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PREFACE

This document is an evaluation of the potential for glacial flour to increase crop yield on land and mitigate climate change. The aim is to consolidate knowledge within the ICEBIO consortium on the beneficial nutritional value of glacial flour as well as the negative impact and knowledge gaps in that area of research. Moreover, the geo-engineering usage of glacial flour will be discussed. By doing so, we contribute to fulfilling the goal of the ICEBIO consortium in improving the understanding of glacial flour as fertilizing agents on land and as a geo-engineering tool.

INTRODUCTION

Sustaining food security is an increasingly important theme in a world where the human population continues to increase. The global population is estimated to peak in 2080's at 10.3 billion people (United Nations, 2024). The need for optimizing agricultural practices is evident with one aspect being the increase of crop yields. A way to optimize crop yields is through the addition of fertilizers. However, generating fertilizers is an energy demanding procedure with around 1% of the global energy demand being channeled towards producing fertilizers (Ramírez and Worrell, 2006). With an expected continued rise in global temperatures, lowering global energy demands in general is paramount (IPCC, 2019).

The dual challenge of increasing crops yields, while mitigating climate change, that may otherwise present further challenges to reduce food insecurity for the global human population, calls for innovative solutions. Recent research has revealed the potential for glacial rock flour to increase crop yields (Gunnarsen et al., 2023, Tingey et al., 2025). However, several aspects related to the harvesting and usage of glacial flour are still unclear. In this report, we aim to briefly compile current knowledge on glacial rock flour's ability to function as a soil amendment to increase crop yields on land, as well as mitigating climate change. The nutritional value of glacial flour will be discussed as well as the geo-engineering capacity of glacial flour to sequester carbon through chemical weathering processes. Moreover, the potential consequences of removing glacial flour from the source and the challenges related to variations in lithology that can impose potential health risks will be debated. This will help reveal current important knowledge gaps and guide future research on the field of global food security, ecosystem sustainability and human health.

Nutritional value of glacial flour and potential toxicity

Through physical and chemical weathering of the bedrock, glaciers have the capacity to generate vast amounts of fine rock particles, known as glacial flour (Sharp and Tranter, 2017, Wadham et al., 2010). It is estimated that, from marine-terminating glaciers of Greenland alone, the yearly flux of glacial flour to fjords is 1.324 Gt (Andresen et al., 2024). Moreover, studies have shown the release of essential macro- and micronutrients in relation to glaciers and glacial flour (Crusius et al., 2011, Bhatia et al., 2013, Hawkings et al., 2016, Wadham et al., 2016, Hawkings et al., 2017, Hawkings et al., 2020b, Pryer et al., 2020). Until recently glacial flour has been seen as a valueless resource. However, proof of concept growth trials using glacial flour as a soil amendment have shown promising results with increases in crop yields of wheat, maize, potatoes and soybeans (Gunnarsen et al., 2023, Tingey et al., 2025). Using minerals as a fertilizer is common practice, albeit crushing rocks into small enough grain size presents challenges in terms of machinery and energy demands (Gunnarsen et al., 2023). Sourcing glacial flour instead, the particles are already milled to a silt or clay size of <63μm, which increases the surface area, thereby enhancing weathering processes and the following releases of nutrients (Andrews, 2000, Gunnarsen et al., 2023).

In one of the aforementioned growth trials, glacial flour sourced from a marine deposit in the fjord of Nuuk, Greenland, was added to sandy test soils in two field trials to assess the short and long term impact of using glacial flour as a soil amendment (Gunnarsen et al., 2023). Upon addition of glacial flour, the dry yield for maize increased with 59 kg ha^{-1} per ton of glacial flour (Gunnarsen et al., 2023). However, no residual impact was measured on the soil in the following years, and no additional effect was seen when adding both glacial flour and a potassium supplement, suggesting that under nutrient saturated conditions the amended glacial flour did not increase the yield further (Gunnarsen et al., 2023).

Despite the beneficial effects of utilizing glacial flour, it is important to consider the presence of potentially harmful trace metals. A recent study by Tingey et al. (2025) revealed the potential for enrichment of arsenic in soybeans grown with Himalayan glacial flour as a soil amendment. Through both SEM-EDS and LA-ICP-MS analyses, it was evident that arsenic was present in the sulfide minerals; arsenopyrite, pyrite and pyrrhotite in the glacial flour (Tingey et al., 2025). Albeit the study showed increases in crop yields, increased nitrogen fixation, plant health and plant biomass, the potential for accumulation of toxic trace metals present in the glacial flour is something of concern (Amann et al., 2020). Tingey et al. (2025) among others have shown that considering the geology of which the glacial flour is derived from is key before considering the glacial flour as a soil amendment (Amann et al., 2020, Hartmann et al., 2013). Therefore, further research is needed on the impact of geology on using glacial flour to fully constrain the consequences of considering glacial flour as a fertilizer on land.

Glacial flour as a geo-engineering strategy

Linked very closely with glacial flours ability to increase crop yields is the emerging geo-engineering strategy of using rock flour to mitigate climate change in a technique referred to as Enhanced Weathering (Hartmann et al., 2013, Amann et al., 2020, Dietzen and Rosing, 2023). In natural weathering processes of silicate minerals, carbon dioxide is sequestered and bicarbonate is generated (Berner, 2003, Renforth and Henderson, 2017). Once transported to the ocean, bicarbonate reacts with cations present generating carbonates that precipitate out (Berner, 2003). Hence, carbon dioxide from the atmosphere can be stored long term in the oceans (Renforth and Henderson, 2017). Under natural conditions, this process happens on geological timescales (Berner, 2003). Enhanced Weathering refers to the process of adding finely grained silicate minerals to agricultural soils (Hartmann et al., 2013). The large surface area to volume ratio of the fine rock particles enhances the weathering – speeding up the sequestration of carbon dioxide. However, as for applying rock flour for its fertilizing capacities, generating fine rock flour is energy demanding. Hence, the idea of using glacial flour has too become a potential solution here (Dietzen and Rosing, 2023).

The importance of glacial flour for ecosystem services

Before considering large-scale harvesting of glacial flour for its fertilizing capacity and geo-engineering potential, the importance of this resource in the environment from which it is produced and cycled needs to be considered. Glacial flour exported with meltwater to downstream ecosystems have proven to have significant impact on especially the coastal ecosystems by transporting bioavailable nutrients (Hopwood et al., 2020, Hopwood et al., 2014). Iron (Fe) and Silicon (Si) are examples of nutrients derived from glacial flour with significant impact on downstream environments (Hopwood et al., 2014, Hendry et al., 2019, Hawkings et al., 2017). As for Fe, glacial flour has been discussed to be an important Fe source to polar waters (Hopwood et al., 2014). In the Southern Ocean Fe is a limiting nutrient for primary production; the high particulate Fe flux from glacial meltwaters can therefore be an important factor to stimulate primary production (Hopwood et al., 2014).

As regards to Si, from the Greenland Ice Sheet, the estimated Si release is 22 Gmol Si yr^{-1} (Meire et al., 2016). The large flux of Si from the Greenland Ice Sheet has been suggested to enhance the growth of Si-dependent organisms, like diatoms, more than other phytoplankton (Meire et al., 2016). This aligns with benthic flux of dissolved Si which has been connected to glacially derived particles found in southwest Greenland, supporting local diatom growth (Hendry et al., 2019). Diatoms constitute about 40% of marine primary productivity in the oceans and are both important for carbon sequestration and in the marine food web (Tréguer et al., 2018).

Because the magnitude of the flux of glacial flour, minerology and bioavailability of macro- and micronutrients released from the flour can vary across catchments and seasons the overall consequences of altering glacial flour inputs to the coastal zone by removal for industrial purposes remain highly uncertain (Hopwood et al., 2020, Hendry et al., 2025, Hawkings et al., 2020a). Large-scale harvesting could potentially shift nutrient ratios, impacting primary productivity and other biogeochemical processes, potentially affecting carbon sequestration (Wehrmann et al., 2014, Meire et al., 2016). However, because of the novelty of the industry, the size of the removal and therefore the actual impact on the environment is uncertain. As such, a precautionary approach is advised as the full impact of implementing large-scale harvesting of glacial flour from the environment is still unknown.

CONCLUSION

It is clear that advances in research in the utilization of glacial flour to increase crop yields and mitigate climate change through geo-engineering are needed to ensure sustainable usage of this resource. Glacial flour may show fertilizing capacity, which in a world with growing populations, becomes increasingly important. Moreover, the dual effect of using glacial flour on fields to sequester carbon, is a promising tool in a warming world. However, as described above, glacial flour is generated and released in often remote locations with still not fully described impacts on the ecological services herein. Hence, removing glacial flour from the origin might have unresolved consequences for the connected ecosystems. It is therefore strongly advised that the research surrounding glacial flour, its ability to be used as a fertilizer, the toxicity risks and their importance in downstream ecosystems is strengthened before initializing large-scale harvesting of this resource.

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