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The overlooked compartment of the critical-zone-complex, considering the evolution of future geogenic matter fluxes: Agricultural topsoils

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Abstract

In the last decades the application of rock powder or comparable products on soils has increased in agriculture areas leading to additional release of elements and alteration of soil solutions and saturation states of solutes. In the future this practice will continue and areas affected will spread. This trend will likely be fuelled by attempts to optimize carbon dioxide removal by increasing biomass production, soil organic carbon stocks, increase crop production or afforestation. All those efforts demand a certain amount of geogenic nutrients, which need to be replaced. To investigate the release patterns and the downward transport of an array of elements, and to study their fate as well as reaction processes, altered through this practice, a mesocosm experiment was established at Antwerp University. Here, first results are shown focusing on the release and transport of DIC and Mg in the soil downwards after the application of 22 kg m^{-2} olivine powder with a grain size smaller than 63 µm on average. Elevated DIC and Mg concentrations are detected in case of olivine is applied to mesocosms with wheat and barley, if compared to the mesocsoms without plants, and without olivine.

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Keywords: Enhanced Weathering, olivine, mesocosm, wheat, barley, DIC

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1. Introduction

The application of rock powder on agricultural soils is used to improve soil properties to achieve productivity increase. This method dates back thousands of years [1] and is still used in modern agriculture, predominantly in the form of liming.

Liming, the application of carbonate rock powder to agricultural soils, is a process to adjust soil-pH [2] and to increase crop production. This practice leads to additional release of cations and anions into the soil-rock system altering chemical composition of the soil solution. Alternatively silicate rock powder can be applied to provide geogenic nutrients and sequester CO_2 via the chemical weathering of the additional minerals [3].

With dwindling resources of rocks with concentrated phosphorus content [4], nutrient replacement by Enhanced Weathering (EW), the spreading of specific rock powders on fields, will likely become a valid alternative to supply not only phosphorus but also further geogenic nutrients, with probable impact on food security in certain areas of the world [4, 5].

However, little is known about the rates of soil solution change in the soil-space with time, specifically considering the transport of the “additional” weathering products through the soil column downwards, with consequences for the “previous” weathering system. Because reasonable values for the parameterization and evaluation of mechanistic models are missing, it remains difficult to provide good estimates for the consequences of the application of rock powder at a large scale to provide geogenic nutrients and sequester CO_2 [3]. However, the timeliness to understand the processes and the movement of applied rock powder to soils is evidenced by the increase in alkalinity of the Mississippi of more than 50%, which is partly attributed to liming and land management processes [6]

In addition to the objectives to provide nutrients to cropland, the application of rock powder to soils will likely increase if further methods proposed for carbon dioxide removal (CDR) are employed, e.g., biochar production, afforestation or biofuel production. Latter named CDR-methods demand, if driven to an optimum, more geogenic nutrients as typically available to plants in the soil-rock-systems in the long-term. This is partly because of supply limitation and permanent removal of geogenic nutrients from the soil-rock-system due to harvesting. These reasons are making an increased application of rock powder on top of soils, globally, very likely, thus leading to altered fluxes of elements through the critical zone and the biological pump, which redistributes parts of the additionally released elements.

To study the effects of Enhanced Weathering and derive release rates and distribution patterns for the added elements in soils, a mesocosm experiment was set up at the University of Antwerp, considering the effect of differences in precipitation patterns, grain sizes of applied rock powder (dunite, mostly composed of olivine) and plant uptake activity of released elements.

2. Methods

Since October 2013, a fully-replicated setup (5 replicates per treatment combination) of mesocosms was built up. Mesocosms were filled with a natural loamy soil from Belgium. Controlled factors are the application of olivine in the top 10 cm of the soils (22 kg m^{-2}) using two different olivine grain size fractions (1-3 mm and <63 μm), two crop types (wheat and barley) and two rain regimes (daily precipitation vs. weekly), while the total amount of rain was the same (adjusted to about 800 mm a^{-1}). Controls were established by using the same setup without olivine application (blanks) and without plants. Soil solutions were sampled at 10, 20, and 30 cm depth and at the bottom of the mesocosms. The release patterns of elements from the upper 10 cm and their transport through the soil column, for major cations, anions, nutrients (dissolved silica, nitrogen and phosphorus), dissolved inorganic carbon (DIC), δ^{13}C-DIC and the metals Ni, Cr, Co, Sr and Fe are analysed. In addition, the soil-PCO_2 and ^{13}C of the PCO_2 are measured at various depths to gain information about the soil atmosphere. A water balance will provide the flux-rates.

Here, the first results for Mg and DIC concentrations during the first 142 days of the experiment are presented.

3. Results and Discussion

Both Mg and DIC concentrations in the soil pore water responded to the treatment with olivine grains of < 63µm diameter with elevated concentrations compared to the blanks without olivine (Fig. 1 and 2). DIC concentrations were consistently higher in the two upper layers (10 and 20 cm depth) compared to the blanks after 60 days (Fig 1). At the beginning of the experiment many mesocosms showed temporarily increased concentrations in many elements (data not shown), which was attributed to the observation that the new soils adjusted to the first wave of water flushing through the soil column, even in the "blank" mesocosm (natural soil from a field without olivine). No effect of olivine weathering was visible in the 30 cm layer in all treatments, suggesting that the signal from the upper 10 cm had not reached this soil level. However, DIC concentrations increased more in the mesocosms with wheat or barley in the 30 cm layer compared to blanks with olivine and without olivine. No apparent differences in DIC concentrations between the wheat and barley containing mesocosms are visible.

The Mg concentrations were consistently higher in the olivine treatment compared to the untreated soil (Fig 2). Highest concentrations were measured in the 10 cm layers of all olivine treatments. In the 20 cm layer the Mg concentrations started to increase after 46, 77, and 106 days after seeding in the barley, wheat, and no crop treatment respectively. In the 30 cm layer Mg concentrations showed a consistent decrease over time in all treatments.

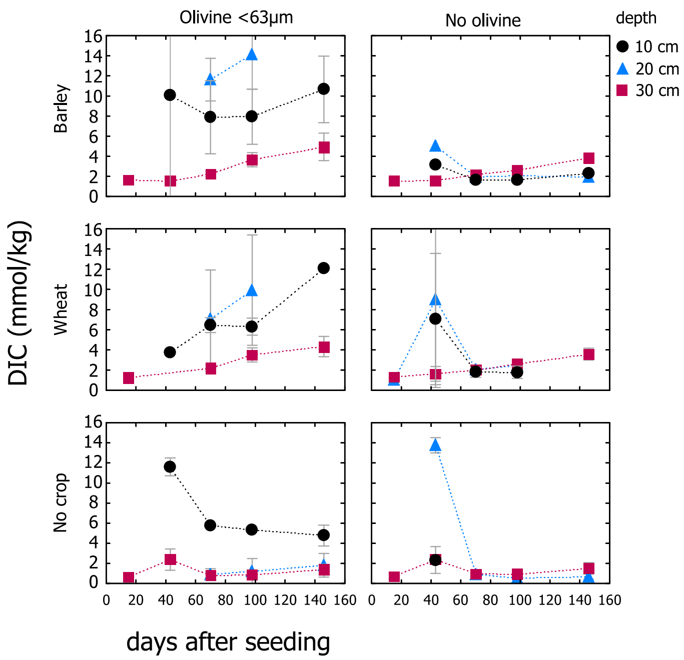

Fig. 1: Depth distribution of average DIC concentrations in the continuous rain treatments. Averages were calculated from up to five replicates. Depending on the water availability the number of replicates varied from 0 to 5 per sampling day. The error bars are the standard deviation.

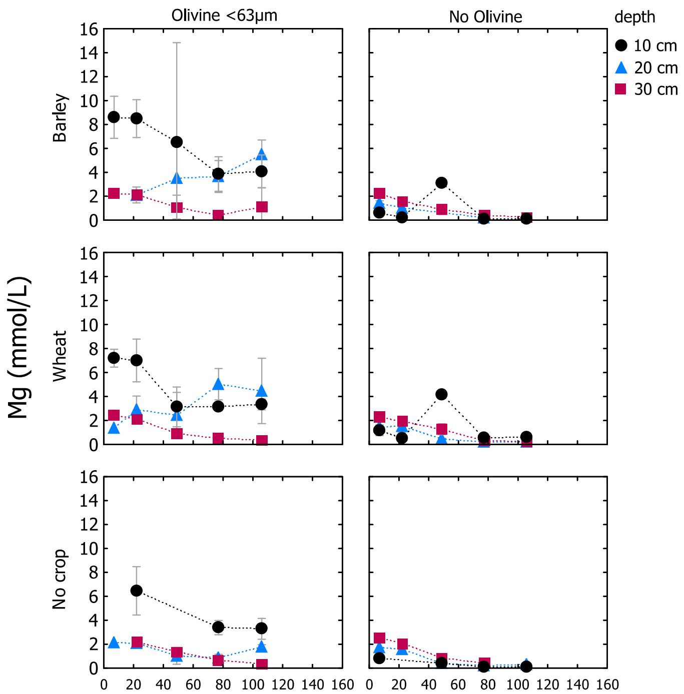

Fig. 2: Depth distribution of average magnesium concentrations in the continuous rain treatments. Averages were calculated from up to five replicates. Depending on the water availability the number of replicates varied from 0 to 5 per sampling day. The error bars are the standard deviation.

The elevated DIC and Mg concentration in the <63µm olivine treatment at the 10 and 20 cm level below the soil surface show clearly the enhanced release from the application of the rock powder, and the transport signal has not reached the 30 cm level after about 100 days.

4. Conclusion:

The experiment setup is suitable to study the application of Enhanced Weathering and the transport of chemical weathering products through the soil column. To track the long term changes associated with the application of silicate powder on agricultural fields the experiment will be continued for two years after the first harvest. Only experiments having a duration perspective longer than one year seem to be able to produce valuable results for the understanding of the changes in soil solution, as evidenced by the slow depth progress of the Enhanced Weathering signal. Uptake of different elements by plants will provide further insight in their enhanced weathering mobilisation, as well as future soil analyses for potential precipitation products.

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