Fire-Derived Charcoal Causes Loss of Forest Humus

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Boreal forests serve as important global sources or sinks of carbon (C), and wildfire is a major driver of C storage in these forests. Although fire releases CO_2 to the atmosphere, it also converts plant biomass into forms of black carbon, such as charcoal, that are resistant to microbial attack and persist in the soil for thousands of years (*1*). It has frequently been suggested that, because of its resistance, black C can serve as an important long-term C sink that may help offset the release of human-induced CO_2 to the atmosphere (*2*, *3*). However, charcoal is not biologically inert and can have important effects on soil biological processes (*4*, *5*). The influence of charcoal on the decomposition of native soil organic matter remains poorly understood.

We conducted a simple experiment in each of three contrasting boreal forest sites in northern Sweden (*6*). Mesh bags were filled with pure humus collected from the forest, pure charcoal created in the laboratory, or a 50:50 mixture of humus plus charcoal (*6*). These bags were left in the field and harvested over 10 years. This approach is conceptually identical to that used for the litter-mix studies that have greatly advanced our understanding of the consequences of mixing different litter types (*7*). This approach allows comparisons of observed values in the mixture with what would be expected on the basis of each of the components of the mixture considered separately.

We found that, over the 10-year period, loss of mass and C from the bags containing mixtures of charcoal and humus was substantially greater than what was expected on the basis of the components considered separately [Fig. 1, Mix (obs) versus Mix (exp)]. Further, nitrogen immobilization was less than expected in the mixture bags (Fig. 1). For these measurements, substrate mixing effects [i.e., values for (observed – expected)/expected] never differed significantly across the three sites [*P* value always greater than 0.20 according to analysis of variance (ANOVA)]. This result is despite the sites differing in both stand history and soil fertility (*6*) and points to similar effects of charcoal across contrasting sites. Given that charcoal decomposition rates in soil are extremely slow (*2*, *8*) and that in our study system charcoal persists for thousands of years in the humus layer without evidence of mass loss (*4*), most of the enhanced loss of mass and C caused by mixing charcoal and humus must have resulted from charcoal promoting humus loss rather than humus promoting charcoal loss.

Substrate (i.e., glucose)-induced respiration (SIR), a relative measure of active microbial biomass (*6*), was always significantly greater in the mixture bags than the value predicted on the basis of the charcoal and humus components considered separately [Fig. 1, Mix (obs) versus Mix (exp)]. These results are consistent with charcoal particles serving as foci for adsorption of organic compounds and microbial growth and activity (*4*, *5*), leading to enhanced decomposition rates and mass loss of associated humus. The enhanced microbial activity in the mixture bags may have led to greater mass and C loss through either greater respiration or greater leaching of soluble compounds (*9*).

Previous short-term laboratory studies have shown that charred plant material causes accelerated breakdown of simple carbohydrates (*10*). Our results extend these findings by indicating that charcoal can promote rapid loss of forest humus and belowground C during the first decade after its formation. Fire often causes substantial losses of ecosystem C, and our results provide evidence for a previously unreported mechanism that could contribute to these losses. Our results are specific to boreal forests and to the type of charcoal that we used, and further work is needed to determine the importance of this mechanism in other biomes and for other types of charcoal (*11*). Although several studies have recognized the potential of black C for enhancing ecosystem C sequestration (*2*, *3*), our results show that these effects can be partially offset by its capacity to stimulate loss of native soil C, at least for boreal forests. The effect of charcoal on native soil C needs to be explicitly considered to better understand the potential of black C as an ecosystem C sink and agent of C sequestration.

References and Notes

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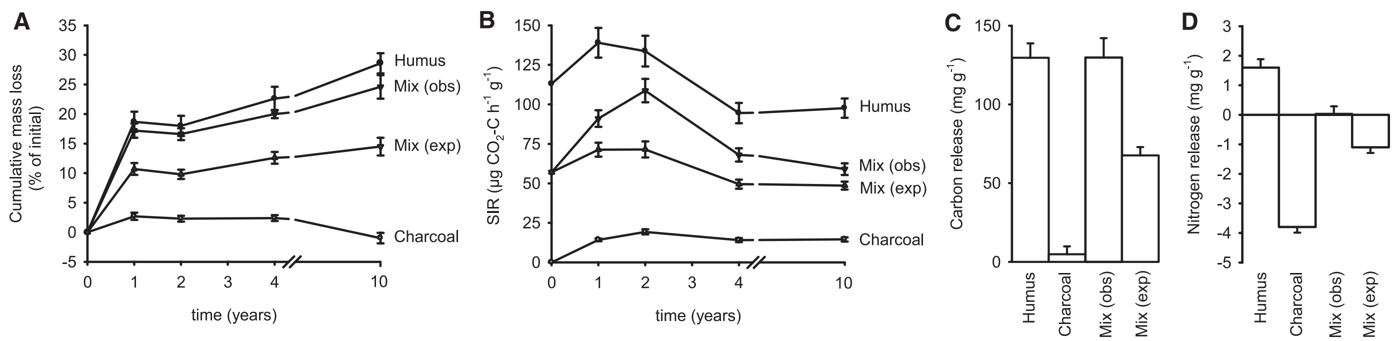

Fig. 1. Changes in litterbag properties over a 10-year period. Humus, Charcoal, and Mix (obs) correspond to litterbags containing pure humus, pure charcoal, and a 50:50 mixture of charcoal and humus, respectively. Mix (exp) corresponds to expected values for litterbags containing 50:50 mixtures of charcoal and humus if no interactive effects between the components occur (*6*). Each data point is the average of all three sites with 11 replicates per site, and vertical bars are mean within-site standard error. For all measurements at all dates and sites, values for Mix (exp) and Mix (obs) differ significantly at $P = 0.01$ (paired *t* tests). (**A**) Total mass loss. (**B**) SIR. (**C** and **D**) Loss of C and N from litter bags (per unit initial mass) over 10 years; negative values in (D) reflect net N gain through immobilization.