Environmental Chemistry Letters (2023) 21:3041–3044
https://doi.org/10.1007/s10311-023-01598-y

Planting trees to combat global warming

Ahmed I. Osman[1] · Samer Fawzy[1] · Eric Lichtfouse[2] · David W. Rooney[1]

Published online: 17 April 2023

Introduction

Climate change has been a pressing issue since the late 20th century when the world recognized the gravity of the situation (Fig. 1). The United Nations Framework Convention on Climate Change (UNFCCC) was introduced in the early '90s, followed by the Kyoto Protocol in 1997, and later the Paris Agreement in 2015. The Paris Agreement aimed to limit the global temperature increase to 2 °C by the end of the century while pursuing efforts to cap it at 1.5 °C. Despite global efforts to combat climate change, evidence suggests that current and future emission reduction commitments are insufficient to meet the Paris Agreement targets (Fawzy et al. 2020). While tree planting is a popular solution, it is crucial to enhance and secure the permanence of the carbon stored in trees and soils. Indeed, if not managed effectively, tree planting could have a negative impact on global warming. In this editorial, we will explore how to effectively use tree planting to enhance carbon permanence and mitigate the detrimental effects of climate change.

Afforestation and reforestation

Afforestation and reforestation are strategies for mitigating the impacts of climate change. Indeed, trees capture carbon dioxide (CO_2) from the atmosphere during growth and store carbon in living biomass, dead organic matter, and soils, making forestation a negative emissions method. Afforestation involves establishing new forests, while reforestation involves re-establishing previous forest areas that have undergone deforestation or degradation. Depending on the tree species, CO_2 uptake during forest growth may span 20–100 years until the trees reach maturity, after which sequestration rates slow down significantly. At this stage, forest products can be harvested and utilized. However, it is argued that forest management practices and activities have a significant environmental impact and should be carefully planned to ensure that the co-benefits of afforestation and reforestation are maximized (Royal Society 2018). These co-benefits include improved biodiversity, flood control, and enhanced quality of soil, water, and air (Harper et al. 2018).

Vulnerable carbon storage

Carbon storage in forests can be a highly effective means of reducing greenhouse gas emissions, but permanent storage is vulnerable to natural and human disturbances (Fig. 2). Indeed, forests face risks from natural disasters such as fire, droughts, and disease, as well as human-induced deforestation activities, which can compromise the integrity of carbon storage. Unlike storage in geological formations, biogenic storage has a much shorter lifespan, making it important to protect forests and manage them sustainably (Fuss et al. 2018). Furthermore, forestation projects require significant amounts of land, which may compete with other land uses (Royal Society 2018).

Local warming

The albedo effect is another issue that needs to be considered when deploying forestation projects. Indeed, forests at high latitudes can actually accelerate local warming and loss of ice and snow cover, while tropical areas are more suitable for hosting such projects. However, competition with agriculture and other sectors for land may pose challenges. According to Fuss et al. (2018), an estimated total area of 500 Mha within global tropical boundary limitations is suitable for forestation

✉ Ahmed I. Osman
aosmanahmed01@qub.ac.uk

Eric Lichtfouse
eric.lichtfouse@gmail.com

1 School of Chemistry and Chemical Engineering, Queen's University Belfast, BT9 5AG, Belfast, Northern Ireland, UK

2 State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, Shaanxi, China

Fig. 1 Effectiveness of planting trees in the forms of afforestation or reforestation and dedicated crops in mitigating climate change

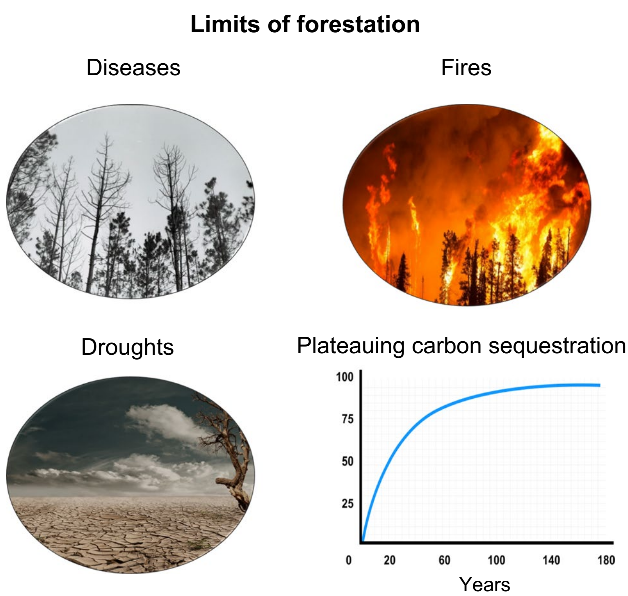

Fig. 2 Challenges of afforestation and reforestation in the context of climate change. These challenges include forest diseases, drought, and fire, which can impede the growth of trees and reduce their carbon sequestration potential. Moreover, after 20–100 years, the carbon sequestration rate of trees may slow down or plateau, which poses additional challenges to sustaining carbon sequestration over the long term

deployment, with a global carbon dioxide removal potential of 0.5—3.6 Gt CO_2 per year by 2050. The estimated removal costs range from \$5 to 50 per ton of CO_2. Thus, while forestation can be an effective means of carbon storage, it is crucial to carefully consider the challenges and limitations associated with it and develop sustainable management practices to ensure the long-term permanence of carbon storage.

Failure of past carbon sequestration plans

Afforestation and reforestation have been adopted globally and integrated into climate policies through the Kyoto Protocol's Clean Development Mechanism program since the 1990s. The introduction of removal units allowed forestation projects to yield tradable credits. However, despite early policy measures, forest-based mitigation efforts accounted for only a small fraction of emissions at that time. In addition to national regulations, the United Nations introduced the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program in 2008 to promote forest-based abatement projects. However, carbon sequestration through forestation remained insignificant, accounting for only 0.5% of total carbon trading in 2013 (Gren and Aklilu 2016). The effectiveness of the REDD+ program is argued in the literature after more than 10 years of the program introduction. For example, Hein et al. present a number of arguments around the program's poor track record in achieving its intended purpose of emissions reduction. However, despite the uncertainty and weaknesses discussed, REDD+' implementation intentions have been indicated by 56 countries in their intended nationally determined contributions (INDC) submissions under the Paris agreement (Hein et al. 2018). Permanence, sequestration uncertainty, the availability of efficient financing mechanisms as well as monitoring, reporting and verification systems are all difficulties associated with forest-based abatement projects (Gren and Aklilu 2016). To enhance the effectiveness of forest-based abatement projects, improved financing mechanisms and better monitoring and reporting systems are required.

Biochar is stable and carbon negative

The process of capturing CO_2 through photosynthesis is a well-established natural process, but to make it a more effective solution for mitigating climate change, it needs to be integrated with technology. Combining tree planting with biochar or bioenergy carbon capture and storage (BECCS) makes it possible to extend the permanence of carbon sequestered by forests while derive additional benefits (Fig. 3). This approach can help to address some of the challenges associated with forest-based abatement projects, such as carbon leakage, verification, reporting and monitoring, as well as a capacity plateau. Biochar is a highly promising negative emissions technology that offers a unique way to capture atmospheric carbon and store it in a stable form for extended periods. This process involves the photosynthetic capture of carbon during plant growth, followed by a thermochemical conversion process that produces a solid carbonaceous material that is highly resistant to thermal and biological degradation and can persist for centuries to millennia. Biochar can then be safely stored in soils, building structures, and various carbon sinks, providing additional benefits depending on its final application (Fawzy et al. 2021, Osman et al. 2022, Monisha et al. 2022, Lin et al. 2023). Biochar's stability

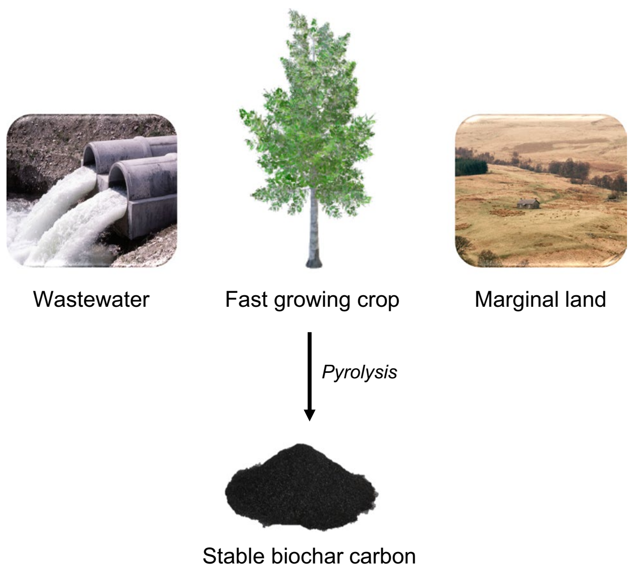

Fig. 3 Maximizing carbon removal through the integration of dedicated crops and technology. The figure illustrates the process of cultivating fast-growing crops on marginal land using wastewater, followed by biomass pyrolysis to produce highly stable carbon biochar. The resulting biochar is then stored in various carbon sinks, including soils, building structures, and other reservoirs, offering additional benefits depending on its intended use. By employing this approach, carbon removal can be maximized, resulting in substantial carbon sequestration and sustainable land use

and adaptability make it an appealing option for achieving carbon permanence and moving climate change mitigation efforts forward.

Bioenergy carbon capture and storage

Bioenergy carbon capture and storage (BECCS) is a promising negative emissions technology (IPCC 2018). This technology integrates biopower and carbon capture and storage to drawdown atmospheric CO_2 through biomass during growth, which is then utilized for energy production through combustion. CO_2 emissions generated during combustion are subsequently captured and stored in geological reservoirs (RoyalSociety 2018; Pires 2019). BECCS has been identified by the Intergovernmental Panel on Climate Change (IPCC) as a potential route to meeting temperature goals (IPCC 2018). This technology can significantly reduce greenhouse gas concentration levels by removing CO_2 from the atmosphere. The carbon dioxide removal potential of this technology varies within the literature; however, a conservative assessment by Fuss et al. presents an estimated range of 0.5–5 Gt CO_2 yr^{-1} by 2050 (Fuss et al. 2018). Regarding global estimates for storage capacity, the literature presents a wide range from 200 to 50,000 Gt CO_2 (Fuss et al. 2018).

Integrating dedicated crops and technology

The integration of tree planting, through the cultivation of fast-growing crops or short-rotation plantations, within a technological framework, such as biochar or BECCS, delivers a robust and effective carbon removal system that provides a variety of co-benefits (Fig. 3). Perhaps the most essential advantage is ensuring long-term carbon storage permanence. Additionally, this approach enhances land use efficiency since land is used in short cycles to sequester carbon, thereby overcoming the growth plateau issue associated with forestation. Moreover, this approach ensures the consistent biomass supply to biochar or BECCS projects, where costs are stable, and biomass quality is controlled. Finally, a dedicated carbon cropping system offers additional carbon sequestration potential via soil organic carbon throughout the plantation's lifecycle.

However, it's important to note that converting carbon-dense ecosystems into dedicated plantations can negatively affect greenhouse gas emissions through land-use change. Furthermore, competition with food production for resources such as land, nutrients, and water may be a significant disadvantage to dedicated biomass cultivation. To mitigate these issues, it's essential to use marginal lands and carry out cultivation in a sustainable manner, while utilizing resources that do not compete with food production systems (Fawzy et al. 2020).

References

Fawzy S et al (2020) Strategies for mitigation of climate change: a review. Environ Chem Lett 18:2069–2094. https://doi.org/10.1007/s10311-020-01059-w

Fawzy S, Osman AI, Yang H et al (2021) Industrial biochar systems for atmospheric carbon removal: a review. Environ Chem Lett 19:3023–3055

Fuss S et al (2018) Negative emissions—part 2: costs, potentials and side effects. Environ Res Lett 13:063002. https://doi.org/10.1088/1748-9326/aabf9f

Gren I-M, Aklilu AZ (2016) Policy design for forest carbon sequestration: a review of the literature. For Policy Econ 70:128–136. https://doi.org/10.1016/j.forpol.2016.06.008

Harper AB et al (2018) Land-use emissions play a critical role in land-based mitigation for Paris climate targets. Nat Commun 9:2938. https://doi.org/10.1038/s41467-018-05340-z

Hein J et al (2018) Deforestation and the Paris climate agreement: An assessment of REDD+ in the national climate action plans. For Policy Econ 90:7–11. https://doi.org/10.1016/j.forpol.2018.01.005

IPCC (2018) Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In: Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy

E, Maycock T, Tignor M, Waterfield T. Accessed 22 Dec 2019. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

Lin M, Li F, Li X et al (2023) Biochar-clay, biochar-microorganism and biochar-enzyme composites for environmental remediation: a review. Environ Chem Lett. https://doi.org/10.1007/s10311-023-01582-6

Monisha RS, Mani RL, Sivaprakash B et al (2022) Green remediation of pharmaceutical wastes using biochar: a review. Environ Chem Lett 20:681–704. https://doi.org/10.1007/s10311-021-01348-y

Osman AI, Fawzy S, Farghali M et al (2022) Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review. Environ Chem Lett 20:2385–2485. https://doi.org/10.1007/s10311-022-01424-x

Pires JCM (2019) Negative emissions technologies: a complementary solution for climate change mitigation. Sci Total Environ 672:502–514. https://doi.org/10.1016/j.scitotenv.2019.04.004

RoyalSociety 2018. Greenhouse gas removal. Accessed 28 Jan 2020. https://royalsociety.org/-/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf