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Does winter warming enhance cold CO_2 emission from temperate continental soils?

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In subboreal and temperate regions, the cold season generally lasts more than 3 months of the year, influencing the carbon cycle in terrestrial ecosystems. The permanent snow pack plays an important role in the functioning of the ecosystem, especially in temperate continental regions, preventing frost penetration into the soil. The extent and duration of the permanent snow pack are predicted to decrease markedly in transitional seasons for many boreal and subboreal regions during the next 50 years. This study focused on: (i) assessment of current winter climate trends in the Moscow region pertaining to the continental temperate region, (ii) comparison of soil temperature regimes at different snow pack depths, (iii) estimation of cold CO_2 fluxes from soils under various frozen regime and vegetation cover, and (iv) the contribution of freezing–thawing events to the total cold CO_2 emission from soils in the temperate continental region. An experiment with regulated snow cover was established on grassland and bare soil (Luvisols Haplic, Moscow region, 54o50'N, 37o36'E; continental temperate climate). The following winter scenarios were foreseen: (1) reference plot, designated "Ref", with natural depth of snow cover, (2) no-frost, "NoFr" (simulation of deep snow cover using artificial heat insulation material), and (3) no-snow, "NoSn" (without snow cover). We observed inverse trends as the air temperature increased and precipitation decreased, which resulted in a 1-month prolongation of the snow-free period and a decrease in the snow pack over the last 20 years. Soil freezing significantly reduced the cold CO_2 fluxes from soils: by 10–70% in the bare areas and by up to double that amount in the grass plots.

There were six freezing–thawing cycles (FTC; 1–7 weeks' duration) from October 2014 to early April 2015, which induced CO_2 emission pulses of varying intensity. The highest peaks of CO_2 emission rate (3–30-fold increase compared to the pre-thawing period) were revealed during the early spring FTC. They corresponded to a rapid thawing of frozen soils due to the customary rise of air temperature at the beginning of March. These CO_2 emission pulses during early spring contributed between 43% and 70% to the total cold CO_2 fluxes from frozen soils ('Ref' and "NoSn" variants). The contribution of spring fluxes from unfrozen soils ("NoFr" treatment) to the total cold CO_2 emission was about 25%.

Our findings produce evidence that winter warming in temperate continental regions has resulted in a reduction in the permanent snow pack, an increase in the frequency of freezing–thawing events and can be followed by a prolongation of the period when soils remain frozen. Soil respiration fluxes were greatly reduced owing to an increase in frost stress both for plants and for the soil microbial community. Therefore, winter warming in temperate continental areas decreases cold CO_2 emissions from soils into the atmosphere and is expected thereby to lead to a rise in the annual carbon sink in ecosystems.

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