

Alteration of the stable soil organic matter pool by ceasing annual burning in savannas

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Abstract

Solid-state nuclear magnetic resonance (NMR) spectroscopy was applied to study the chemical alteration of the stable soil organic matter (SOM) pool in various savanna soils from Southern Brazil after ceasing annual burning. Irrespective of the time passed since the last fire, the topsoils showed the typical pattern of humifying unburnt material, with considerable low contributions of pyrogenic organic matter (PyOM), although stopping the fire decreased the organic-C content. The latter is most tentatively caused by the reduced input of decaying roots of killed plants and lower biomass production due to the missing of the liming effect of fire. Unexpected high aromaticity was detected for the SOM in the deeper soil (15-45 cm). This is attributable to increasing accumulation of PyOM that had been transported through the soil column. Our results clearly demonstrate that elucidating the impact of annual burning on the global C and N cycle, one has to consider the fertilizing effect of fire as well as the fact that some black carbon (BC) can be transported to deeper horizons. Here it may accumulate to important amounts that should not be neglected in C budgeting studies.

Introduction

Annual burning is a common practice to remove old vegetation and to stimulate regrowth of grass in savannas, since it increases soil pH and releases nutrients for the next crop cycle (liming effect). However, the impact of this practice on the environment and the consequences it has on the global C- and N-cycle are still much debated subjects of controversy. In particular in the last decades, burning of crop residues as means for disposal and fertilization is often criticized for accelerating soil degradation, losses of SOM and nutrients (Biederbeck et al., 1980; Fynn et al., 2003), increasing C-emission causing intense air pollution, and reducing soil microbial activity. It is reported that 1 ton of straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO₂, 199 kg ash and 2 kg SO₂ (Gupta et al., 2004). It was estimated that in 2000, 110 Gg CH₄, 2306 Gg CO, 2.3 Gg N₂O and 84 Gg NO_x were emitted from field-burning of rice and wheat straw in India. As CO₂, CH₄ and NO_x, are important green-house gases their release is suspected to contribute to global warming.

A part of the released carbon, however, will return to the biosphere by rain and photosynthesis (Johnson and Curtis, 2001) and the charcoal accumulating after incomplete combustion of the vegetation will finally be incorporated into the soil system. As one of the most resistant forms of reduced organic matter, PyOM is assumed to be a major constituent of the slow-cycling SOM pool and thus to represent an efficient sink within the global C and N cycle.

On the other hand, reports show that with prolonged recovery time after ceasing annual burning in grassland soils the typical char pattern (Golchin et al., 1997) is lost for the A horizon within the first 20 to 30 years. This may be indicative for unexpected fast degradation of PyOM, but could also be induced by losses due to erosion or even by translocation into deeper horizons. In order to examine the stability of BC in grassland soils and its impact on the humification chemistry, the SOM in a soil chronosequence with increasing time span after ceasing annual burning was characterized.

Material and Methods

The soils under pasture derived from Silveiras in the highland of Rio Grande do Sul, Southern Brazil and developed on Basalt. According to the Brazilian classification system, they are assigned to Neosolos. They were sampled 1 year, 5 years and 22 years after ceasing annual burning from the A horizon in depth intervals from 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, 15 to 30 and if possible from the AC horizon between 30 to 45 cm. After air-drying and manual removal of root and plant material, the samples were passed through a 2 mm sieve.

Their C and N content was determined with an Elementar Vario EL microanalyzer. The chemical composition of SOM was characterized by solid-state ^{13}C and ^{15}N NMR spectroscopy (Bruker DSX 200 and a Bruker DMX 400) after demineralization with 10% hydrofluoric acid (Gonçalves et al., 2003), the samples. To elucidate the BC content, the HF-treated samples were oxidized with 0.1 M $\text{K}_2\text{Cr}_2\text{O}_7$ / 2 M H_2SO_4 solution at 60°C in an ultrasonic bath for 6 h. Subsequently the presence of black carbon (BC) was revealed by signals in the chemical shift region of aromatic C of the solid-state ^{13}C NMR spectra from the chemical oxidation resistant elemental carbon (COREC).

Results

Increasing the time after stopping annual burning resulted in a decrease of the organic C concentration at all soil layers. Comparable result was obtained for organic N (data not shown). The higher SOM concentration at the frequently burnt site may be caused by the continuing annual input of refractory PyOM whereas at the other sites the fast degradation of fresh litter prevents ongoing humus accumulation. The preferential preservation of PyOM in such environments should be indicated by a relative high aromaticity. However, the ^{13}C NMR spectra of the top 5 cm of all soils show comparable but relative low aromatic C contribution of only 17% of total organic C and the respective ^{15}N NMR spectra identify the organic N as mainly derived from fire-unaffected organic residues. Characterizing the residue after chemical oxidation with dichromate assigns only 1 to 2% of the total organic C to aromatic COREC. Taking a loss of 60% which was revealed to occur during chemical oxidation of grass-BC (Knicker et al., 2007), this attributes approximately 5% of the total SOM to BC (corresponding to $< 6 \text{ mg g}^{-1}$ soil). Interestingly, with depth, the calculated relative BC contributions to the total organic C rise to 10 to 20% (approximately 6 to 12 mg g^{-1} soil) in the layer between 15 and 30 cm. Accordingly, about 80% of the aromatic-C intensity in the respective ^{13}C NMR spectra can be assigned to BC. The increase of PyOM with depths can also explain the appearance of the shoulder in the region of pyrrolic N of the ^{15}N NMR spectra of the soils in this layer. Such heterocyclic N are typical features of burnt material and, up to now, remained undetected in spectra of fire unaffected soils increases biomass production after the fire event.

Conclusions

The observed SOM decline in the soil after ceasing burning cannot be explained by a reduction of BC input, since in particular the top layers show relatively comparable and low aromatic C contents. It seems more likely that it is caused by the reduction of the amount of decaying roots, remaining in the soil after combustion of the aboveground vegetation. Since in the studied grassland, artificial fertilizers are rarely applied, the missing of ash input lowers the nutrient contents which contributes to a further decline of the biomass and thus litter productions. It seems that at least in the top layers, the increase of biomass production due the fertilizing effect of burning has a higher relevance with respect to C sequestration than the actual PyOM input. In particular in the top layers, the PyOM concentrations were unexpectedly low, considering that in this region annual burning was applied since the arrival of the first Europeans. Possibly the high combustibility of grass prevented the accumulation of decent amounts of charred residues, or the climatic conditions fostered their fast degradation. However, although visually charcoal was not detected, the amount of PyOM identified by chemical analysis increased with depth, most likely due to transportation with leaching soil water. This observation points to the conclusion that transport of BC within the soil may be of higher importance than commonly assumed and has to be considered if the role of charcoal as a C sink in soils is elucidated.

References

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