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Viewpoint

Urban Farming with Enhanced Rock Weathering As a Prospective Climate Stabilization Wedge

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ABSTRACT: With no single carbon capture and sequestration solution able to limit the global temperature rise to 1.5−2.0 °C by 2100, additional climate stabilization measures are needed to complement current mitigation approaches. Urban farming presents an easy-to-adopt pathway toward carbon neutrality, unlocking extensive urban surface areas that can be leveraged to grow food while sequestering CO_2. Urban farming involves extensive surface areas, such as roofs, balconies, and vertical spaces, allowing for soil presence and atmospheric carbon sequestration through air-to-soil contact. In this viewpoint we also advocate the incorporation of enhanced rock weathering (ERW) into urban farming, providing a further opportunity for this recognized negative emissions technology that is gaining momentum worldwide to gain greater utilization.

KEYWORDS: *alkaline silicates, green roofs, climate change mitigation, organic carbon, soil inorganic carbon*

Continuous urban migration has resulted in 4.2 billion people living in cities in 2020, which is more than half (55.3%) of the world's population today according to the World Bank's 2020 Urban Development study[1] and is expected to increase to 66% by 2050 according to the United Nations' World Urbanization Prospects 2018 report.[2] Ample urban land is therefore available worldwide, and this land area has been projected to increase in the decade to come.[3] Urban farming is therefore gaining attention in view of sustainable development plans, including its untapped food production potential[4] with calls for revisions to local food supply chains and urban zoning,[5] as well as reduced transportation of vegetables from farms to cities, further enhancing the net negative carbon emissions.[6]

Roofs and balconies are typically unused urban spaces and constitute approximately 20−25% of the urban surface area (e.g., in metropolitan Sacramento, CA, of the ∼800 km^2 in total land area, 150 km^2 comprise roof area, compared to

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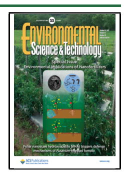

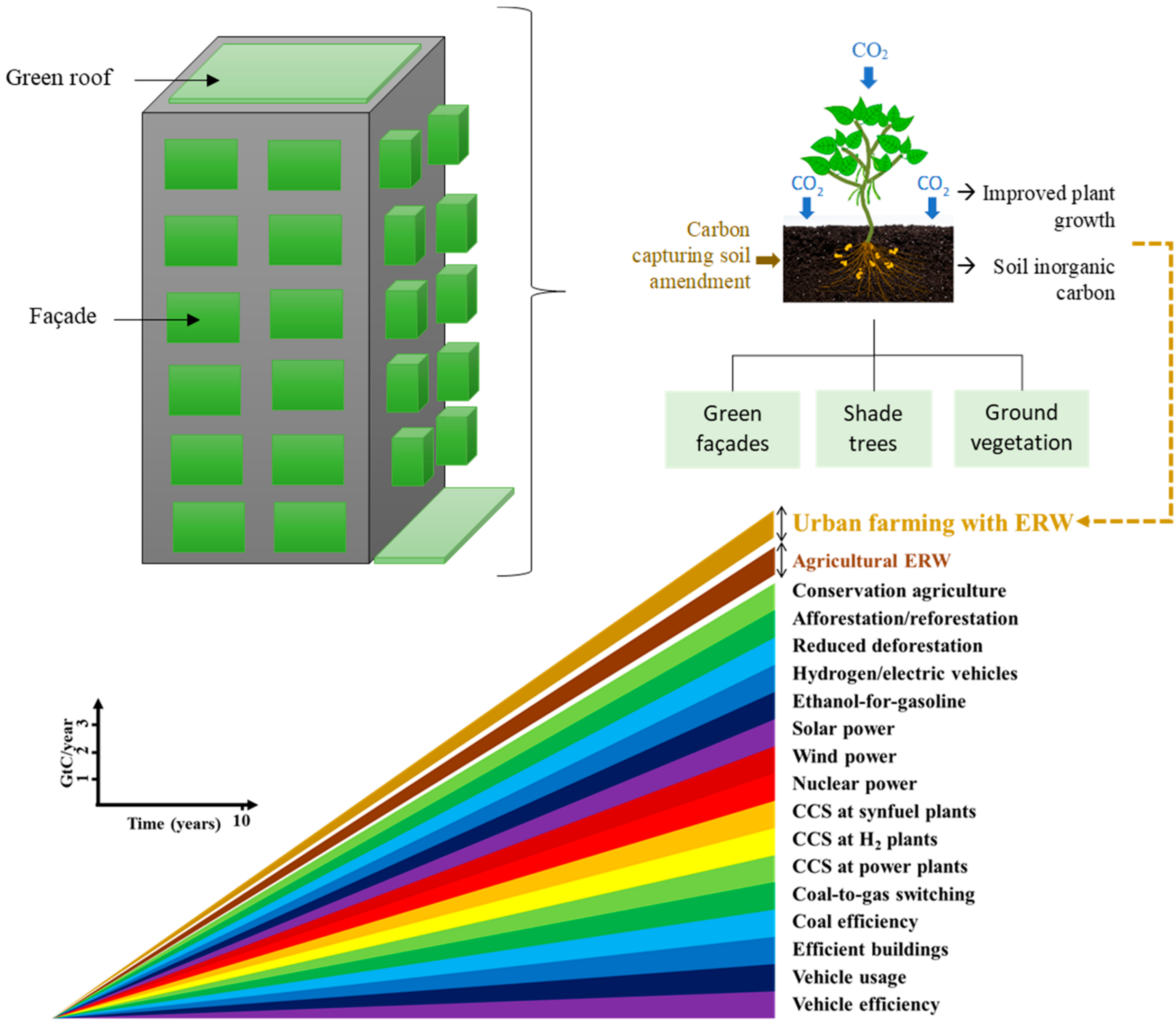

Figure 1. Urban farming combined with ERW is proposed as a new addition to the stabilization wedge concept (adapted from Johnson et al.[15]). Each wedge represents an approach that can reach at least 1 GtC/year of reduced emissions or sequestration within 50 years of implementation. Agricultural ERW is also added, as proposed by Haque et al.[14]).

230 km^2 as vegetated area);[7] therefore, they provide a unique opportunity to sequester carbon. At the city level, Hume et al.[8] posed that urban farming in Adelaide, Australia, could supply residents' vegetable needs under medium- (5.08 kg·m^{-2}·year^{-1}) to high- (16.07 kg·m^{-2}·year^{-1}) yield scenarios. At the national level, Dobson et al.[9] assessed that the United Kingdom's allotments used for urban horticulture also contribute to improved soil health, including a substantially greater organic carbon content (58.2 mg·g^{-1}, median average) than the country's traditional arable and horticultural lands (23.5 mg·g^{-1}), disproportionally contributing to the national total organic carbon stocks. The benefits of urban farming can also be extended beyond decreases in food security risks to include improving other urban risks, such as unemployment levels and community decline, and reversing the longstanding negative environmental effects of urbanization.

Urban farms have been shown to store carbon in both plants and soils; for example, Getter et al.[10] analyzed the organic carbon sequestration potential of 12 green roofs and concluded that green roof systems could sequester 0.375 kg C·m^{-2} of organic matter in above- and belowground biomass. This form of sequestered CO_2 can be considered organic carbon sequestration, that is, plant biomass and associated soil organics that form as a result of photosynthesis and microbial activity.

In addition to the carbon sequestration potential from the growth of additional plant biomass and locking organic carbon into urban soils, another promising strategy is enhancing the inorganic carbon sequestration capacity of soils by amending the soil with crushed calcium- or magnesium-rich silicate rock. In our prior study,[11] milled wollastonite rock (primarily $CaSiO_3$ and $CaMgSi_2O_6$ minerals) was used as a soil amendment while growing green beans and corn in pots placed on a rooftop. The amended soil cultivated with beans sequestered over a period of two months 0.70 kg C·m^{-2} as organic carbon in plant biomass and 1.28 kg C·m^{-2} as inorganic carbon in soil. Both green beans and corn showed better growth (90−170% greater dry biomass) with mineral soil amendment, confirming that silicate minerals (which can contain appreciable amounts of P and K) can enhance soil health and plant productivity. Recent field studies using wollastonite ($CaSiO_3$) have demonstrated its scalable potential, sufficiently fast rate of carbon sequestration, and economical and practical feasibility under favorable scenar-

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ios.[12] Less favorable scenarios include those where silicate rock weathers more slowly or incompletely (e.g., basalt) or where comminution or transport needs become prohibitive.[13] With the right mineral feedstock, urban farming can be the next frontier for ERW.[14] Lower barriers to entry for soil amendments and higher margins of retail products for gardening use make this route easier to adopt for ERW than in croplands. Hence, there is an opportunity to intensify the carbon storage potential of urban farm soils in terms of both organic and inorganic carbon pools.

In summary, we propose that urban farming, alongside the addition of agricultural ERW, should be considered an additional wedge to mitigate climate change within the stabilization wedge carbon capture and storage model shown in Figure 1 (adapted from Johnson et al.[15]). Globally, 68 827 950 ha of urban land (according to The Food and Agriculture Organization's FAOSTAT Land Cover database[16]) could include up to 17 207 987 ha of green roofs; if all these green roofs were supplemented with finely comminuted wollastonite as an alkaline silicate soil amendment and used to grow green beans as in Haque et al.,[11] they would sequester as much as 0.34 Gt C per year. The concept of using carbon-capturing silicates as soil amendments can also be applied to types of urban farming other than green roofs, that is, green façades, shade trees, and ground vegetation. Considering the sequestration rate of Haque et al.,[11] if any urban area was covered with vegetation using wollastonite-amended soil, then every 1% of urban area used for farming could potentially sequester 13.6 Mt C.

The amount of carbon sequestered by urban farming would change depending on the location, the specific silicate mineral used as the soil amendment, the different types of plants grown, the frequency of the growing period, and the duration of the growing season. It is also important to consider the larger life-cycle aspect of adopting urban farming. On the other hand, Wielemaker et al.[17] warned about the possible overuse of nutrient inputs in urban agriculture, which would have negative effects on the carbon footprint of the practice, and Goldstein et al.[6] suggested that in certain scenarios, the adoption of solar panels rather than urban agriculture can be a better use of urban land area from a life-cycle perspective, especially for low-yield crops that result in the inefficient use of production inputs. A collection of long-term studies across different regions and climatic conditions would provide sufficient information and data to allow decision-makers and stakeholders to make rational decisions regarding whether to adopt the practice of using alkaline silicates in urban farming.

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Notes

The authors declare no competing financial interest.

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Prof. Emily Yi Wai Chiang is an Associate Professor in the School of Engineering at the University of Guelph. She received her PhD degree in Bioscience Engineering from KU Leuven in Belgium, and her Master's and Bachelor degrees in Chemical Engineering from the University of Toronto. Chiang specializes in the implementation of mineral carbon sequestration in agricultural setting, promoting alkaline mineral soil amendment as a climate change stabilization wedge with environmental relevance and based on fundamentals of earth sciences. Her work for the first time verified that wollastonite soil amendment can lead to accumulation of inorganic carbon in soils, and that leguminous crops enhance the weathering of wollastonite. She is working on both experimental and modeling work to gain useful insights of the geochemical interactions among the minerals, plants, soils and air, as well as to assess the risk of applying minerals to agricultural soil.

Prof. Rafael M. Santos is an Assistant Professor in the School of Engineering at the University of Guelph. He received his Summa Cum Laude PhD degree in Chemical Engineering from KU Leuven in Belgium, and his Master's and Bachelor degrees in Chemical Engineering from the University of Toronto. Santos is a Fellow of the Negative Emissions Science Scialog, was a contributing author to the Mission Innovation Carbon Capture Experts' Workshop Report, and a co-organizer of the Fourth International Conference on Accelerated Carbonation for Environmental and Materials Engineering. He has published 71 journal articles to date in the fields of CO_2 sequestration/utilization, sustainable and intensified processes, applied mineralogy and geochemistry.

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