Australian climate–carbon cycle feedback reduced by soil black carbon

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Annual emissions of carbon dioxide from soil organic carbon are an order of magnitude greater than all anthropogenic carbon dioxide emissions taken together[1]. Global warming is likely to increase the decomposition of soil organic carbon, and thus the release of carbon dioxide from soils[2–5], creating a positive feedback[6–9]. Current models of global climate change that recognize this soil carbon feedback are inaccurate if a larger fraction of soil organic carbon than postulated has a very slow decomposition rate. Here we show that by including realistic stocks of black carbon in prediction models, carbon dioxide emissions are reduced by 18.3 and 24.4% in two Australian savannah regions in response to a warming of 3 °C over 100 years[1]. This reduction in temperature sensitivity, and thus the magnitude of the positive feedback, results from the long mean residence time of black carbon, which we estimate to be approximately 1,300 and 2,600 years, respectively. The inclusion of black carbon in climate models is likely to require spatially explicit information about its distribution, given that the black carbon content of soils ranged from 0 to 82% of soil organic carbon in a continental-scale analysis of Australia. We conclude that accurate information about the distribution of black carbon in soils is important for projections of future climate change.

For predictions of climate change to be accurate, they must include key processes controlling responses of C pools to global warming. Recent improvements in general circulation models include the coupling of terrestrial biogeochemical processes with atmospheric and oceanic processes[1]. Soil C cycling has an important role in such coupling because soil organic C (SOC) stocks are almost four times greater than C in the atmosphere, and annual emissions of CO_2 from soil are one order of magnitude greater than all anthropogenic CO_2 emissions together[1]. Therefore, small uncertainties in soil processes may have large effects on climate-change predictions for those general circulation models that incorporate terrestrial biogeochemical cycles[9].

Mineralization of organic C by microorganisms is generally found to increase with warming[5]. Thus, emission of CO_2 from soils will probably increase with increasing temperature[2–5], creating a positive climate-change feedback[6]. SOC consists of a complex mixture of compounds interacting with soil minerals and aggregates leading to the recognition of multiple pools of SOC with different turnover times[8]. Such variation causes biogeochemical simulation models that include multiple soil C pools[8] to predict a slower response to temperature change than do models with a single pool[7]. However, for models that will fully incorporate soil C stocks[9], failure to identify significant but highly stable fractions could render predictions of global climate change, even by simulation models with multiple soil C pools, inaccurate.

Black C, the carbonaceous residue of incomplete combustion of biomass and fossil fuels[10], has recently been detected in several soils worldwide, and is generally considered to be a highly stable form of SOC[10–12]. Charring typically increases the mean residence time (MRT) of biomass by one order of magnitude in short-term decomposition experiments[13]. The ^{14}C ages of black C were found to lie between 1,160 and 5,040 years BP (ref. 14) and are greater than the most stable non-black C pools[15]. However, reliable information about the MRT of black C in soils is hampered by a lack of longitudinal mass balance data[16] and by the heterogeneity of black C (ref. 10), which poses a challenge to its quantification (see the Methods section).

We hypothesize that neglecting or underestimating the size and stability of black C significantly inflates the mineralization predicted for total SOC under warming and thus future CO_2 emission from soils. In turn, recognizing black C as a soil C pool with a long MRT decreases estimates of the temperature sensitivity of SOC, with important implications for predictions of global warming. Using longitudinal field data of black C cycling and stocks, we carried out a modelling exercise to estimate MRT using contrasting assumptions about formation and loss. Assuming uniform sensitivity of these MRTs to warming, we assess the likely significance of the existence of black C to the climate-change feedback from total soil C using a multi-pool SOC model, RothC[2]. The soil samples analysed in the study were the representative soil profiles of the Australian National Soil Archive (NSA), and two landscape transects (Queensland QLD; and Darwin DWN) of approximately 3,000 km, totalling about 1,900 black C data from 452 soil profiles.

An analysis of the black C pool size suggested, at a continental scale, a wide variation in black C proportions, ranging from