Study on ponding water management by intermittent irrigation to reduce methane emission from paddy fields
（水田からのメタン放出削減のための間断灌漑による湛水管理に関する研究）

Soken Matsuda

Alternate wetting and drying (AWD), an intermittent irrigation method, has been attracting attention in recent years to reduce methane ($CH_4$) emissions from rice paddies. However, AWD has limited direct benefits for farmers, and there are few examples of its application in farmed areas. In this study, we proposed a system for implementing AWD in a wide area of rice paddies in the Red River Delta of Vietnam by constructing new water division works and managing them by a water users' group and verified its feasibility and effectiveness in reducing $CH_4$ emissions.

This doctoral thesis consists of six chapters: a general introduction, a review of previous studies, three main chapters, and a summary. Chapter 1 describes the background, research problems, and objectives of the study. Chapter 2 contains a review of previous studies, with a focus on the mechanisms that underly the production of $CH_4$ in paddy soils and its emission from these soil to the atmosphere, the approaches that exist to mitigate $CH_4$ emissions, and the nature of AWD water management. In Chapter 3, the feasibility of AWD in experimental block units (conventional, weak-dry, and strong-dry) in paddy fields of approximately 44 ha in the Red River Delta area of Vietnam was investigated by examining the effects of intermittent irrigation (i.e., AWD) on the ponding depth, $CH_4$ and $N_2O$ emissions, and rice yield in blocked experimental plots. Although AWD water management is known to be effective and save water, practical examples of AWD at the district or farm level are limited. Intermittent irrigation was expected to be achieved through the operation of irrigation pumps and sluice gates of water division works by the water management organization (water user group) of the district. However, the ponding depth was not controlled as initially planned because of frequent rainfall and low rate of decrease of the ponding depth in the study area. It was, however, confirmed that the period during which the ponding depth decreased below the soil surface was mostly (but not always) longer in the dry-type blocks. $CH_4$ emissions decreased with an increase in the drying period and this reduction was large in the summer-autumn season. There appeared to be no relationship between $N_2O$ emissions and water management. Rice yield decreased due to extreme drying in the summer-autumn season but was not affected by drying in the winter-spring season. This study demonstrated that $CH_4$ emissions can be reduced and rice yield can be maintained by achieving a maximum drying index (i.e., ratio of the period during which the ponding depth is below the soil surface) of 0.6 in the summer-autumn season in the paddy fields of the target area. In chapter 4, to achieve organizational ponding water management sustainably, the optimal ponding water management schedule to reduce $CH_4$ emissions was identified by using the measured data of ponding depth, soil redox potential (Eh), and $CH_4$ fluxes from field experiments in the Red River Delta area of Vietnam and its effects on $CH_4$ emission and water conservation was shown. Observations in the winter-spring cropping season showed that the non-flooding period of 3–8 days suppressed $CH_4$ emission, and the continuous flooding period of 14–22 days caused $CH_4$ re-emission. Information regarding the non-flooding period to be maintained and the flooding period to be avoided to suppress $CH_4$ emission was not obtained for the summer-autumn cropping season due to abundant rainfall. The proposed schedule could suppress $CH_4$ emission by 27%–85% and increase the amount of conserved water by up to 18% compared with traditional flooding protocols, but it may increase irrigation water due to the frequency and the amount of re-flooding. In Chapter 5, to investigate the effect of infiltration rate, which is thought to affect the non-flooding period to be maintained and the continuous flooding period to be avoided, which is important in determining the schedule, rice plants were cultivated in pots with three different infiltration rates (0, 9, and 18 mm $d^{-1}$) under AWD. As a result, the soil was more oxidative than the conditions generally required for $CH_4$ production (Eh > –150 mV) under intermittent irrigation, regardless of the infiltration rate. $CH_4$ emission was suppressed by at least 37% compared to continuous flooding and no-infiltration conditions; however, temporary emission was observed 1–2 h immediately after the flooding receded. This phenomenon is important for more accurately determining $CH_4$ emissions in water management techniques such as AWD. $CH_4$ emissions during the heading stage, including temporary emissions after the flooding receded, were greatest under the highest infiltration rate (18 mm $d^{-1}$). The infiltration rate did not affect the rate of soil Eh reduction; however, the total organic carbon concentration in the drainage water suggested that more carbon, a substrate for methanogens, migrated to the bottom of the pot with increasing infiltration rate, which likely increased $CH_4$ emissions. Chapter 6 provides a summary of the study, with a focus on what has been found so far and the issues that require clarification in future research.