tea plants to the total N_2O emissions from entire tea fields, and also determined the environmental factors that are responsible for changes in N_2O emissions. This part of the study was performed in an experimental tea field over a period of 2 years. Total N_2O emissions from the entire tea field were 10.6 and 14.8 kg-N ha^{-1} yr^{-1} in 2008 and 2009, respectively. Total N_2O emissions from the soil under the canopy of the tea plants were approximately 35% of the total N_2O emissions from the entire tea field, suggesting that these make a fairly significant contribution to the overall N_2O emissions. The key factors that contributed to high N_2O fluxes in the soil under the canopy were increases in soil temperature and WFPS. By contrast, high N_2O fluxes from the soil between the rows were observed after fertilizer application in spring and autumn, and there was a significant positive correlation between the N_2O flux and ammonium-N (NH_4^+-N) concentration in this soil.

In Chapter 4, I conducted laboratory experiments to investigate the contribution of nitrification and denitrification to N_2O emissions from green tea field soils and their relationships with soil water content and soil pH. I found that the total N_2O emissions gradually increased with increasing water content and that the contribution of nitrification to total N_2O emissions also increased with soil water content to reach more than 50%. In addition, total N_2O fluxes were highest at soil pH 3.4 and lowest at pH 4.7 among three treatments (pH 3.4, 4.7, and 6.3). Together, these results suggested that the inhibition of nitrification and the application of lime are promising strategies for reducing N_2O emissions from tea field soils. Therefore, I next evaluated the effect of applying nitrification inhibitors lime nitrogen and DCD on N_2O emissions from tea field soils. This showed that the application of both fertilizers effectively reduced N_2O emissions from tea field soils, though the effective duration of this reduction is expected to be shorter for DCD than for lime nitrogen.

In Chapter 5, I assessed the mitigating effects of lime nitrogen (calcium cyanamide) and DCD application on N_2O emissions in experimental green tea fields over 2-year period. I found that the mean cumulative N_2O flux from the soils between the rows of tea plants was approximately 51% lower in the lime nitrogen plots (3.5 ± 0.1 kg-N ha^{-1} yr^{-1}) than in the control plots (7.1 ± 0.9 kg-N ha^{-1} yr^{-1}). However, the cumulative N_2O flux in the DCD plots was not significantly different from that in the control plots. The seasonal variability in N_2O emissions from the DCD plots differed from that in the control plots and the application of DCD sometimes increased N_2O emissions from the tea field soil. The nitrification inhibition effect of lime nitrogen and DCD helped to delay nitrification of NH_4^+-N in the soil. However, N uptake by the tea plants was almost the same among all three treatments. Therefore, the use of lime nitrogen appears to be a promising option for mitigating greenhouse gas emissions from green tea fields.

In conclusion, the results of this study revealed that the research and development of effective fertilizer management methods to reduce the leaching of NO_3^--N from tea fields and the efforts that have been made by farmers and concerned authorities to reduce the use of N fertilizer in tea fields have successfully improved NO_3^--N concentrations in the water systems around an intensive tea-growing area in Japan. I also found that N_2O emissions from tea fields could possibly be reduced by controlling nitrification and soil pH, through the application of lime nitrogen, which results in lower N_2O emissions than conventional fertilizer application.