Potential Global Sequestration of Atmospheric CO_2 by Drylands Forestation

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Introductions

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Abstract: https://arxiv.org/abs/2205.10641 + Revisions

Potential Global Sequestration of Atmospheric Carbon Dioxide by Drylands Forestation

01 Carbon sequestration was studied in the planted Israeli Yatir forest, a 28 km^2 Aleppo pine forest growing at the semi-arid timberline.

02 Organic carbon sequestration rate was measured as 550 gram CO_2 $m^{-2}yr^{-1}$. By extrapolating to 30% of the global hot drylands area, 9.0 million km^2, we estimate a global organic sequestration rate of roughly **5.0 billion tons** CO_2 per year, after future global forestation.

03 Inorganic carbon (mainly calcite) precipitation rate was measured as 22 mg CO_2 $L^{-1}yr^{-1}$. CO_2 exhaled into the soil by tree roots is hydrated by soil water to produce mainly bicarbonate HCO_3^-, which combines with soil Ca^{2+} to precipitate calcite $CaCO_3$. Extrapolating as above, roughly **1.2 billion tons** of inorganic CO_2 could potentially be sequestered globally each year. An additional **0.8 billion tons** of CO_2 per year could potentially be precipitated each year in the soil as calcite, as a result of microbial activity in drylands.

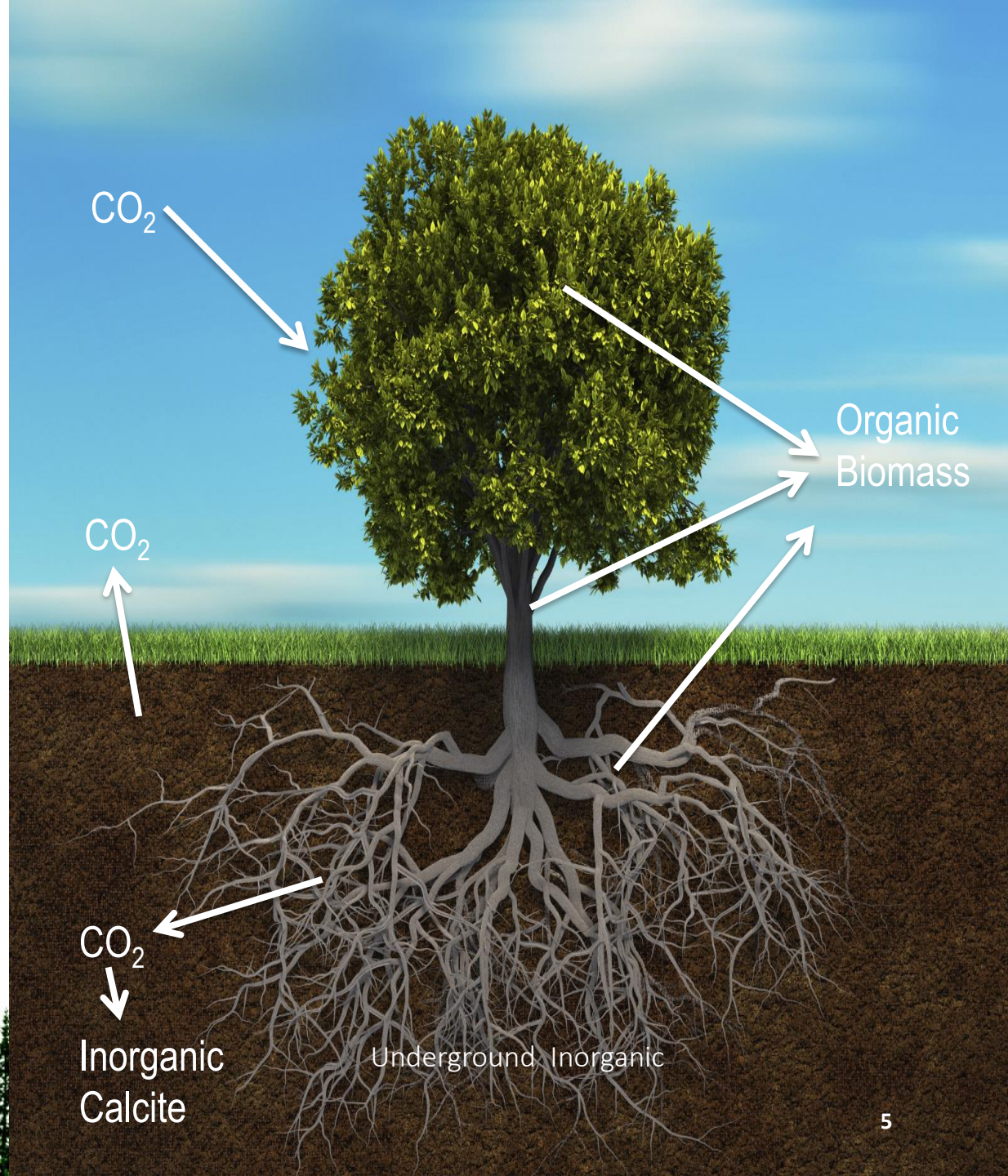
Details and references are given in arxiv 2205.10641 (MITI preprint).
Part of Rafat Qubaja forestry research was carried out as a member of Dan Yakir's Weizmann Institute Biogeochemistry Group.

AgroForestry

- Our version of Agroforestry focuses on drylands forests that produce wood, fruits, nuts, increase biodiversity, improve soil structure and health, reduce erosion, sequester carbon, produce oxygen, increase rainfall, improve water quality, and provide wildlife habitat. This agroforestry approach differs from land use management systems in which trees are grown around or among crops or pastureland.

Photosynthesis carbon sequestration

- Photosynthesis - Leaves inhale CO_2. Roots in semi-arid regions are deep, and also exhale CO_2 into USZ at high partial pressure
- $CO_2 + H_2O \rightarrow$ produces HCO_3^- bicarbonate, which combines with soil Ca^{+2}, to precipitate inorganic $CaCO_3$ (calcite salt) in the soil.
- These trees also sequester atmospheric CO_2 as organic biomass.



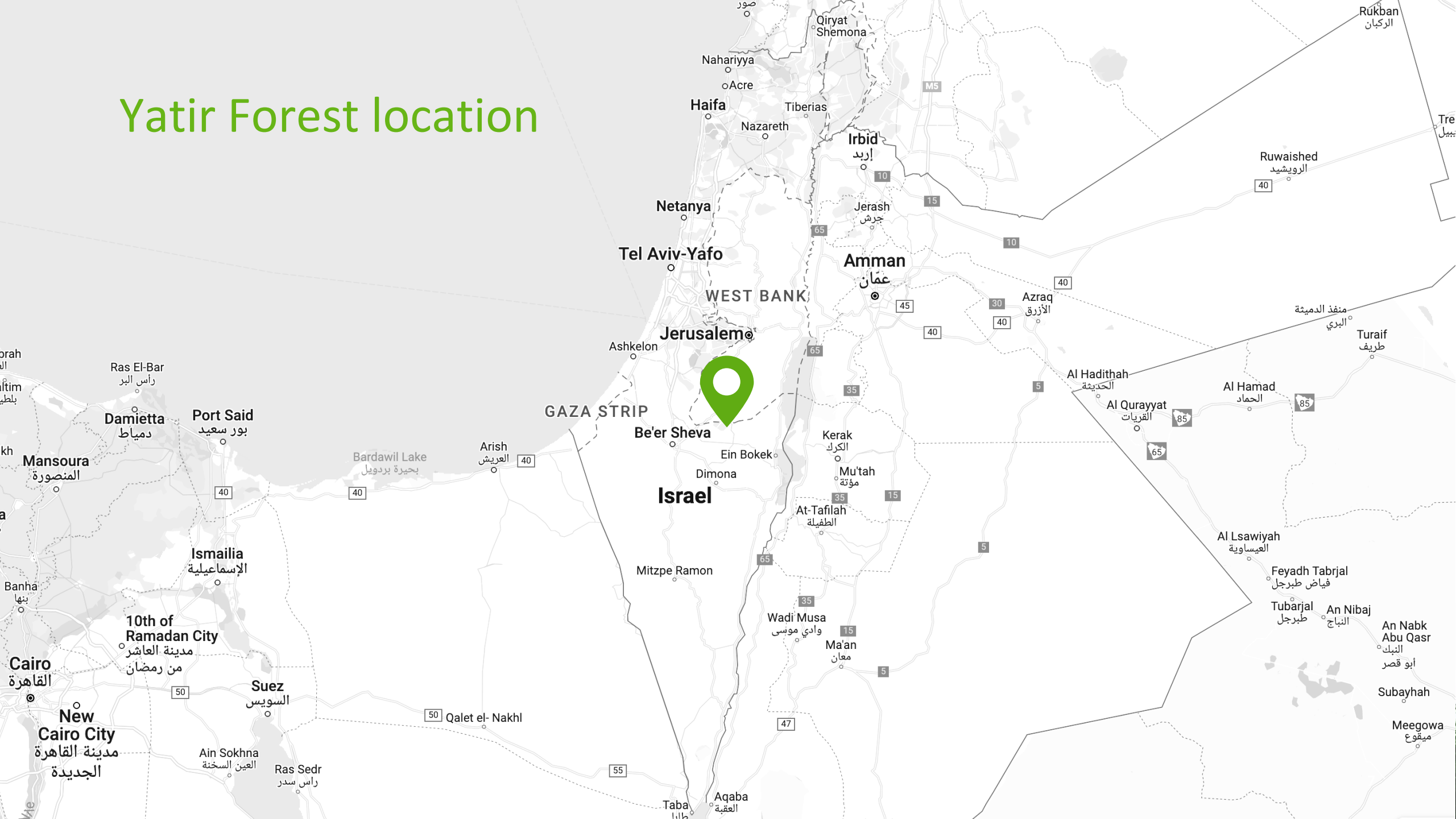
Tree Respiration and Calcite Precipitation

- During the day, the tree inhales air (CO_2, O_2, etc.) through the stomata. and uses CO_2 via photosynthesis to produce O_2 and $C_6H_{12}O_6$ glucose:
  $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. This sequesters atmospheric CO_2 in tree mass as **organic carbon**. Besides CO_2 sequestration, the trees release needed O_2.

- The tree's biological function releases CO_2 via the roots, in turn, to the soil zone:
  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$, building up high partial pressures of CO_2 in the soil gas.

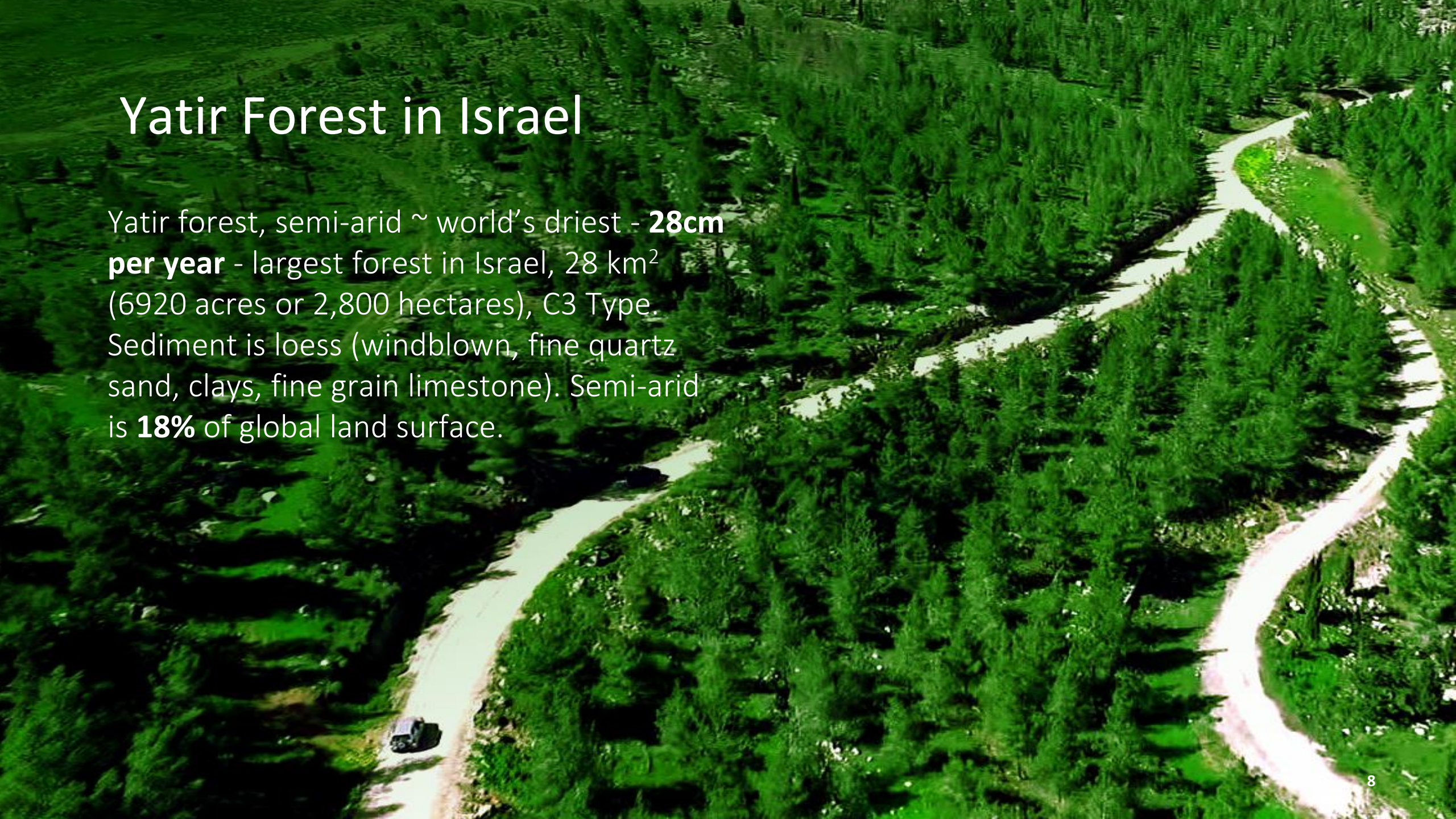
- Rain water percolating down interacts with the soil gas $CO_2 + H_2O \rightarrow$ forms HCO_3^- This bicarbonate combines with soil Ca^{2+}, to precipitate $CaCO_3$ (calcite). In temperate zones, this calcite redissolves. In semi-arid zones, the calcite can be stable for thousands of years as **inorganic carbon**.

Yatir Forest location



Yatir Forest in Israel

Yatir forest, semi-arid ~ world's driest - **28cm per year** - largest forest in Israel, 28 km^2 (6920 acres or 2,800 hectares), C3 Type. Sediment is loess (windblown, fine quartz sand, clays, fine grain limestone). Semi-arid is **18%** of global land surface.



Methods – Carbon stocks based NEP (NEP_{CS}) approach

The annual net storage of organic carbon in the land biosphere is known Net Ecosystem Production (NEP). It is the difference between gross carbon uptake and carbon loss. NEPCS was estimated at Yatir via Carbon Stock (CS) forest inventory counting, by keeping track over 15 years of standing biomass and litter (leaves, above and below ground wood), soil, and carbon removal due to mortality, thinning, and sanitation.

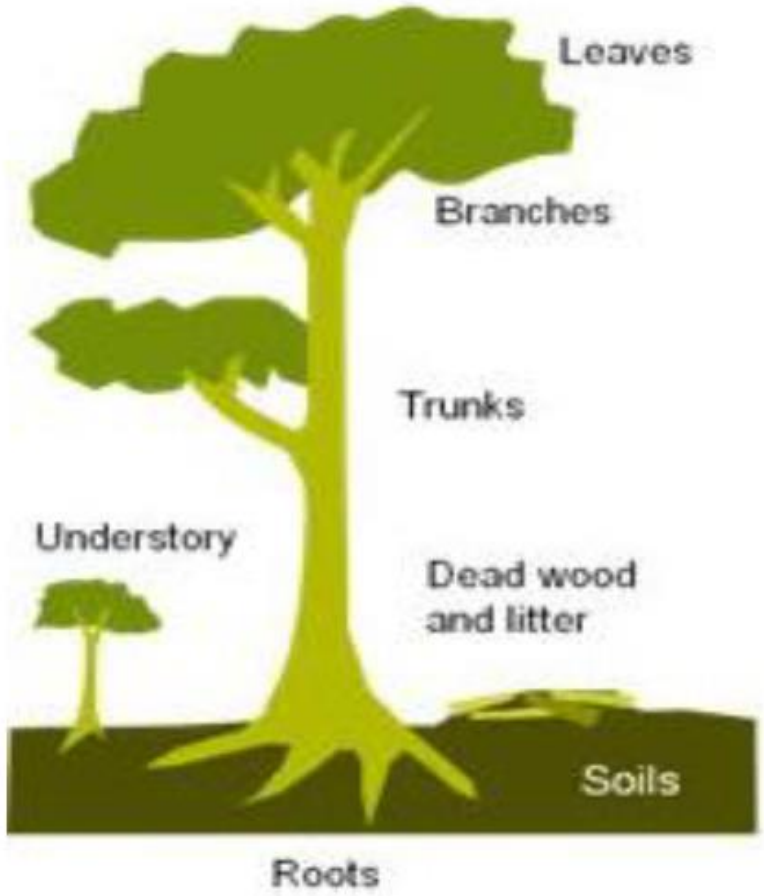
Methods – Carbon fluxes based NEP (NEP_{EC}) approach

Net Ecosystem Production (NEP) was also estimated at Yatir using an Eddy Covariance (EC) tower to measure soil and canopy emitted CO_2 gas over 15 years. The EC meteorological system measured the exchange of CO_2 between Yatir's soil and trees and the atmosphere.

Organic Carbon Sequestration Rate

Semi-arid organic carbon sequestration rate was thereby measured as 550 gram CO_2 $m^{-2}yr^{-1}$, by combination of EC and CS measurements, comparable (75%) to NEP in temperate climates. By extrapolating to 30% of the global hot drylands area, 9.0 million km^2, we estimate a global organic sequestration rate of roughly 5.0 billion tons CO_2 per year, after future global forestation.

Carbon Stocks



Global Extrapolation of Inorganic Carbon Precipitation in Forest Soil Sediment

- Consider sediment volume 1 km^2 & 6 m depth ($6x10^9$ L). Inorganic precipitation ~132 tons of CO_2 per year per km^2
- Extrapolating the hot drylands sequestration rate globally (to 9.0 million km^2) yields **~1.2 billion tons** inorganic CO_2/yr
- In addition, **soil microbes** in desert soils interact with penetrating atmospheric CO_2 , forming calcite (Liu 2020, Scheibe 2023) at the level of 100 mg yr^{-1} L^{-1}. Assuming 1 m as the global average depth of such microbial activity in drylands, extrapolating as above, roughly **0.8 billion tons** of CO_2 may be precipitated globally each year in the soil as calcite.

Fossil Groundwater

In many drylands areas, plentiful water is available from immediately underlying local paleowater (fossil) aquifers. Our estimate uses this water, doubling the functional dryland forestation area to at least 9.0 million km^2; thereby yielding a potential estimated total sequestration rate of ~7.0 Gt CO_2 yr^{-1}. This quantity removed from the atmosphere would also reduce ocean acidification. However, the global cooling effect would be partially offset by the reduction of a forest's land surface albedo. For a 7.0 Gt yr^{-1} total rate, the total CO_2 "equivalent" atmospheric cooling sequestration rate would be reduced to 5.0 Gt yr^{-1}. This corresponds to a significant 25% of the annual increase of 20 billion tons of CO_2 presently accumulating in the global atmosphere.

Maintain Albedo by Covering Forest Canopy with an active plastic radiative cooling sheet

- Cover trees with a plastic radiative cooling sheet designed to transmit photosynthesis effective wavelengths, reflect mid-infrared wavelengths back to space, cool ambient air temperature, and reduce water evaporation. Such a sheet has been designed (J. Li et al., PRCF Film, Nature Sustainability).

- Albedo is thereby Maintained

Carbon Sequestration

- Despite low precipitation, Yatir is productive and stores organic and inorganic carbon relatively effectively without irrigation or fertilization
- Inorganic sequestration = millennia; organic sequestration=centuries.
- Many rainfall deficient drylands areas often overlie large groundwater reserves of fossil water that can be exploited. (Examples: Nubian Sandstone Aquifer, Milk Aquifer, Great Artesian Aquifer Australia).
- Extrapolating Yatir rates to 30% of global hot drylands areas yields an estimated **total** sequestration rate of ***~7.0 billion tons CO_2/yr (***35% of annual increase).
- Our estimate demonstrates the global potential, the need for further measurements, and the need to begin implementing a global land management policy of widespread tree planting in semi-arid regions.

Advantages of carbon sequestration in Drylands Forests

- Extensive thickness of USZ (deep roots) compared to temperate regions – therefore greater active volume for inorganic sequestration.
- **Low rainfall precludes dissolving calcite**. **Yatir** receives only ~28 cm/yr rainfall. World's **driest and still healthy forest**.
- Drylands afforestation does not reduce food supply by decreasing productive temperate-region agricultural land
- **Organic Net Ecosystem Production is comparable (75%) to NEP in temperate climates.**
- Provide steady employment in economically depressed areas instead of marginal herding & agriculture
- **The forests provide** useful products (lumber, charcoal, off-sets, etc.); **and needed O_2**

Sequestration Summary

- **Global extrapolation (30%)** yields annual drylands sequestration rate of ***~7.0 billion tons CO_2/yr, organic plus inorganic, a respectable ~35% of rate of atmospheric CO_2 increase.*** **Inorganic carbon sequesterd very longer-term, organic ~150 years.**

- Forests may thereby **generate valuable annual carbon reduction credits**.

- **Need more data** to better characterize the potential global sequestration rate.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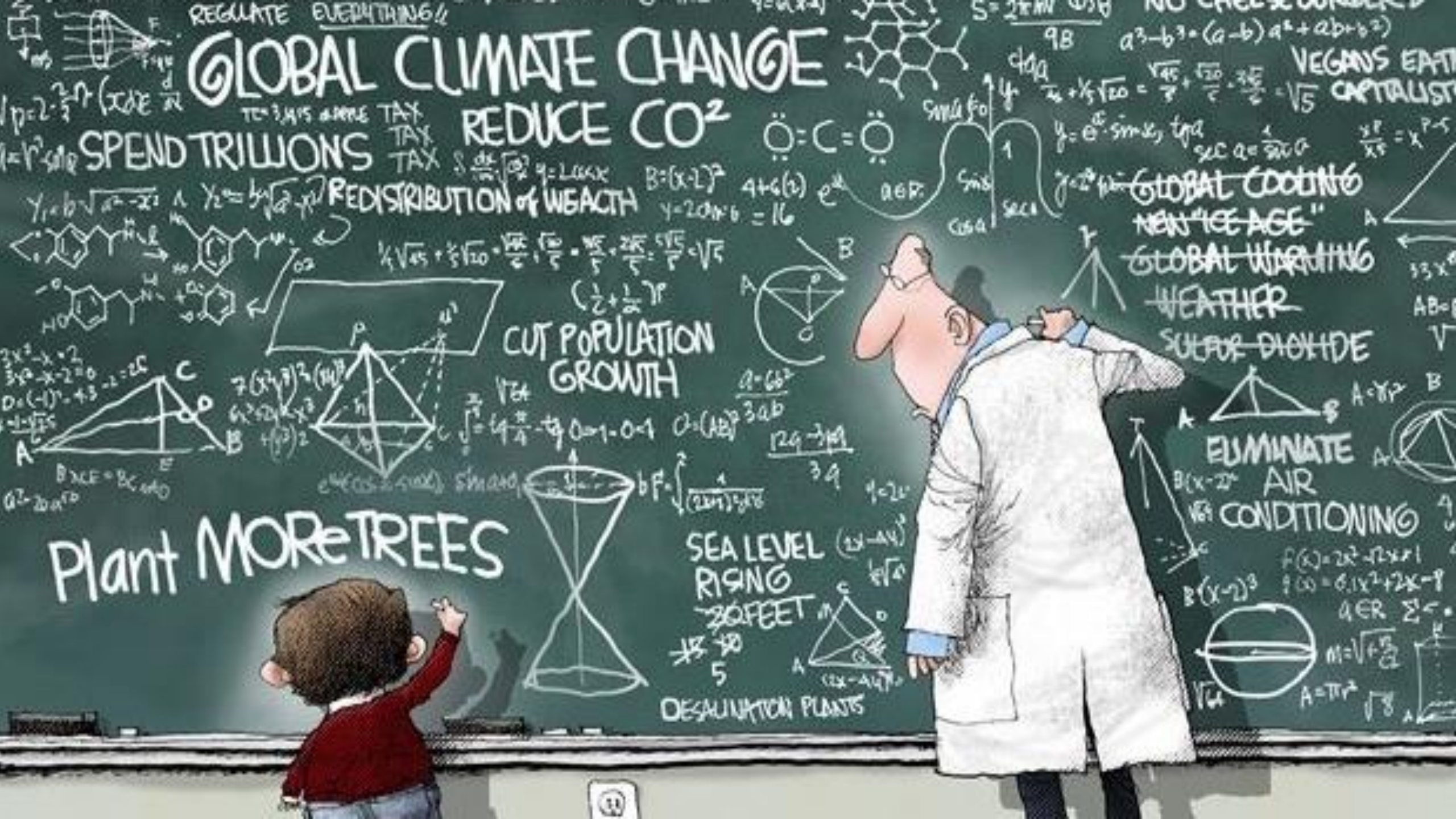
REGULATE EVERYTHING
GLOBAL CLIMATE CHANGE
SPEND TRILLIONS
TAX
TAX
TAX
REDUCE CO^2
REDISTRIBUTION OF WEALTH
CUT POPULATION GROWTH
Plant MORE TREES
SEA LEVEL RISING
30 FEET
DESALINATION PLANTS
GLOBAL COOLING
"NEW ICE AGE"
GLOBAL WARMING
WEATHER
SULFUR DIOXIDE
ELIMINATE
AIR CONDITIONING
VEGANS
CAPITALIST