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CARBON SEQUESTRATION BY ENHANCED SILICATE WEATHERING IN AGRICULTURAL SOILS

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INTRODUCTION

Enhanced silicate weathering is a carbon dioxide removal technology that could be applied at scale on croplands to reduce greenhouse gas emissions associated with agriculture, one of the largest sources of emissions globally (Schuiling and Krugsman, 2006; Renforth, 2012; Hartmann et al., 2013; Beerling et al., 2018; Andrews and Taylor, 2019). Agricultural applications of enhanced weathering leverage existing infrastructure used to spread crushed rocks on soil for nutrient and pH management (Figure 1; Gillman, 1980; van Straaten, 2006; Anda et al., 2015). In place of more traditional materials (like carbonate rocks used for liming), silicate rocks rich in Ca and Mg (e.g., basalt) are attractive because their dissolution consumes atmospheric carbon dioxide (CO_2) and ultimately stores that carbon as alkalinity in the oceans (Renforth, 2012; Hartmann et al., 2013). Through applications of crushed silicate rocks, then, rates of mineral dissolution and carbon sequestration could be accelerated through increasing the available mineral surface area for weathering.

Recent international reports (IPCC, 2018; IPCC, 2021) include enhanced weathering in the mix of emerging carbon dioxide removal technologies needed to limit global temperature increase below the internationally established threshold of 2°C. However, the vast majority of available literature on enhanced weathering is based on modeling or theoretical frameworks that constrain potential rates of carbon sequestration (e.g., Wilson et al., 2009; Renforth, 2012; Hartmann, 2013; Beerling et al., 2018; Beerling et al., 2020). Observational data directly testing enhanced weathering are limited. Several studies evaluate enhanced weathering in controlled systems where crops are grown in a greenhouse or garden (ten Berge et al., 2012; Haque et al., 2019; Haque et al., 2020a; Amann et al., 2020; Kellend et al., 2020) but only one study is currently available with published data from a field trial (Haque et al., 2020b).

Figure 1. Example of crushed basalt being applied to croplands in this study using spreading equipment designed for lime.

This research project contributed to establishing a three-year field experiment on an agricultural field at Carleton College to test the carbon sequestration potential of enhanced silicate weathering along with associated impacts on soils and crops. A team of four students participated through the Keck Gateway program. Gateway students worked to help collect and analyze important baseline data for soils in the study area, and contributed to a pilot greenhouse study.

FIELD TRIAL

This Gateway project is part of a longer-term research effort aimed at evaluating enhanced silicate weathering in agriculture over a three-year experimental period. The field trial utilizes a randomized block design that distributes control and treatment plots across the study area (Figure 3). The initial round of treatments were

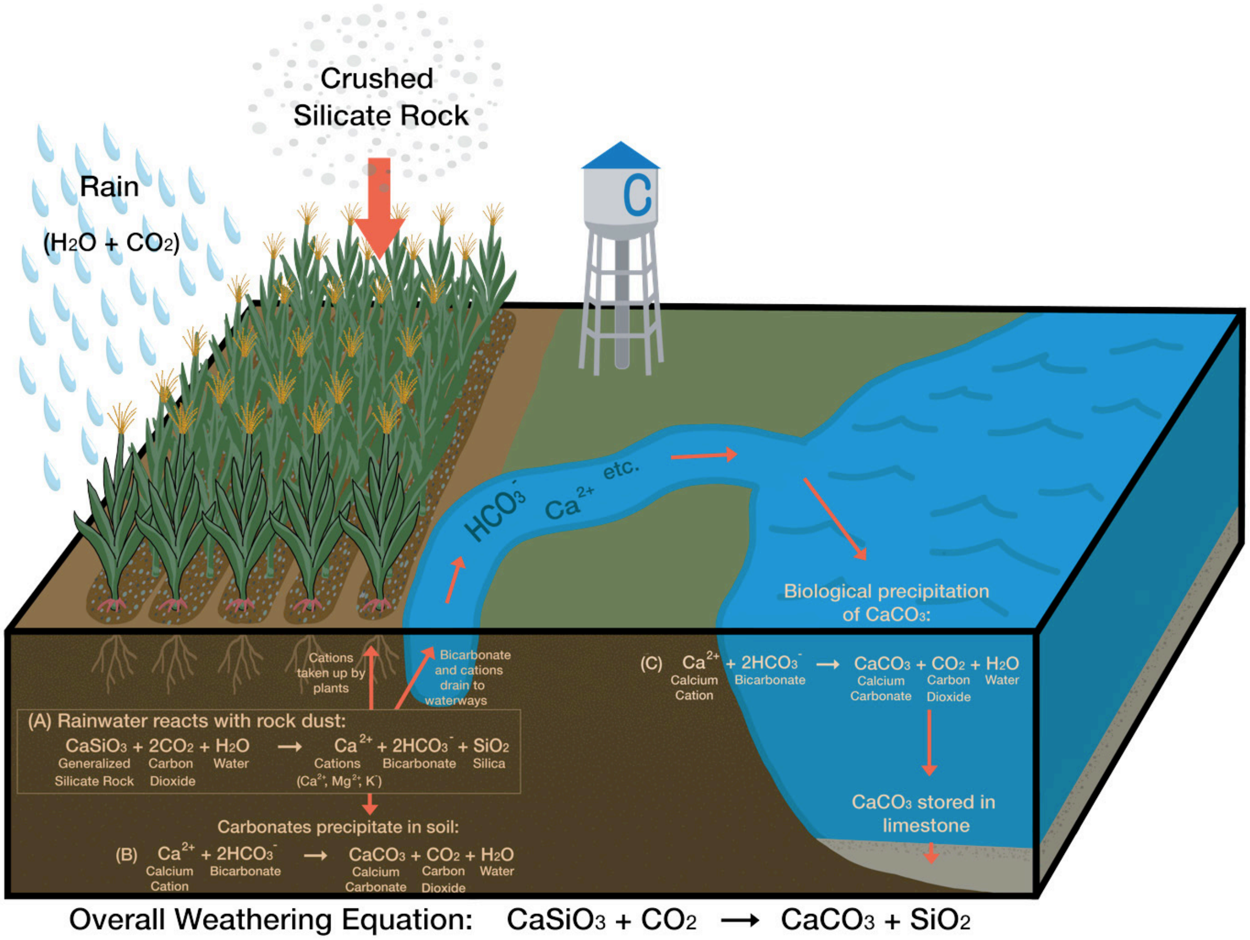

Figure 2. Schematic overview of enhanced silicate weathering in agriculture. (A) Initial reaction of silicate minerals with carbon dioxide in soils leads to the release and transport of cations and bicarbonate in soils and the local watershed. The ultimate fate of bicarbonate is to be precipitated as a carbonate mineral (B) or to contribute to carbonate mineral formation in the oceans (C). Figure and schematic adapted from Andrews and Taylor (2019).

applied during November of 2021 and monitoring of soil greenhouse gas flux and water chemistry is currently ongoing.

Baseline soil data collected during the summer of 2021 as part of the Gateway project described here is shown in Figure 4. Annual soil sampling and analysis will be conducted and compared against baseline data to compare the impacts of silicate treatments on soil properties and soil carbon storage. Soil pH ranges from ~5-8 and generally pH increases with depth in the soil profile (Figure 4). Soil in blocks A and B have notably elevated pH in comparison to blocks C and D, with the exception of the slag treatment plot in block A (Figure 3 and 4).

Based on personal communication with our cooperating farmer, dredged lake sediments from a man-made lake on campus at Carleton College were spread on the northern half of this field in the early 2000's. Based on the preliminary data collected here it is fairly clear that this impacts blocks A and B. Trends in soil organic matter, carbonate, and cation exchange capacity (CEC) mimic soil pH. The slag treatment plot in block A does not follow these trends, and more closely reflects soil properties in blocks C and D, indicating that the dredged material was not spread on this portion of block A. The observed gradient in soil pH across treatment plots should provide a good opportunity to determine how soil pH interacts with the efficacy of enhanced weathering for carbon sequestration (rate of dissolution) and co-benefits to growers (improving crop yield and soil properties).

GREENHOUSE EXPERIMENT

Students in this Gateway project initiated a greenhouse experiment aimed to test the impacts of enhanced silicate weathering in a more controlled setting compared with the field study. This report provides a

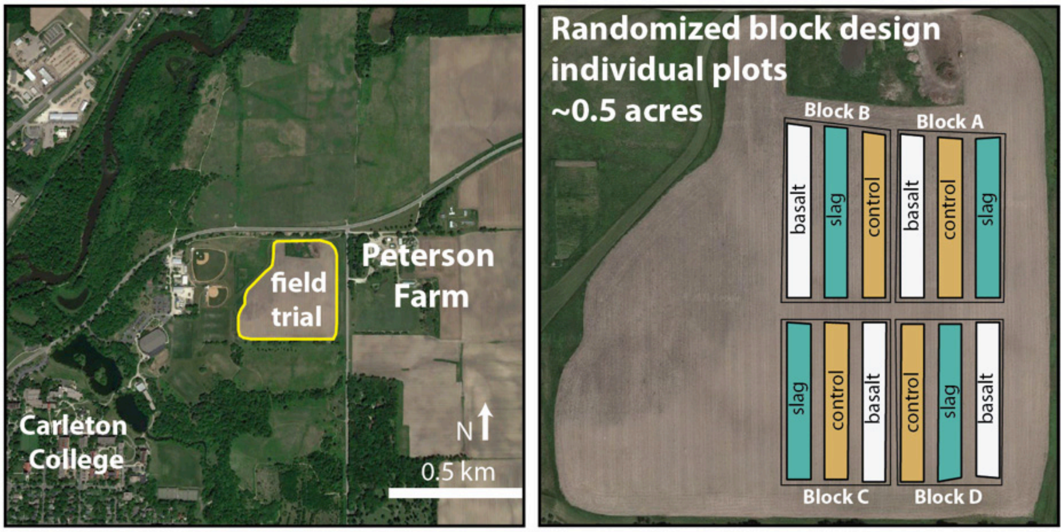

Figure 3. Location of field trial relative to Carleton College in Northfield, MN. Peterson Farms is the cooperating farmer partnering in this research. Location of field trials is only a ~10-minute walk from science center on campus at Carleton.

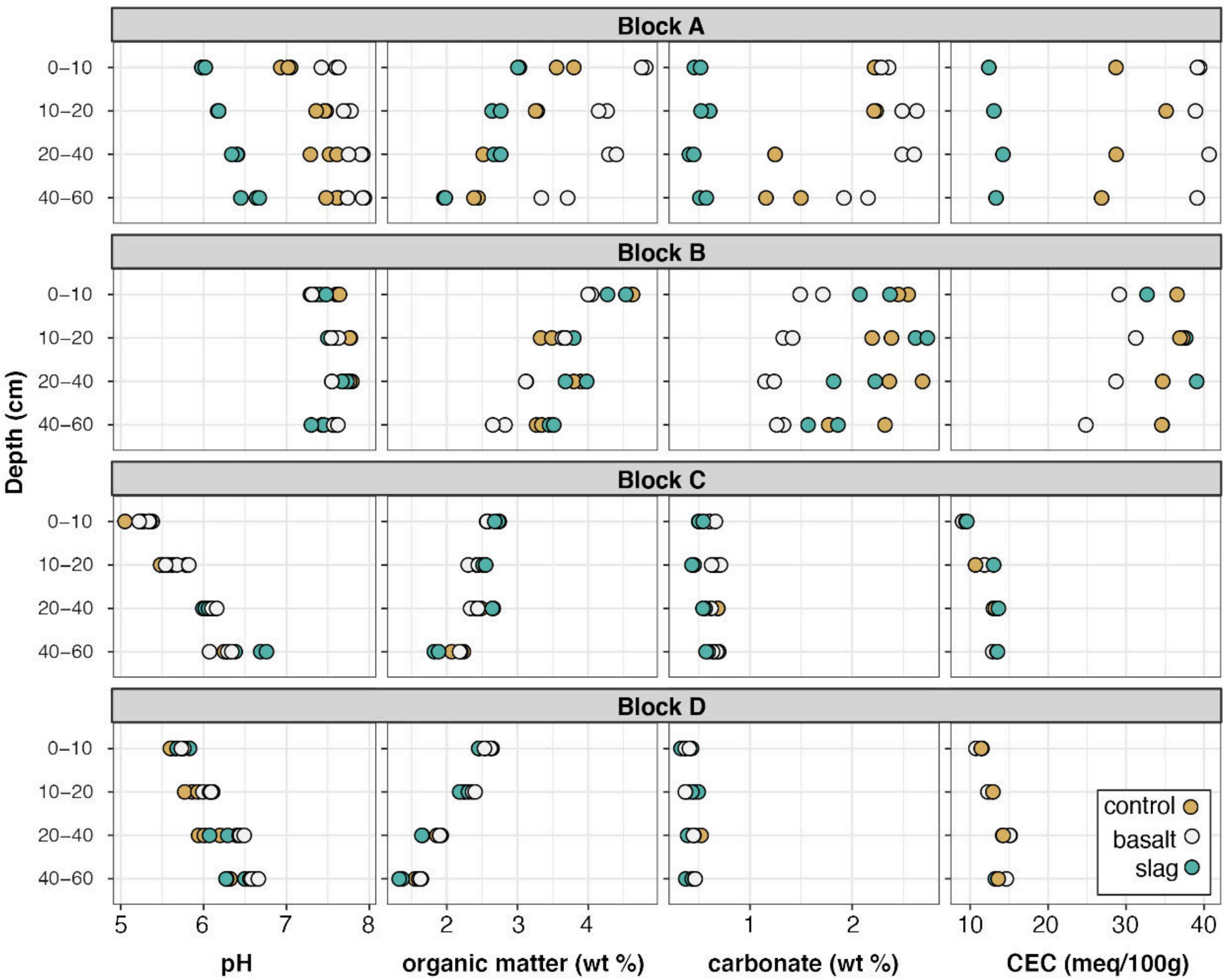

Figure 4. Preliminary soils data for field trials. Panels from left to right show soil pH, weight percentage organic matter and carbonate mineral, and cation exchange capacity (CEC) at various depths for homogenized plot samples. Data are organized by block (grey header blocks) and treatment (colored circles, see key in lower right corner).

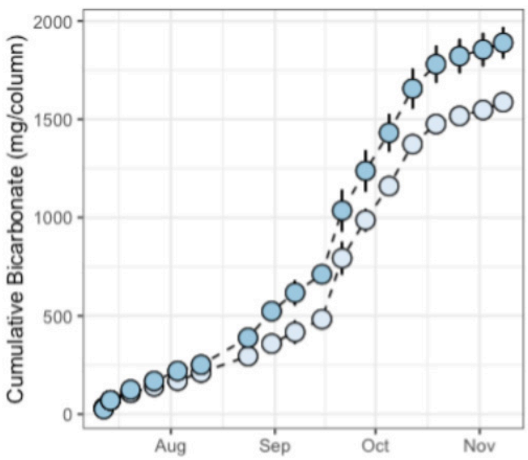

Figure 5. Cumulative bicarbonate leached from treatment (dark blue) and control (light blue) soil columns. Bicarbonate was calculated from measurements of total alkalinity. Error bars represent one standard deviation.

brief overview of our experimental design and a key result of the project.

A set of 12 soil reactors were packed to an approximate bulk density of 1.3 g cm-3 with sieved and homogenized topsoil (upper 20 cm) and subsoil (below 20 cm) collected from native silty loam soil from the agricultural field described in the previous section (see Figure 3; soils from NW corner of field used in field trial). Basalt was mixed into the upper 10 cm of topsoil in 6 of the reactors at a rate equivalent to 20 tonnes acre-1 prior to planting. Our application rate for our initial greenhouse experiment exceeds what we intend to apply in the field, but remains on the low end of rates applied in most previous greenhouse or pot studies (~60-200 tonnes acre-1; Haque et al., 2019; Haque et al., 2020a; Kellend et al., 2020; Amann et al., 2020). Despite the unlikely case that farming partners would adopt such high dosages, we evaluate a higher rate in our preliminary greenhouse study to ensure we are able to observe a signal with our methods for carbon sequestration accounting, if one exists at high loads.

A total of 48 corn seeds were germinated in small starter trays and kept moist for 2 weeks while seedlings developed. The 12 healthiest seedlings were transplanted into the soil reactors after 2 weeks marking the start of the experiment. The sample size for corn plants here follows other recent pot studies. Our irrigation scheme intended to match local rainfall during the growing season, with each reactor receiving 500 mL of water per week. However, beginning with week 6 of the experiment, additional water was added as the corn plants grew and increased their water use. This was done to ensure that enough drainage water could be collected for analysis – limited drainage water has impacted the ability of previous greenhouse studies to consistently evaluate carbon sequestration rates using bicarbonate concentrations (ten Berge et al., 2012; Kellend et al., 2020; Amann et al., 2020).

We harvested corn after an 18-week (~126 days) experiment, in line with the duration from other studies (Kellend et al., 2020). Trends in total bicarbonate in leachate water are shown in Figure 5. Basalt treated soil columns in our experiment have a significantly higher amount of total bicarbonate produced in leachate waters collected and analyzed from each soil column ($p < 0.05$ for simple t-test). These results suggest an increased rate of silicate weathering due to basalt amendments which corresponds to an increase in carbon removal.

The greenhouse study described here provides exciting data that suggests carbon removal through enhanced weathering is detectable through simple measurements of water chemistry, although ongoing work is continuing to evaluate these results and better clarify actual rates of carbon removal along with associated impacts to crops and soil.

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