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Effect of temperature, water availability, and soil properties on soil CO_2 efflux in beech-fir forests along the Carpathian Mts.

KEYWORDS: Canopy gap, carbon content, nitrogen content, soil respiration, soil water content

Introduction

Carpathian Mountain beech-fir forests are exposed to severe pressures related to climate change. Soil CO_2 efflux contributes substantially to ecosystem carbon flux and affects the forests' carbon storage due to its climate sensitivity, especially temperature and precipitation (Rodrigues et al. 2023). Forest gaps are an integral part of forest ecosystems and play a crucial role in the regeneration of mixed beech-conifer forests (Čater and Diaci 2017) but they also alter the microclimate (Londo et al. 1999, Čater et al. 2021), new carbon input (Hukić et al. 2021) and soil CO_2 efflux (Han et al. 2020).

Soils are a big carbon pool but increased CO_2 emissions from soil respiration due to climate change can decrease these carbon reserves (Rodrigues et al. 2023). Within the terrestrial carbon cycle, soil respiration is the largest carbon efflux into the atmosphere (IPCC, 2021) and, therefore, it plays a crucial role in the response of the ecosystems to climate change. Soil can either be a net source or a net sink of CO_2. This depends on which flux prevails, the input of carbon into the soil due to plant growth, or the losses of carbon, i.e. soil respiration.

The objective of this study was to assess soil CO_2 efflux in beech-fir forests along the Carpathian Mountains, to determine potential topographical, biological, and climatic factors driving soil CO_2 efflux variability, and to evaluate the effect of forest gaps on soil CO_2 efflux and soil properties.

Methods

The study was conducted on eight experimental sites along the Carpathian Mountains during two-week campaigns in 2022 and 2023. The sites were numbered from 1 (the southernmost site in Romania) to 8 (the northernmost site in the Czech Republic). At each site, we found a medium gap size (100–200 m^2) according to Han et al. (2020) or Lyu et al. (2022) where three plots were selected: forest with closed canopy cover (closed), forest adjacent to the gap (edge),

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and the gap without canopy (open). On each plot, we measured soil CO_2 efflux at nine positions using a portable infrared gas analyzer Li-8100 (LI-COR, USA) and a 20cm-survey chamber, soil temperature (TPD32 penetrate thermometer, Omega, Stamford, CT, USA), and soil water content (ThetaProbe ML2x, DeltaT Devices, Cambridge, UK). Moreover, the top 10 cm of soil (containing organic and mineral horizons) was sampled in each plot using a portable stainless steel soil core sampler with a diameter of 5 cm. The samples were dried and sieved through a 2-mm sieve and analyzed in the laboratory for pH (H_2O), carbon, and nitrogen content (%).

Results

Mean soil temperature at 1.5 cm (Ts) under the closed canopy ranged between 13.5 and 17.4 °C in 2022 and between 9.8 and 15.8 °C in 2023. Soil water content (SWC) under the closed canopy exceeded 20% at all sites, except for site 5 in 2023 (Fig. 1).

Soil C content ranged between 4.4 and 12.9% (Fig. 1). The highest C content of 12.9% was found at site 2 and highly exceeded C content at other sites. The second highest C content was found at site 6 and the lowest at site 7. The same trend was observed also for soil N content and C:N ratio. N content ranged between 0.32 and 0.58%, while C:N ranged between 13.6 and 22.2. The soil was mostly strongly acidic with a pH below 5.5. Exceptions were site 3 with a pH of 5.6 (acid soil) and site 4 having neutral soil with a pH of 7.0.

Mean soil CO_2 efflux (Rs) under the closed canopy ranged between 2.5 and 7.8 µmol m^{-2} s^{-1} (Fig. 1). The differences in Rs between 2023 and 2022 depended significantly on soil water content but not on temperature. Correlations of Rs with different climatic and topographical variables, and soil properties were analyzed to evaluate, which factors drive the Rs spatial variation along the Carpathians. In 2022, Rs significantly decreased with latitude and increased with C:N, while in 2023, Rs significantly increased with both C and N content (Fig. 2).

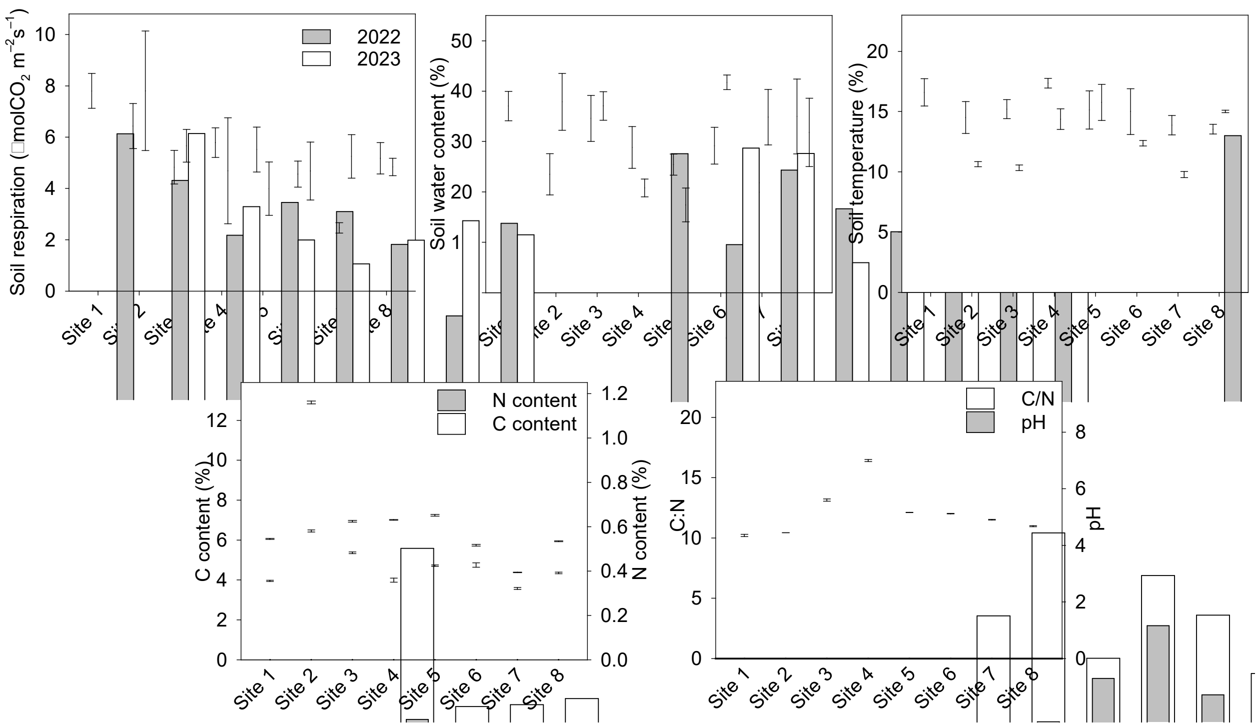

Fig. 1. Mean (±SD) soil CO_2 efflux, and soil properties on the plots with closed canopy at eight study sites along the Carpathians.

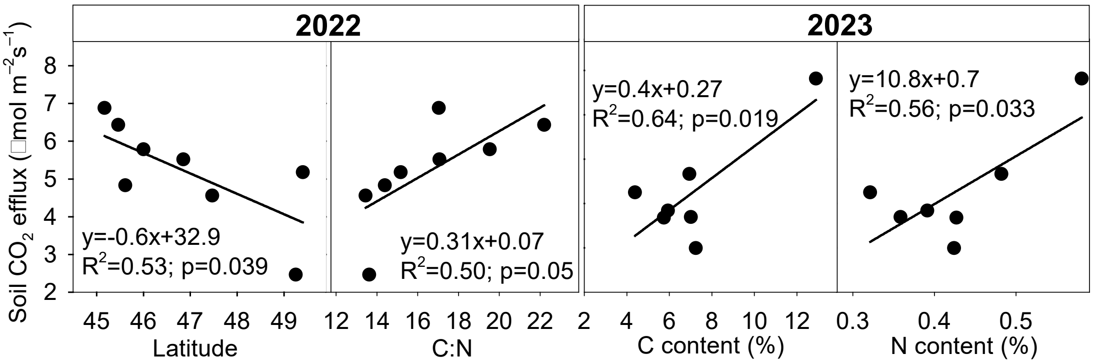

Fig. 2. Statistically significant linear regressions between different site characteristics and parameters measured on plots with the closed canopy during the campaigns in 2022 and 2023.

Canopy openness did not have any uniform effect on soil CO_2 efflux and soil properties. However, when analyzing the effect of soil properties and microclimatic conditions on the overall variability over all sites and plots, the effect of the soil C and N content was substantial, while soil temperature, SWC, and pH affected soil CO_2 efflux variability negligibly (Fig. 3).

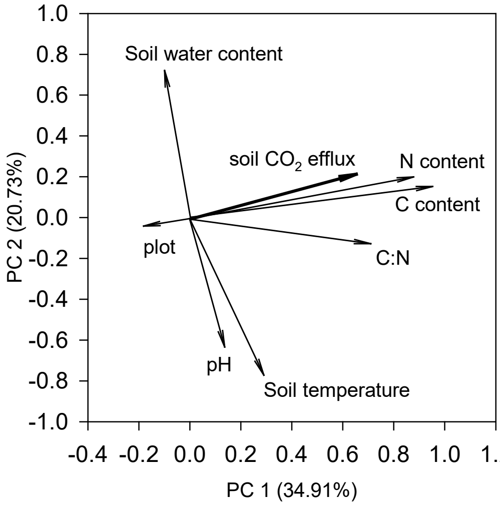

Fig. 3. The Loading Plots of Principal Component Analysis (PCA) of soil CO_2 efflux, soil microclimatic parameters, and soil properties of all sites, plots (with the closed canopy, at the forest edge, and with the open canopy), and years (2022 and 2023). The angle between arrows indicates the direction of the relationship (acute angle positive relationship, obtuse angle – negative relationship, right angle – no relationship).

Conclusions

On eight experimental plots along the Carpathian Mountains within beech-fir forests, the soil CO_2 variability efflux among the plots was driven by soil properties such as carbon and nitrogen content rather than by climatic conditions. Therefore, we may assume that climate effect on new organic matter input through forest productivity and species composition will have a big effect on soil organic matter decomposition and storage. The changes in climate can be attributed to changes in air temperature and precipitation. Air temperature at the studied sites has gradually increased for several decades, while annual precipitation showed no trend (Darenova et al. 2024). Nevertheless, there was a substantial decrease in summer precipitation during the last decade at all sites except for the two northernmost. Canopy gaps bring uncertainty to the estimation of the forest carbon balance as we did not find any uniform effect of the canopy openness on soil CO_2 efflux or soil properties. That could be a result of the different ages of these gaps, which we were not able to estimate.

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