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*Editorial*

# Disturbance Effects on Soil Carbon and Greenhouse Gas Emissions in Forest Ecosystems

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**Abstract:** Forests cover around 30% of the global land area and forest ecosystems can store over 70% of total soil organic carbon (SOC) of all terrestrial ecosystems, but SOC stocks and greenhouse gas (GHG) emissions may be affected by both natural and anthropogenic disturbances. Even though the changes in forest soil C pool can have a significant effect on climate change, there are some contradictory results regarding the role of forest disturbance on SOC sequestration, GHG emissions, and the mitigation of global changes. Therefore, there is a need to better understand the impact of different disturbance regimes on forest soil C storage and GHG emissions. A Special Issue was therefore organized for discussing the responses of soil C storage and GHG emissions to various types of disturbances in forest ecosystems and a total of 15 studies were accepted for this special issue to assess these responses. This Special Issue includes the effects of storms and beetle outbreaks, Karstification, rock desertification, warming, nitrogen addition, land-use change, field tillage, and biochar application on soil C dynamics and/or GHG emissions.

**Keywords:** $CH_4$ emissions; $CO_2$ emissions; climate change mitigation; global change; land-use change; $N_2O$ emissions; soil carbon sequestration

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Disturbances from natural (e.g., insect outbreaks, geologic processes and wildfires) and anthropogenic (e.g., logging, applying soil amendments and land use change) are important drivers of changes of ecological processes in forest ecosystems, and the impact of disturbances on ecosystem processes may vary with the type and level of disturbances [1–3]. These disturbances are expected to markedly affect the amount, form and stability of soil organic carbon (SOC) and the emission of three major trace greenhouse gases (GHGs) ($CO_2$, $CH_4$ and $N_2O$) from forest ecosystems [4,5]. More than 70% of total SOC of all terrestrial ecosystems can be found in forest ecosystems [6] and thus, a minor change in the size of the forest SOC pool can exert a large impact on climate change on a global scale. The assessment of the variability in forest SOC storage and GHG emissions is thus a critical consideration for evaluating regional and global climate change [7]. It is vitally important to improve the understanding of the impact of different disturbance regimes on forest SOC storage and GHG emissions for guiding future research, forest management practices, and policy development. We therefore organized a Special Issue to bring together researchers working on different aspects of forest ecology to share their findings on disturbance effects on SOC storage and GHG emissions in forest ecosystems. We are pleased that we received a strong response from the scientific community to this call for the Special Issue and a total of 15 papers have ultimately been accepted for inclusion in this Special Issue.

Three papers in this Special Issue address the effect of natural disturbances on SOC content and GHG emissions. Storms and beetle outbreaks are two major forms of disturbance in European forests, but Kosunen et al. did not find any consistent effect of either storm or European spruce bark beetle (*Ips typographus* L.) outbreak on soil total and heterotrophic respiration, and soil total respiration rates were found to be related to the basal area of living trees, and also to soil temperature and soil moisture content [8]. Karstification, the dissolution of calcite and the formation of the karst landform in an area where the bedrock is dominated by limestone, can also affect soil C dynamics; in this respect, Huang et al. found that the C sink in karstified calcareous soils was 11.97 times that of non-karstified red soils, while the role of calcareous soils as a C source was only 1.12 times that in red soils [9]. The overall mean $\delta^{13}C$-$CO_2$ value in calcareous soils was 0.87‰ higher than that in red soils, and these results indicate that karst soils play a key role in the reduction of atmospheric $CO_2$ [9]. Rock desertification is a process of land degradation that may reduce soil productivity and some natural environmental factors can induce this process [10], but the effect of desertification on forest soil stoichiometry remains poorly understood. Yang et al. reported that soil C:N (nitrogen) ratio was not significantly affected by the degree of desertification, but soil C:P (C: phosphorus) and N:P ratios increased with increasing degree of desertification [11]. Yang et al. also pointed out that P might be the limiting factor for plant growth during restoration and calcium could play an important role in soil C, N and P stoichiometry in the ecosystem they studied [11].

Eleven papers in this Special Issue address the effect of anthropogenic disturbances on soil C and GHG emissions. Soil C and N cycling can be significantly affected by climate warming and N deposition that are caused by human activities [12,13]. An eight-year experiment with warming and N addition treatments in a subalpine spruce (*Picea asperata* Mast.) plantation forest showed that soil $CO_2$ emissions were solely influenced by warming while both N addition and its interaction with warming significantly elevated soil $N_2O$ emissions, there were different response patterns and different factors governed soil $CO_2$ and $N_2O$ emissions in the forest ecosystem [14]. Interestingly, Zhou et al. found that in a subtropical forest dominated by *Castanopsis carlesii* Hayata and *Schima superba* Gardn. et Champ, a high-level N addition treatment significantly reduced but a low-level N addition treatment markedly enhanced soil respiration, with the high-level N addition treatment reduced soil pH and increased C and P co-limitation of microorganisms, which resulted in decreases in total phospholipid fatty acid (PLFA) content and alterations in microbial community structures [15]. Zhou et al. also concluded that the altered microbial community structure and suppressed microbial biomass under increasing N deposition could ultimately lead to the accumulation of recalcitrant C and reduction in soil C emissions in the studied subtropical forest [15].

Changes in land use patterns can also alter soil C and N cycling and the structure of soil microbial communities [5,6]. The research in Qiu et al. indicated that *Proteobacteria*, *Verrucomicrobia* and *Acidobacteria* were the dominant bacteria and their relative abundances were different in the woodland, shrubland and grassland soils in a karst graben basin in subtropical China, and soil bacterial communities were markedly influenced by SOC, total N, and available potassium contents [16]. Studying SOC mineralization under different land uses is essential for improving our understanding of SOC responses to land-use change. The study of Yang et al. in the karst region showed that the establishment of plum (*Prunus salicina* Lindl.) plantations markedly reduced the SOC content as compared with abandoned lands, but the SOC content did not vary with plum plantation age; however, the cumulative and potential SOC mineralization rates were different among plum plantation ages, and both increased with increasing soil calcium concentration; thus, more attention should be paid in the future to the critical role of calcium in SOC mineralization in the studied subtropical area [17]. In contrast, the study conducted by Zhao et al. in a larch (*Larix principis-rupprechtii* Mayr) forest showed that the contents of SOC, total N and total K were all increased with increasing stand age, and clear-cutting reduced SOC, total N, and total K contents [18]. The effect of the conversion of natural evergreen broadleaved forests to an assisted natural regeneration and Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook) and mason pine (*Pinus massoniana* Lamb.) plantations was conducted by Yang et al. in subtropical China [19]. The conversion led to 42%, 60%, and 64% reductions in SOC contents for assisted natural regeneration, Chinese fir, and mason pine plantations, respectively, with microbial residue C accumulation varying with SOC content and rate of litter input [19]. In addition, Zhu et al. investigated the responses of SOC and soil organic N to soil erosion and forest conversion in the development of sloping economic forests in mountain areas in Jiangsu province in China; they reported that the conversion of coniferous broadleaved mixed forests into economic forests aggravated soil erosion, and the intensive management of the economic forest also reduced soil C storage and increased the loss of soil nutrients; the loss of soil C and N caused by soil erosion can therefore be detrimental to the development of local agriculture and forestry [20].

Although tillage in forest ecosystems does not take place as often as in agricultural ecosystems, tree planting and tillage are practices commonly used for vegetation restoration [21]. In a forest soil profile inversion and mixing study, Wang et al. showed that $CO_2$ concentration in forest soil profiles was governed by both soil properties related to $CO_2$ production such as SOC and soil microbial biomass content and those related to gas diffusion, such as soil bulk density and gas molecular weight; however, soil surface $CO_2$ emissions were not affected by soil profile inversion but were increased by soil profile mixing; soil surface $CO_2$ emissions were mainly controlled by soil surface temperature [21].

Mangrove wetlands are a potential source for atmospheric $CH_4$, but there remain considerable uncertainties regarding the importance of mangrove wetlands for contributing climate warming [22]. Through a field study at three tidal zones of two mangrove ecosystems in southeastern China, Zheng et al. found highly variable $CH_4$ emission patterns among the three zones and attributed this phenomenon to the heterogeneity in the mangrove soil environment [23]. After analyzing the data from these three zones and those from 24 mangrove wetlands worldwide, the authors summarized that undisturbed mangrove sites had very low rates of $CH_4$ emissions, which were much lower than the global warming potentials generated by soil $CO_2$ emissions from the same sites. Although $CH_4$ emissions from mangrove soils were not significantly affected by plant species, study site, tidal position, sampling time, and soil characteristics, the nutrient inputs driven by anthropogenic activities could markedly elevate mangrove soil $CH_4$ emissions, and the estimates of regional or biglobal inventory of $CH_4$ emission should affirmatively consider the part from mangrove wetlands intensively affected by human activities [23].

Even though biochar has a great potential to mitigate climate change, much less research on biochar effects has been carried out in forest ecosystems in comparison to agricultural ecosystems [24]. Two papers in this Special Issue address the effect of biochar on altering forest soil C storage and mitigating GHG emissions. The study of Criscuoli et al. in northern Italy showed that conifer woodchip-derived biochar application did not significantly influence the temperature sensitivity of soil $CO_2$ and $N_2O$ emissions, but significantly reduced the sensitivity of soil $CH_4$ uptake [25]. In the second biochar study included in this Special Issue, Deng et al. conducted an in situ experiment to examine the effects of shell-derived biochar and dicyandiamide (DCD) on soil $N_2O$ emissions from a tea oil camellia (*Camellia oleifera* Abel) plantation with intensive N application in Jiangxi province, China [26]. The authors found that N application enhanced cumulative soil $N_2O$ emissions by 307%, adding biochar and DCD to the N-fertilized field reduced cumulative soil $N_2O$ emissions by 36 and 44%, respectively, suggesting that the mitigation potential of biochar on soil $N_2O$ emissions may reach that of DCD under the conditions studied [26].

It should be noted that estimating forest C stock and improving the accuracy of GHG inventory for each country are very important for evaluating the impact of land management and land use change on regional and global climate change [5–7]. The work done by Lee et al. in South Korea showed that forests could continue to store C and absorb $CO_2$ even under the declining total forest area and their study provides methodologies to facilitate the estimation of C stock changes and $CO_2$ removal by different forest types or plant species [27].

We are pleased to make this Special Issue available to readers. As guest editors, we would like to thank the authors for their valuable contribution to this Special Issue and express our deep appreciation to the many reviewers for their insightful comments that improved the quality of an earlier version of each of the published papers. We would also like to express our sincere gratitude to the Editorial Office for their valuable assistance throughout the publication process.

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