Probing the Future: Response of Soil Organic Carbon and Nitrogen dynamics to elevated CO_2 in a paddy field

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Rice is the staple food for approximatively half of people on Earth and, because of the projected increase in the world population, the sustainability of paddy fields ecosystems is of great importance. Continuous increase in atmospheric CO_2 concentration is likely to alter rice ecosystems productivity directly via photosynthesis or indirectly via global climate change. Less is known for how elevated CO_2 (eCO_2) affect soil C pool which is linked to soil N availability and long-term soil fertility. Free Air CO_2 Experiments (FACE) give an opportunity to simulates future atmospheric CO_2 concentrations in open-field environment by maintaining an elevated CO_2 concentration throughout the field. Here we report results from a rice paddy FACE at Tsukuba, Ibaraki started in 2010. We examined how the eCO_2 altered soil C and N stocks as well as the fate of rice-derived C over a four year period.. We analyzed surface (Ap) horizon samples from 2010, 2012 and 2014 and determined their C and N contents. The soils were fractionated into three density fractions (i.e. free light fraction, occluded light fraction and heavy fraction) that correspond to soil organic matter pools with different degrees of decomposition state and mineral association. The free light fraction corresponds to relatively recent plant residues which were not extensively decomposed by soil microorganisms. The occluded light fraction is composed of organic matter that was entrapped in soil aggregates. This organic matter is physically entrapped into soil aggregates. The heavy fraction is enriched in mineral particles and the organic matter present in this fraction is associated with mineral particles and underwent more pronounced microbial transformation. Because the CO_2 added in this experiment derived from fossil C, its carbon isotopic signature differed from natural atmospheric CO_2. This isotopic signature allowed us to track the flow of photosynthesized C into different soil organic matter pools and to estimate mean residence time of C in each fraction.

Both soil C and N contents progressively decreased over the four year period due presumably to a shift in management (i.e. removal of rice straw form the field since 2010). It is worth mentioning that this decrease in soil organic matter was 25% more pronounced in the control plot compared to the plot exposed to eCO_2, suggesting that eCO_2 significantly enhanced organic matter input to the soil. The decrease in N contents was not as pronounced relative to C, leading to an increase in C:N ratios. The higher C:N ratios of soil and plant observed are likely to promote N immobilization by soil microbial community, which might lowered N availability for rice.

Further soil analysis using stable isotopes measurements revealed that, after four years, significant proportions of original soil C were replaced with recent C at different degrees among the three soil density fractions. The mean residence time of C was on average 6.5, 120 and 56 years in free light fraction, occluded light fraction and heavy fraction, respectively. About 60% of soil organic matter was distributed in the heavy fraction and the relatively rapid turnover of C in this fraction was not expected. The heavy fraction contains the organic matter bound with mineral particles, which is more stable into the soil. We found that, after four years, about 7% of the C in the heavy fraction was originating from C assimilated by rice plants since 2010.

The relatively rapid incorporation of newly added carbon into the heavy fraction and the higher soil C contents measured under eCO_2 suggest that the soil may be acting as a C sink under the open-field eCO_2 conditions. As it corresponds to a negative feedback for the rise in atmospheric CO_2 concentration, further research investigating this process are necessary.

Keywords: Soil, C and N cycling, Free Air CO2 Experiment (FACE), Density fractionation, 13C, Climate change

