学位論文内容の要旨

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Effects of basalt application on soil physical properties and CO_2 dynamics in agricultural soils

（玄武岩施用が農地土壌の土壌物理性およびCO_2動態に及ぼす影響）

Enhanced rock weathering (ERW) using finely crushed silicates such as basalt has gained attention for its potential to transform atmospheric CO_2 to bicarbonate through mineral dissolution while improving soil fertility. However, existing studies have focused mainly on geochemical effects, such as pH shifts, dissolution rates, and inorganic carbon formation, whereas the impacts on soil physical properties, coupled water–gas transport, and CO_2 production remain insufficiently understood. This study investigated how basalt application alters soil physical properties, mass transport, and soil carbon dynamics in agricultural soils.

1. Effects of basalt application on soil CO_2 respiration: Incubation experiments

90-day incubation experiments in a Gray-lowland soil and a Red-yellow soil were conducted to quantify short-term basalt effects on CO_2 emission, DOC (dissolved organic carbon) fractions, and pH under constant soil moisture and 25 °C in open air. Both soils showed an initial CO_2 pulse that rapidly declined, with basalt increasing CO_2 emission at the early stage due to a transient rise in H_2O-extractable DOC. It is likely due to stimulated respiration and DOC release from exchangeable pool under elevated soil pH. And the increased exchangeable Mg in both soils indicates rock dissolution. Overall, basalt did not increase consistent CO_2 production, instead, pH-driven DOC desorption might produce short-term respiration peaks, with soil types determining the magnitude and duration of responses.

2. Effect of basalt application on soil physical properties and soil CO_2 dynamics: Field monitoring

A two-years field monitoring was carried out in a cultivated (soybean in 2023, maize in 2024) gray-lowland field (Hokkaido University) following the surface application of basalt (15 kg m^{-2}). Soil CO_2, water content, temperature, and water potential were continuously measured at 10–40 cm. Basalt application increased bulk density and reduced total porosity while enhancing water retention, but effects on saturated hydraulic conductivity and gas diffusivity were minimal. In 2023, basalt-amended plots exhibited higher CO_2 concentrations and fluxes, with cumulative CO_2 production at a given depth exceeding the control, likely suggesting pH-driven stimulation of microbial activity under wetter conditions. In 2024, treatment differences became smaller, consistent with the diminished pH contrast between treatments.

3. Reactive transport modeling of soil CO_2 dynamics under ERW

Reactive transport model against mass and heat transport considering CO_2 production and rock dissolution was developed. Scenario-based (compaction-only and compaction with weathering scenarios) simulations were conducted to isolate physical and geochemical effects of basalt application. In the compaction-only scenario, the increases in bulk density produced lower total and air-filled porosity, leading to consistent higher CO_2(g) peaks especially after rainfall but almost no change in cumulative CO_2 flux. In the compaction with weathering scenario, olivine dissolution increased pH by ~1 unit and elevated DIC (dissolved inorganic carbon) concentrations, whereas soil CO_2(g) generally decreased due to dissolution consumption. Cumulative DIC fluxes also slightly increased in the presence of olivine although gas diffusion and water percolation were limited due to enhanced water retention. Weathering effects were stronger in the clayey soil, where higher water residence enhanced CO_2 retention and dissolution. Overall, basalt-induced chemical changes highly dominated soil CO_2 profiles and dynamics.