How Fungi can Slow Climate Change:

Impact of Mycorrhizae on Terrestrial Carbon Sinks Under Elevated CO_2 Levels

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INTRODUCTION

Atmospheric CO_2 concentrations have risen 50%+ above pre-industrial levels since the mid-1700s, a trend that will continue to warm the Earth for thousands of years. This study explored the crucial role of mycorrhizal fungi in mitigating carbon capture, and investigates mycorrhizae's potential as a natural solution to slow global warming.

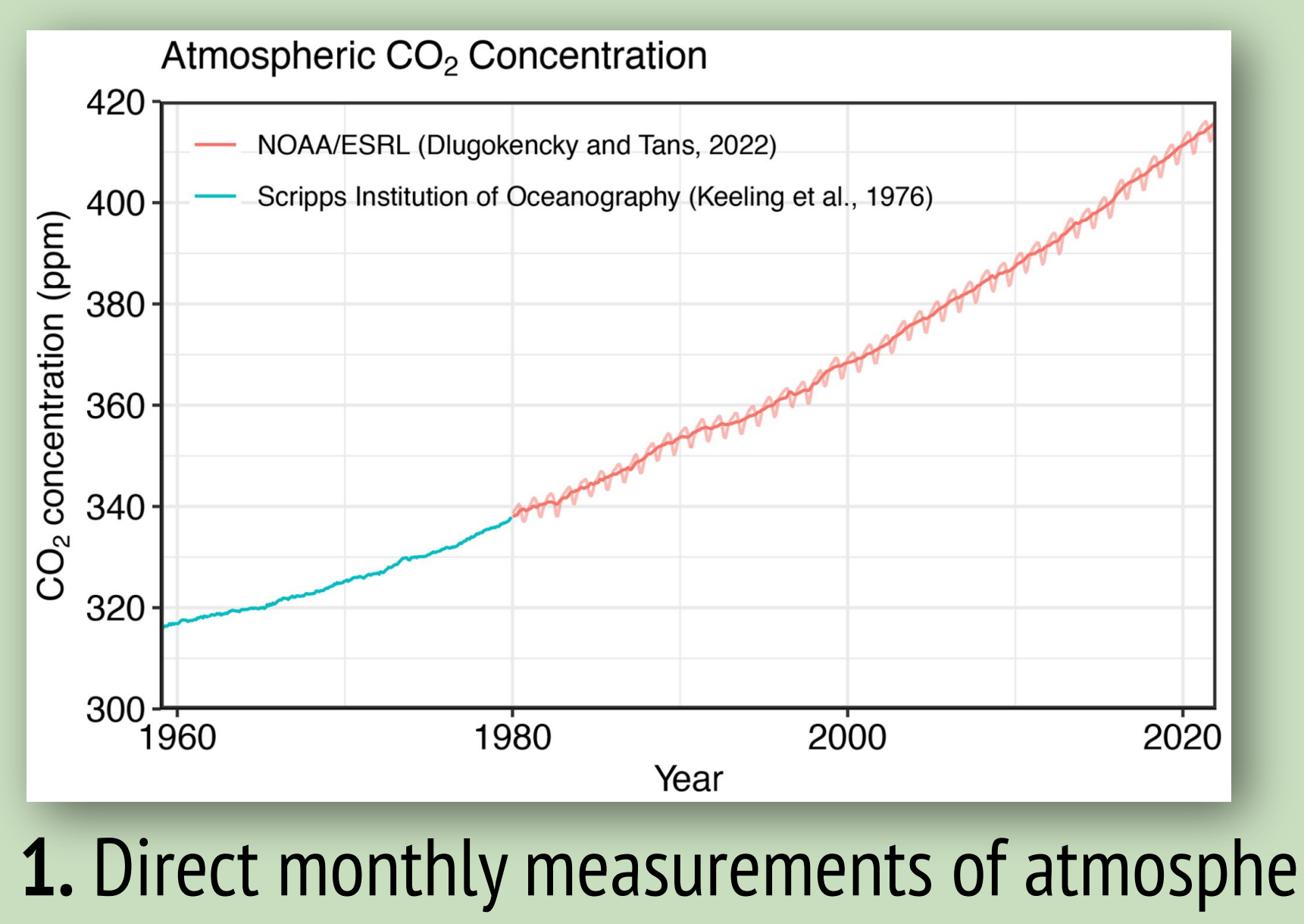

Figure 1. Direct monthly measurements of atmospheric CO_2 levels in parts per million (ppm) from 1958 to present. The rising level of greenhouse gas (GHG) emissions is the leading contributor to climate change. Data source: NOAA (2022)

BACKGROUND / HYPOTHESIS

Terrestrial carbon sink, or soils' ability to sequester carbon from the atmosphere, can mediate Earth's carbon cycle. Yet the amount of land is insufficient to keep up with anthropogenic emissions (Walker, 2020, p. 24).

Mycorrhizal fungi form symbiotic networks with plant roots and can enhance or diminish the Earth's giant soil organic carbon (SOC) pool of ~1,500 gigatons (Gt). Therefore, it is imperative to identify which mutualistic relationships can effectively increase the ecosystem's future land carbon sink.

Hypothesis: As CO_2 levels increase, certain mycorrhizae have the potential to sequester additional levels of carbon relative to most policy or technological offsets.

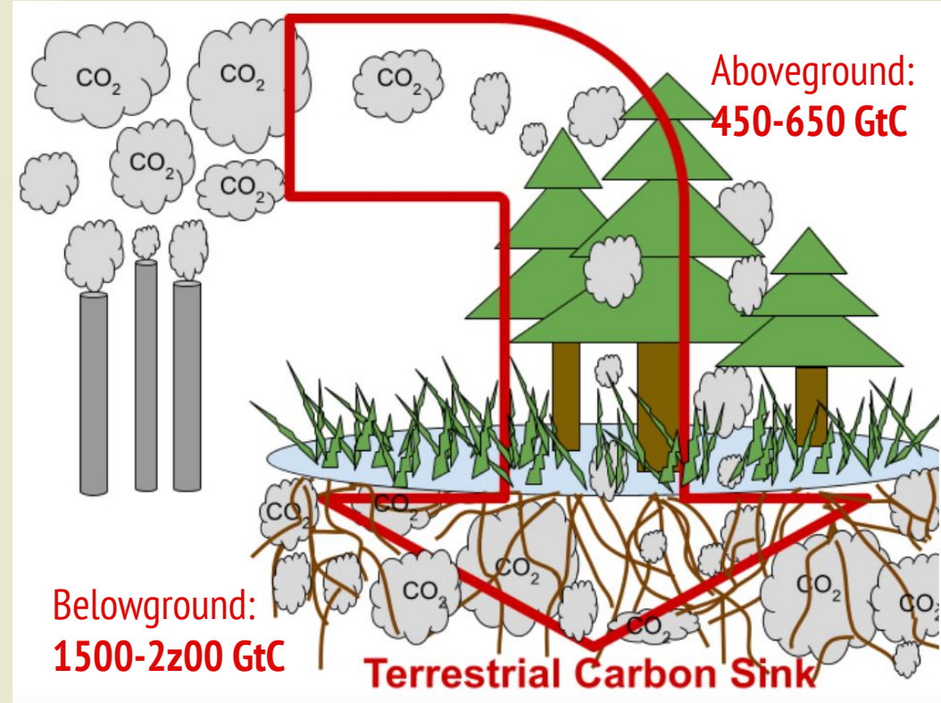

Figure 2. Terrestrial carbon sink's ability to store soil organic carbon (SOC) with increased atmospheric carbon dioxide (iCO_2) concentrations.

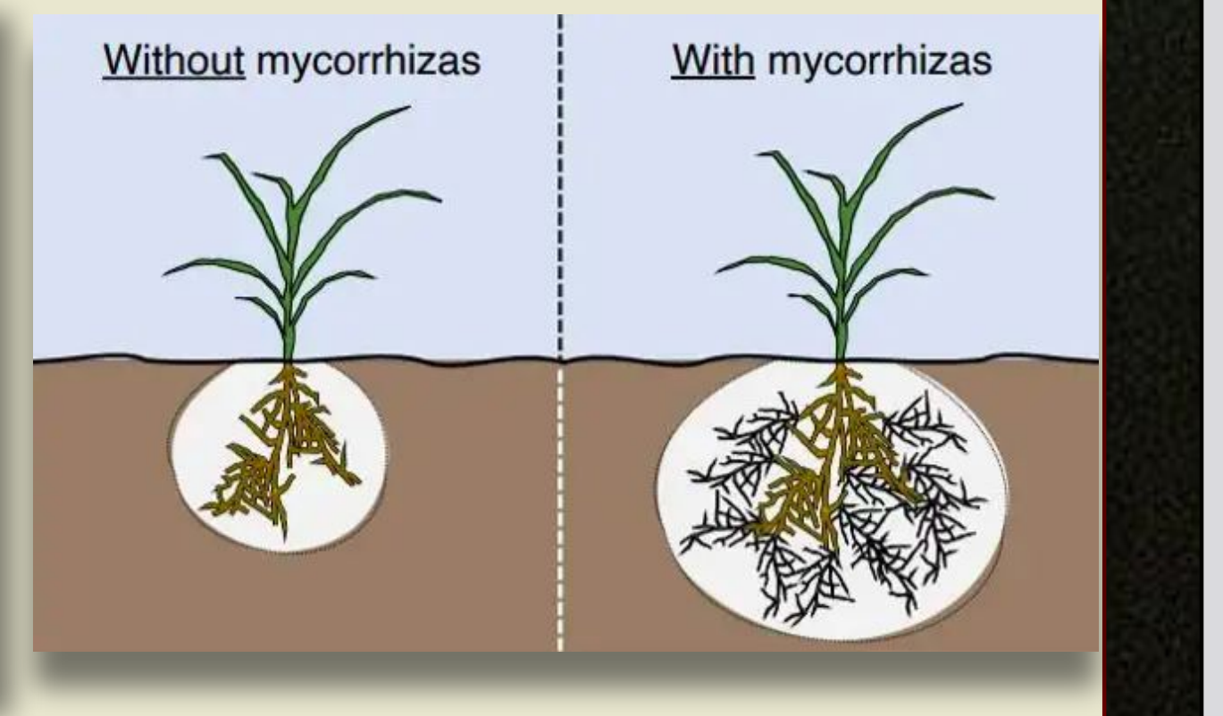

Figure 3. A plant colonized by mycorrhizal fungi reaches more soil and impacts SOC levels via biochemical interactions. Source: ECHO Asia Note # 43 (2020)

RESEARCH METHODOLOGIES

This study used R language for statistical computing to quantify the effect of each fungi-biome on soil organic carbon (SOC) levels. A meta-analysis of 123 global CO2-enrichment experiments focused on Arbuscular mycorrhiza (AM) and ectomycorrhiza (EcM), which colonize over 77% of vegetated biomes. Additionally, a multivariate regression was performed to predict the gains in SOC resulting from applying optimal fungi-biome combinations in ecosystem restoration.

Figure 4. CO_2 enrichment experiments where rings are pumping CO_2 into trees. These experiments are very expensive and require an enormous amount of infrastructure. Source: FACE Experiments (2020)

Biomes

Mycorrhizal Type	Shrubland	Cropland	Grassland	Temperate Forest	Tropical Forest	Alpine Forest	Subalpine Forest	Nutrient Strategy (Weighted Mean)
Arbuscular mycorrhiza (AM)	37.59%	7.812%	6.802%	14.24%	16.00%	N/A	N/A	12.579%
Ectomycorrhiza mycorrhiza (EcM)	-26.58%	N/A	N/A	-0.8071%	N/A	1.377%	-3.279%	-2.731%

Figure 5. A meta-analysis and multivariate regressions of 123 global CO2-enrichment experiments from the past three decades, ranging from weighted means of 372 ppm (ambient) to 616 ppm (elevated), revealed strong correlations between SOC levels and mycorrhizal types. Arbuscular mycorrhizal (AM) fungi symbioses showed the largest gains in SOC levels across different land types. In contrast, ectomycorrhiza (EcM) fungi symbioses showed no gain in SOC levels.

RESULTS / FINDINGS

Earth contains ~472 million hectares of abandoned agricultural land and ~2 billion hectares of deforested land. Simulation results from this study suggest that the inoculation of AM fungi during re-vegetation of these lands could increase soil carbon storage by weighted means of 12.6% or 118 grams per m^2, when CO_2 levels projected from 372 ppm (~year 2000) to 616 ppm (~year 2100). AM symbioses could offset anthropogenic emissions by 9.5 to 15 Gt CO_2 equivalent, lowering global temperatures by ~0.5°C.

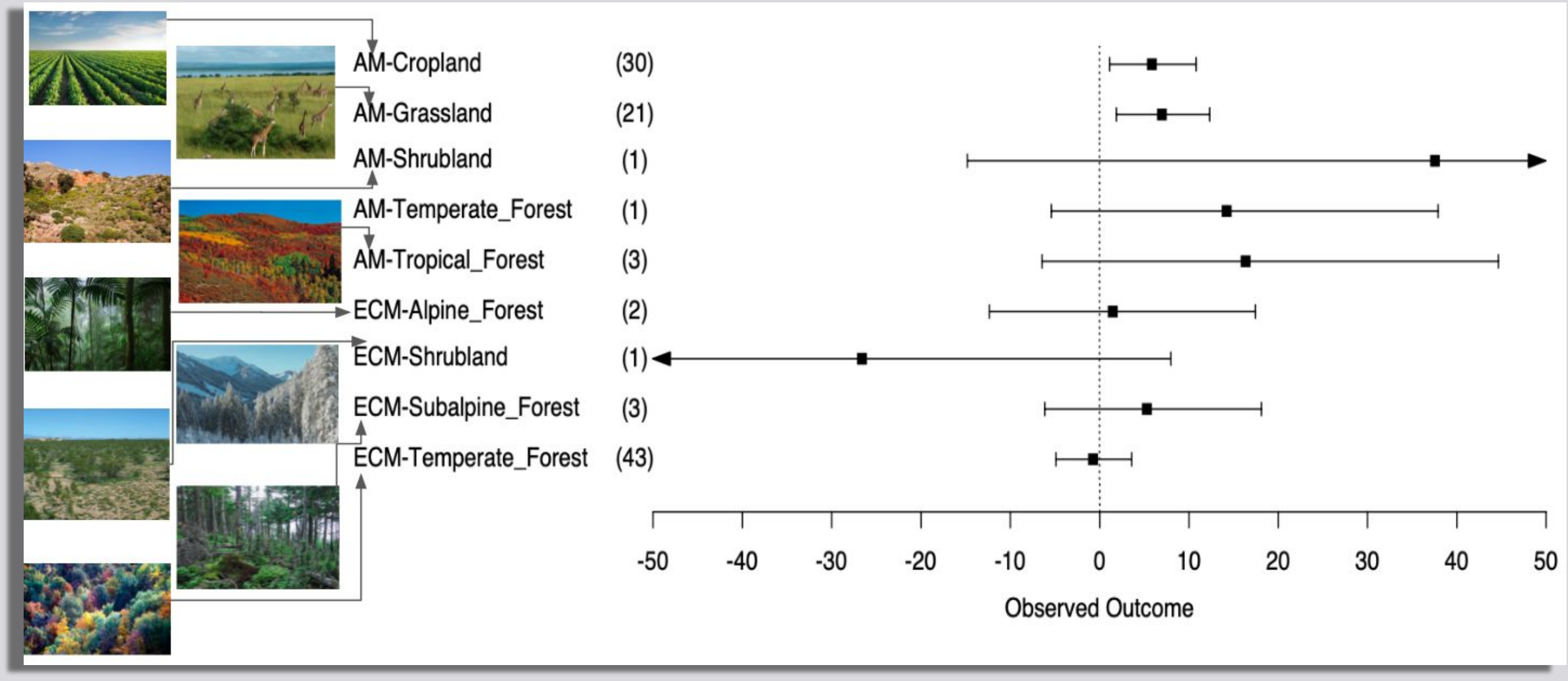

Figure 6. Meta-analysis of the effect of elevated CO_2 levels on % of SOC changes across each fungi-biome symbiosis. Plots illustrate overall mean and 95% confidence level. Arrows indicate confidence level beyond the plot limits. Numerical data in parentheses represent sample sizes.

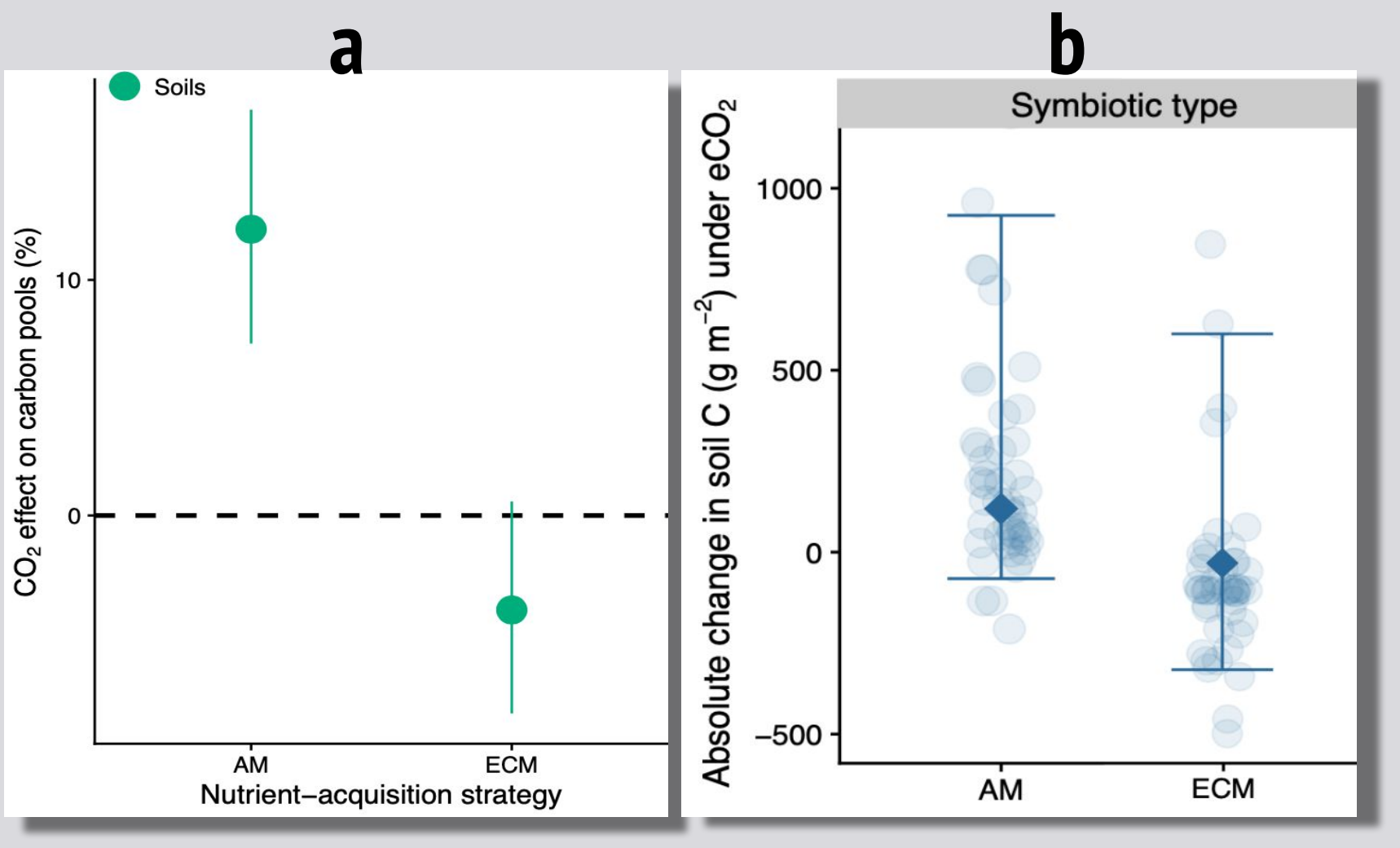

Figure 7. Multivariate regression shows the predicted SOC effect under iCO_2 (a) in relative terms (%) and (b) in absolute terms (grams per m^2). Dots in (a) represent overall effect size; in (b) the individual experiments with dot intensity are proportional to model weight.

Figure 8. Ecosystem restoration opportunities

Inoculating AM fungi during re-vegetation of ~472 million hectares of abandoned agricultural land and ~2 billion hectares of deforested land could offset anthropogenic emissions due to iCO_2 by 9.5 to 15 Gt CO_2 worldwide. At 9.5 Gt CO_2, this would be equivalent to removing all vehicles from the road for a year. At 15 Gt CO_2, it would mean not generating any electricity or heating for a whole year.

CONCLUSIONS

AM mycorrhizae have the potential to lower global temperatures by ~0.5°C naturally. AM shows significant promise in increasing the ecosystem's future land carbon sink to remedy the greatest global environmental threat.

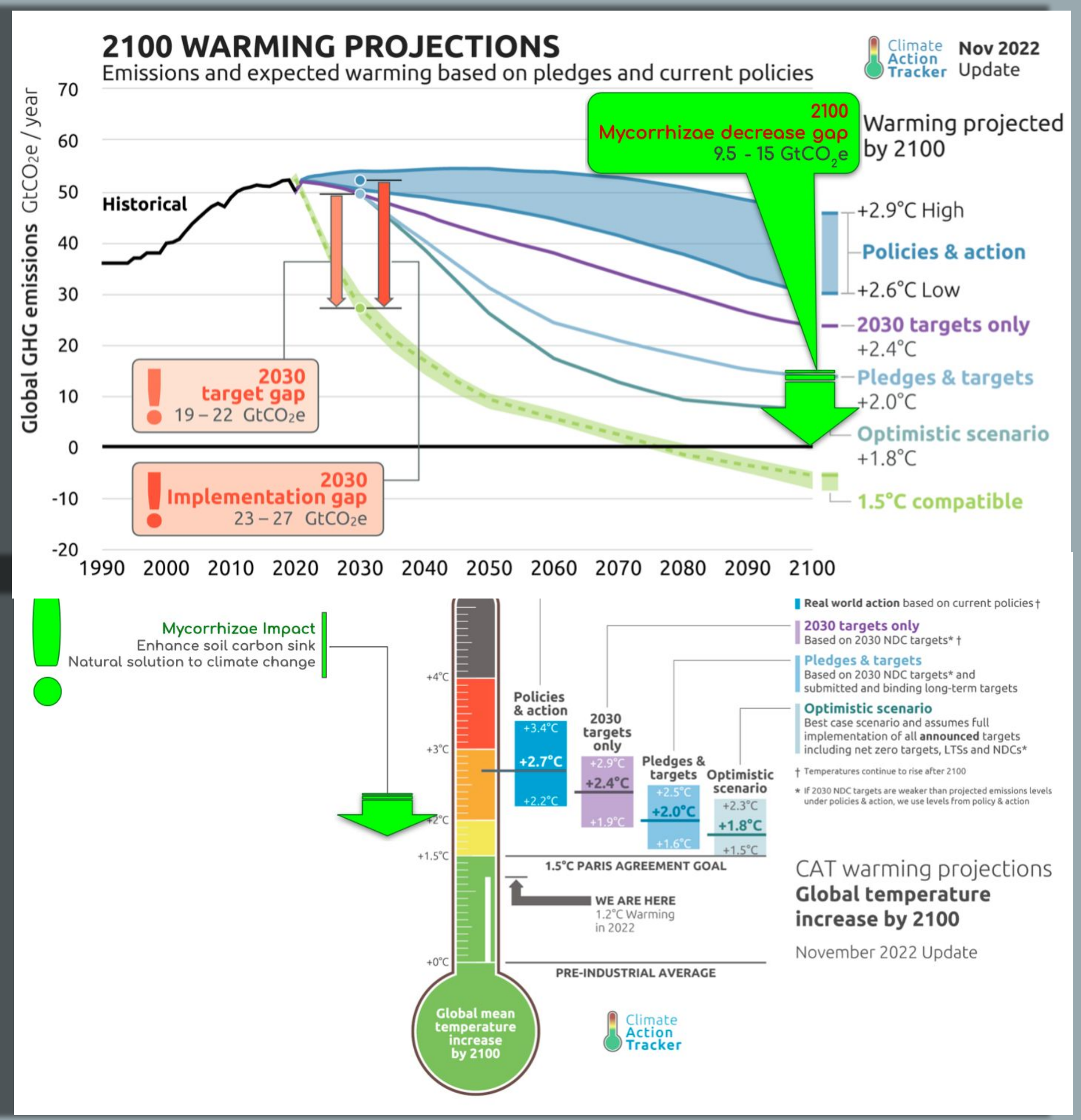

Figure 10. Impact of mycorrhizae on climate change. Source for 2100 Warming Projections: Climate Action Tracker 2022.

FUTURE WORK

The accuracy of the current model can be improved by incorporating additional CO_2 enrichment data when available, particularly from AM-Tropical Forest, AM-Temperate Forest, AM-Shrubland, ECM-Alpine Forest, ECM-Subalpine Forest, and ECM-Shrubland.

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