2nd International Conference on Negative CO_2 Emissions
May 12-15, 2020, Chalmers University of Technology, Gothenburg, Sweden

Sequestration of Atmospheric Carbon Dioxide as Inorganic Carbon in Semi-Arid Forests

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Abstract

Inorganic carbon, in the form of allogenic (transported) and pedogenic (soil) carbonates in semi-arid soils may comprise an important carbon sink. Carbon dioxide, CO_2, originating from the atmosphere and exhaled by tree roots into the soil, may be hydrated by soil water within the unsaturated zone (USZ) of semi-arid soils to produce the carbonic acid (H_2CO_3) solutes HCO_3^- bicarbonate and H^+ Hydrogen ion. This H^+ may then dissolve relict soil $CaCO_3$ carbonate (calcite), to release Ca^{+2} calcium cations and more HCO_3^- bicarbonate. When conditions allow, one mole of Ca^{+2} and two moles of HCO_3^- combine to precipitate one mole of calcite, releasing one mole of CO_2: $Ca^{+2} + 2HCO_3^- \rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$. However, it has been claimed that such carbonates do not sequester significant amounts of present day atmospheric CO_2. The reasons given were that they originate in part from the pre-existing limestone; and that for every mole of calcite precipitated, one mole of CO_2 may be liberated to the atmosphere. We have tested these assumptions under field conditions at two semi-arid sites in Israel. Studies in the Yatir and Nizzanim forests have tracked atmospheric CO_2, as it transits through the soil, until it is sequestered as carbonate salts. While a small amount of these salts are re-dissolved by percolating rainwater, radiocarbon dating of these precipitates in Israeli low rainfall semi-arid forests yields ages of thousands of years, proving that their removal is long term. We found that bicarbonates, originating from root exhalation, are depleted and are incorporated within the USZ as the carbonates precipitate. The deposition rate of inorganic carbonate onto the sediment was found to be 22 mg CO_2 from the atmosphere per year per liter of sediment. Thus, a net sequestration of atmospheric CO_2 does occur under semi-arid forests. Moreover, most of the CO_2 liberated in the precipitation reaction may remain in the soil. And Ca^{+2} in the sediment may also be supplied from sources other than pre-existing calcite. Forestation can therefore augment pedogenic carbonate formation. Semi-arid regions comprise ~24 million km^2, ~17.7% of the global surface area. We extrapolate to the global semi-arid regions, assuming that the topsoil composition and depth and calcite precipitation rate in Yatir is representative of the global semi-arid area, following forestation. Taking 6 m as the global average depth of root respiration, the area 24 million km^2 gives a sediment volume of 1.44×10^{17} liters. Therefore, roughly 3.0 billion tons of CO_2 (22×10^{-3} g $L^{-1} \times 1.44 \times 10^{17}$ L ~3.0 Pg) could potentially be precipitated globally each year in the USZ as calcite, following forestation. More accurate estimates can be made once more data are obtained globally on the carbonate precipitation rate into USZ sediments. An annual value of 3.0 billion tons of CO_2 removed from the atmosphere represents a respectable ~15% of the present annual increase of 20 billion tons of CO_2 in the atmosphere. In addition, the sequestration of organic carbon following global semi-arid forestation has been estimated by other investigators as ~2 billion tons of CO_2 each year. The total carbon sequestration rate then represents ~25% of rate of atmospheric CO_2 increase. Tentatively, based on these data, sequestration of atmospheric CO_2 as inorganic and organic carbon in semi-arid forests represents a sustainable and economic method to help suppress the rate by which CO_2 is increasing in the atmosphere. A detailed description of our study is available at Catena 173, 93-98, 2019.