学　位　論　文　要　旨

Effects of tillage regimes and cover crop treatments on greenhouse gas emissions and carbon sequestration on Andosols, Japan
黒ボク土壌における耕うん方法とカバークロップの利用が地球温暖化ガスの排出と炭素隔離に及ぼす影響

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No-tillage (NT) and the introduction of cover crops, owing to their positive effects on soil organic carbon (SOC) sequestration and crop yields, are potential agricultural practices that both support food security under the new realities of climate change and alleviate greenhouse gas (GHG) emissions. Characterization of soil carbon dioxide (CO_2) emission responses to different agricultural managements in specific soil and climate conditions is critical for an accurate estimate of soil carbon (C) storage and loss processes. However, the effects of the combination of long-term NT systems and cover crops on non-carbon dioxide (CO_2) emissions and SOC sequestration have not been adequately documented, particularly in East Asia. Additionally, there is a lack of studies on the effects of tillage and cover crops on soil CO_2 emissions on Andosols in the humid, subtropical climate.

In chapter 2, We conducted a split-plot field experiment involving two tillage systems [NT and moldboard plowing (MP)] and three cover crops, namely, fallow (FA), hairy vetch (HV), and rye (RY). NT had a slightly higher soybean yield than MP, although tillage methods and cover crop treatments had no significant effects on soybean yield. Cover crop treatments rather than tillage methods significantly affected methane (CH_4) emissions; under FA and RY treatments, we observed CH_4 uptakes, whereas, under HV, we observed CH_4 emissions. In contrast, rather than cover crop treatments, tillage methods affected nitrous oxide (N_2O) emissions. Higher WFPS and soil bulk density under NT resulted in significantly higher annual N_2O emissions than those under MP. However, under NT, the annual SOC sequestration rate significantly increased compared with that under MP, the global warming potential (GWP) caused by CH_4 and N_2O emissions was fully offset by net CO_2 retention under NT. Additionally, treatment under NT reduced net GWP and yield-scaled GWP to a significantly greater degree than did treatment under MP.

Treatments under NT with RY cover crop had the lowest net GWP (−2324 kg CO_2 equivalent ha^{-1} $year^{-1}$) and yield-scaled GWP (−1037 kg CO_2 equivalent Mg^{-1} soybean yield).

Chapter 3 aimed to quantify soil CO_2 emissions and identify the factors accounting for CO_2 emissions among NT and MP systems under different cover crop treatments at an experimental site established in 2002 in Kanto, Japan. A split-plot field experiment was conducted from May 2017 to November 2018 comprising two tillage systems (NT and MP) and three cover crops: FA, HV, and RY. Higher soil CO_2 daily emissions at 80% of the measurements and significantly greater CO_2 seasonal and annual emissions were observed in the NT system as compared to the MP system. The relationship between CO_2 daily flux and soil temperature was well-described by exponential functions ($p < 0.001$). Soil volumetric water content (θv) was significantly positively associated with soil CO_2 daily emissions when soil temperature ranged from 10°C to 20°C ($p < 0.05$) and 20°C to 30°C ($p < 0.01$), and the response of soil CO_2 flux to soil temperature and θv was well-described by a multiplicative model (RMSE: 1.2920, R^2: 0.7777). Although there was no difference in soil temperature between NT and MP, significantly higher soil θv was found in NT than in MP. In addition, significant exponential correlations were observed between SOC stocks and annual CO_2 emissions in four different soil layers (0–2.5 cm, 0–7.5 cm, 0–15 cm, and 0–30 cm). The HV and RY cover crops had a positive effect on SOC stocks. NT increased SOC stocks significantly compared to MP at 0–2.5 cm ($p < 0.001$) and 0–7.5 cm ($p < 0.05$) depth while no significant SOC stock difference at 0–15 cm and 0–30 cm depth between NT and MP were observed.

In chapter 4, the driving factors e.g., physical (temperature and volumetric water content), chemical (SOC stock), and biological (microbial biomass and community) soil factors, in asynchronous CO_2 emission responses from Andosols caused by two tillage regimes i.e., no-tillage (NT) and moldboard plow (MP), and two cover crop systems i.e., fallow (FA) and rye (RY), were assessed. A 2.5-years consecutive study was conducted from October 2018 to April 2021 using a field trial (established in 2002) in a humid subtropical climate in Japan. Overall, NT and RY cover crop systems increased soil CO2 emission relative to emissions with MP and FA systems; indeed, the combination of MP and FA hampered CO_2 evolution from the soil surface on a daily or annual scale. Soil CO_2 emissions were significantly positively correlated with soil temperature, soil volumetric water content at a depth of 0–12 cm, SOC stock at various soil layers (0–2.5, 0–7.5, 0–15, and 0–30 cm), and soil microbial biomass in summer determined as soil ATP content, substrate-induced respiration, and ergosterol content. Changes in soil microbial biomass and community due to tillage regimes rather than cover crop treatments were associated with asynchronous CO_2 emission responses.

These findings suggest that (1) treatments under NT with cover crop systems—especially RY cover crop—in the long-term organic soybean field maintains sustainable crop production and reduce net GWP and yield-scaled GWP, which will be an effective climate-smart agriculture practice in the humid, subtropical regions prevailing in Kanto, Japan; (2) The NT and RY cover crop treatment positively affected soil volumetric water content, SOC stock, soil microbial biomass, and the abundance of *Bacteroidetes*, *Basidiomycota* and *Ascomycota*-affiliated species known as organic matter decomposers; consequently, this treatment stimulated CO_2 emissions.