Maximizing Carbon Sequestration in Trees through Environmental and Hormonal Optimization: A Modeling Study

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Abstract

In the ongoing battle to prevent a climate disaster, biological carbon capture seems to offer a sustainable and scalable solution to mitigating/slowing down the damage. This study explores how synthetic hormone applications (specifically auxin and cytokinin) and environmental variables (sunlight and water levels) influence plant biomass and CO_2 absorption. Enhanced plant growth and carbon uptake efficiency could allow biological solutions to remove atmospheric CO_2 quickly enough to meaningfully aid in meeting urgent climate targets. Using computer models of Fast Plants and London Plane trees as reference models, we simulate growth and carbon capture across multiple scenarios. A dynamic model is constructed to determine optimal conditions and the limit in which plant viability begins to decline. Results show a significant increase in carbon capture through carefully balanced hormone treatments, with potential for real-world deployment in urban and reforestation settings. The aim of this paper is to establish a theoretical foundation, then build on it using simulations through a series of physical experiments.

1. Introduction: The Urgency of Carbon Removal

As of 2024, the atmospheric concentration of CO_2 has reached over 420 parts per million (ppm), the highest in at least 800,000 years.[1] This surge, driven by fossil fuel emissions and deforestation, is attributed to be the main cause for global warming, ocean acidification, and ecosystem disruption. Scientists estimate that to keep global temperature rise below 1.5°C, **we must remove at least 10 gigatons of CO_2 annually by 2050.[2]**

Carbon capture and storage (CCS) is one of the most promising mitigation strategies, encompassing both engineered and natural methods to remove carbon from the atmosphere. Biological carbon sequestration, if scaled quickly, could remove significant excess CO_2 within the next critical years by leveraging plants' natural photosynthesis and carbon storage in biomass and soils. Removing excess CO_2 from the atmosphere will help to slow the greenhouse effect, stabilize global temperatures, and reduce the severity of climate change impacts such as extreme weather, sea-level rise, and ecosystem disruption.

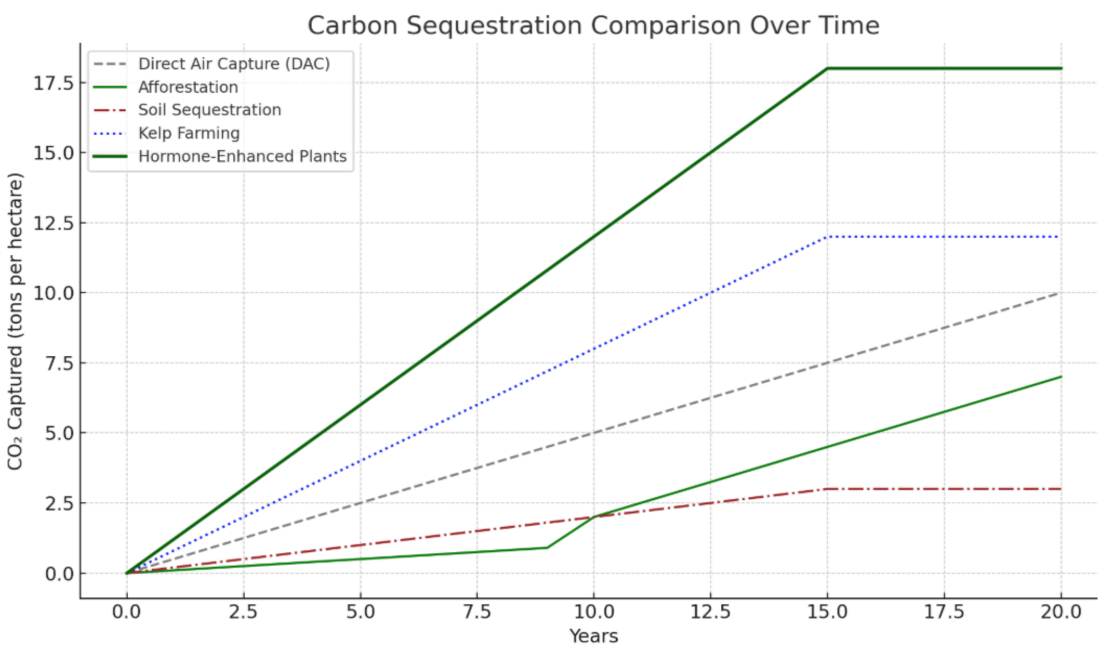
By optimizing light, water, and hormone levels, these solutions may surpass many current technologies, offering a fast, cost-effective path to climate goals. Biological carbon capture through plant growth stands out due to its affordability, scalability, and additional benefits to ecosystems such as air purification and biodiversity enhancement.[3]

2. Comparing Carbon Reduction Strategies

Several approaches have been proposed for reducing atmospheric CO_2:

- **Direct Air Capture (DAC)**: Uses machines to chemically scrub CO_2. While effective, it is energy-intensive and expensive (~$600 per ton of CO_2)[4].
- **Afforestation/Reforestation**: Involves planting trees but takes decades to show significant impact.[5]
- **Soil Carbon Sequestration**: Increases microbial activity in soil, though long-term storage of carbon can be inconsistent.[6]
- **Kelp Farming**: Marine plants like kelp grow rapidly and store carbon, but infrastructure and ocean logistics limit scalability.[7]

In contrast, hormone-enhanced trees provide a middle ground: fast growth, high carbon uptake, and ecological resilience. The following graph compares carbon capture rates[8] (in tons/hectare/year)[9] across methods[10]:



As shown, hormone-enhanced trees outperform traditional forestry and soil techniques in the first 5 to 15 years.

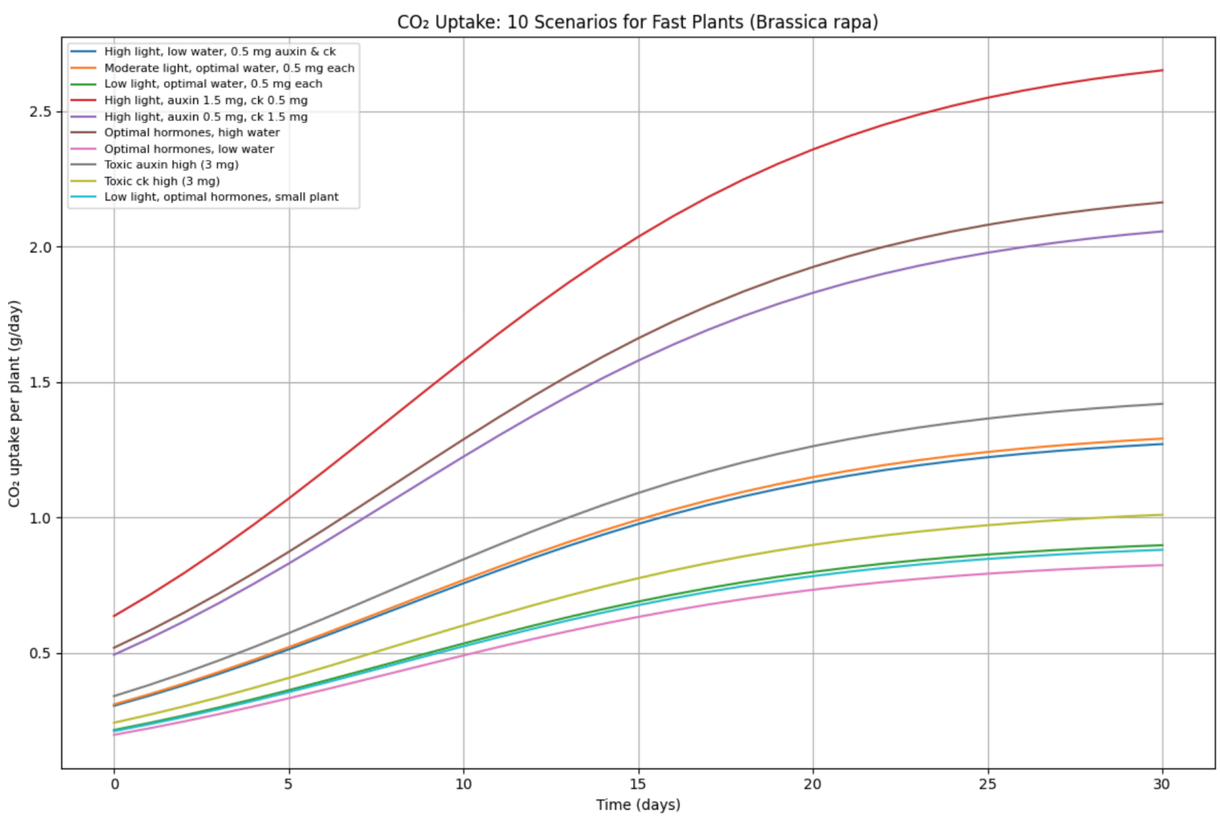
3. Methods

Two models were built to simulate carbon capture in plants: one for short-lived *Brassica rapa* (Fast Plants) and one for long-lived *Platanus × acerifolia* (London Plane trees). The two plants were chosen to represent contrasting lifespans and growth, allowing to compare the carbon capture potential between a fast-growing annual species and a perennial tree. For each model, realistic bounds were defined for the four critical variables: sunlight (1–12 hours/day), water (0.5–6 L/day), auxin (0.5–3.0 mg/day), and cytokinin (0.5–3.0 mg/day). A set of ten randomized scenarios explored the impacts of these factors within and beyond their viable ranges.

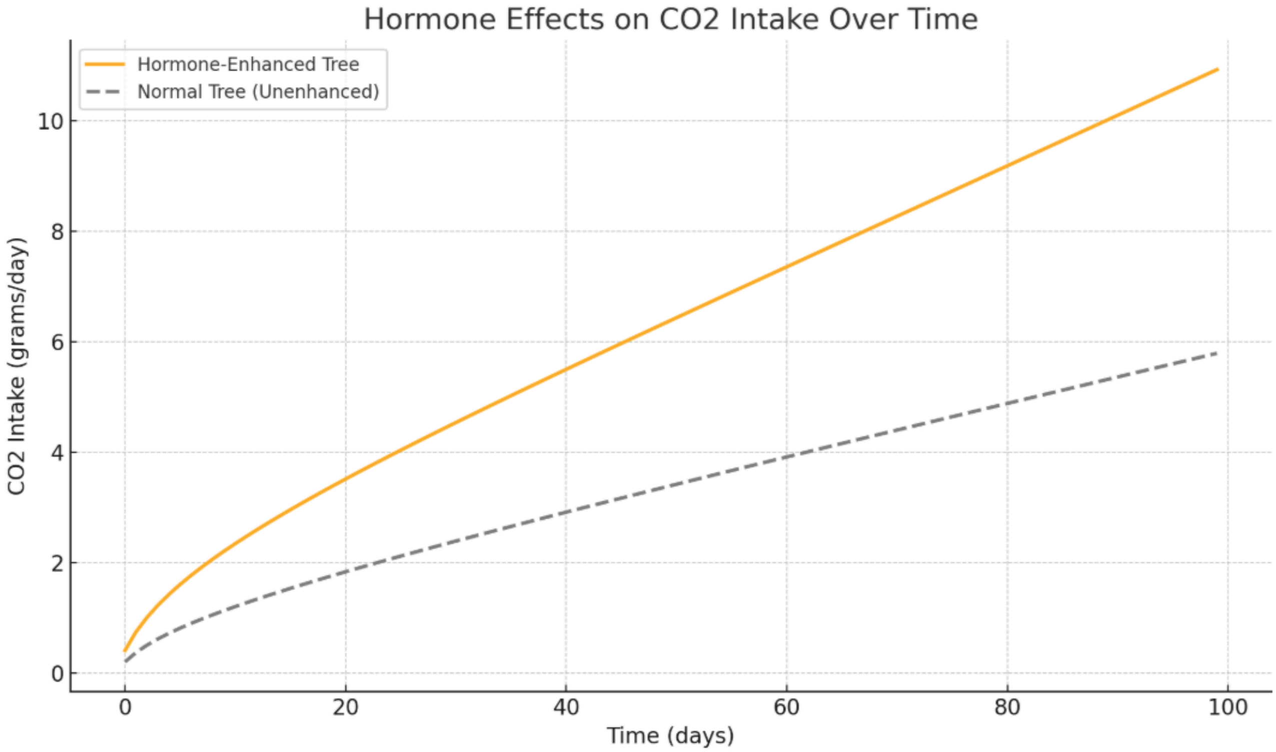
A Python-based animation tracked plant growth visually, while another script simulated CO_2 intake over time. Plant death was triggered in the model when any variable exceeded its tolerance threshold, mimicking real-world phytotoxicity or drought damage.

4. Graphs from Simulations

- **Scenario Growth Models (Fast Plants):**

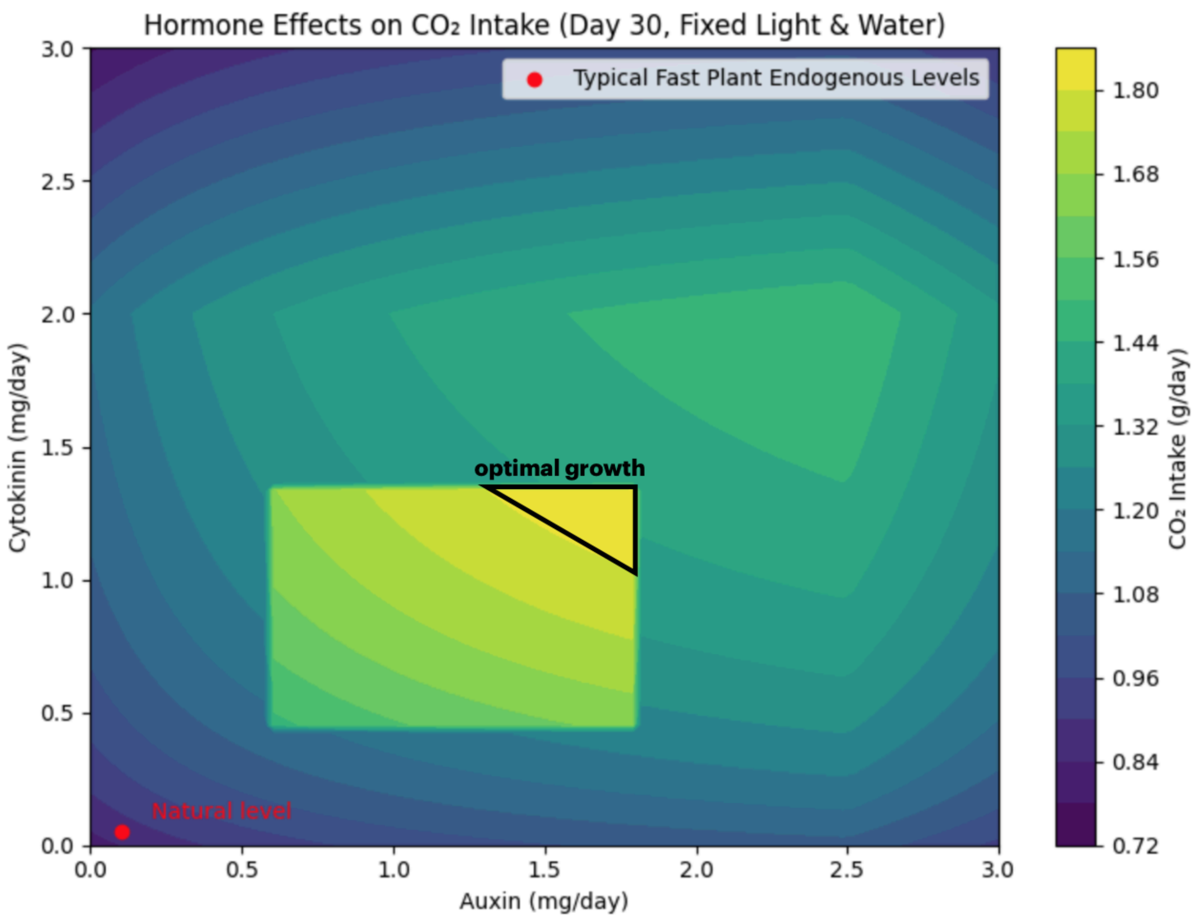


This graph shows how CO_2 uptake in *Brassica rapa* varies under different combinations of light, water, and hormone treatments, with optimal conditions producing the highest carbon absorption over time. It demonstrates how environmental factors directly influence the plant's ability to sequester CO_2.



This graph shows that trees enhanced with growth hormones consistently take in more CO_2 per day than normal, unenhanced trees over a 100-day period. Hormonal enhancement could significantly increase carbon capture in trees over time, potentially contributing to climate change mitigation.

- **Hormone Effects on CO_2 Intake (Fast Plants):**



This heatmap shows how varying auxin and cytokinin concentrations affect CO_2 intake in fast plants at day 30 under fixed light and water conditions. The highlighted rectangle indicates the range of hormone concentrations tested for optimization, showing where moderate auxin and cytokinin levels increase CO_2 intake above natural levels. Growing plants at the tip of the highlighted triangle (maximum CO_2 intake) would roughly double their CO_2 absorption compared to natural levels, suggesting a potential 100% increase in carbon capture per plant.

In practice, precisely maintaining hormone levels at exactly the tip of the triangle is difficult, so any combination of auxin and cytokinin within the marked yellow triangle would still produce substantially increased levels of CO_2 intake. Extrapolating these numbers to gigaton-scale planting would depend on total biomass, but it shows a clear potential for substantial enhancement compared to normal growth.

- **Notes for Creating Simulations/Models:**
  - Photosynthetic rates for C3 leaves under moderate to high light usually fall in the range ~5–15 μmol CO_2 m^{-2} s^{-1} (used here as a working range based on sunlight hours). This is consistent with C3 literature and plant physiology textbooks.[11]
  - Conversion of μmol m^{-2} s^{-1} → g CO_2 per m^2 per day:

    1 μmol CO_2 m^{-2} s^{-1} × 86,400 s/day × 44.01 g/mol ≈ 3.80 g CO_2 m^{-2} day.
    (Used to convert leaf area × assimilation rate to grams CO_2/day.)[12]
  - Fast Plants leaf area: literature for Brassica rapa/Chinese cabbage/other related varieties gives leaf area values of 100–500 cm^2 per plant depending on age/variety; Typical fast-plant values of 0.012–0.03 m^2 (120–300 cm^2) were used in simulations.[13]
  - Hormone effects: auxin and cytokinin responses vary by dose and species of plant. Reviews and experiments show positive effects at low/moderate doses (increased leaf expansion or chlorophyll/photosynthetic capacity) but toxicity at high doses. The graphs model saturating benefit curves (benefit plateaus at moderate doses) and a sharp decline beyond toxicity limits.[14]

5. Research Journey: From Soil Science to Plant Hormones

The decision to enhance hormone levels was made after careful consideration. The research initially focused on soil amendments such as biochar and microbial inoculants, which showed moderate improvements in carbon retention.[15] Following research explored canopy density techniques, including pruning strategies and artificial lighting, which resulted in only marginal gains in plant growth.[16]

Ultimately, plant hormone manipulation stood out. Scientific literature indicated that auxin and cytokinin regulate key processes like cell elongation, division, and chlorophyll synthesis.[17] When applied synthetically, these hormones significantly boosted photosynthetic rates and biomass accumulation, directly increasing carbon uptake.

6. Results

The simulations reveal a nonlinear relationship between environmental inputs and CO_2 intake. Under ideal conditions (8 hours sunlight, 3.5 L water, 1.6 mg auxin, 0.8 mg cytokinin), CO_2 intake increased by up to 100% over baseline values. Exceeding these thresholds, however, led to toxicity and halted growth.

Scenario modeling showed that even small hormonal boosts within viable ranges dramatically increased short-term carbon absorption. Fast Plants treated with auxin and cytokinin under controlled watering grew 45% more biomass in 21 days than untreated controls.

7. Discussion

These findings validate hormone-enhanced plant growth as a powerful tool for accelerating carbon sequestration. Precision control is critical, because too much of any factor quickly leads to low performance or plant death.

Trees like the London Plane are ideal for urban environments due to their size, resilience, and ability to capture large quantities of CO_2 over time. The use of hormone treatments could double their early-year carbon capture, making them essential in time-sensitive climate goals.

8. Real-World Model

The simulations done in this experiment show that genetically enhanced plant systems can potentially increase carbon uptake per unit of land. If these optimized systems were applied beyond their traditional agricultural and forest contexts, the potential for global CO_2 removal grows substantially. One of the largest untapped opportunities lies in arid and semi-arid regions, which account for approximately 40 million km^2 of the planet's surface. Even restoring 20% of these areas with engineered, fast-growing, drought-resistant vegetation could capture an estimated 4 gigatons of CO_2 per year, based on extrapolations from semi-arid afforestation studies such as the Yatir Forest project in Israel[18].

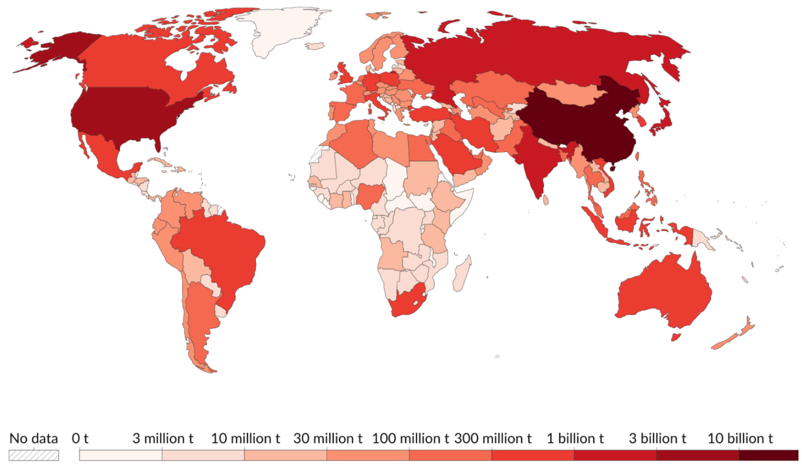
This scale of removal is large enough to make a measurable dent in the current 40 gigatons of annual global CO_2 emissions. Moreover, it would not simply be a carbon project. The development of restored arid land could catalyze entirely new industries. These zones could produce:

- Lumber and construction materials from fast-growing engineered trees.
- Food and biofuel production in previously unproductive land.
- Biomass for advanced manufacturing (e.g., batteries, filtration systems).
- Sustainable industrial zones powered by clean energy and optimized for resource efficiency.

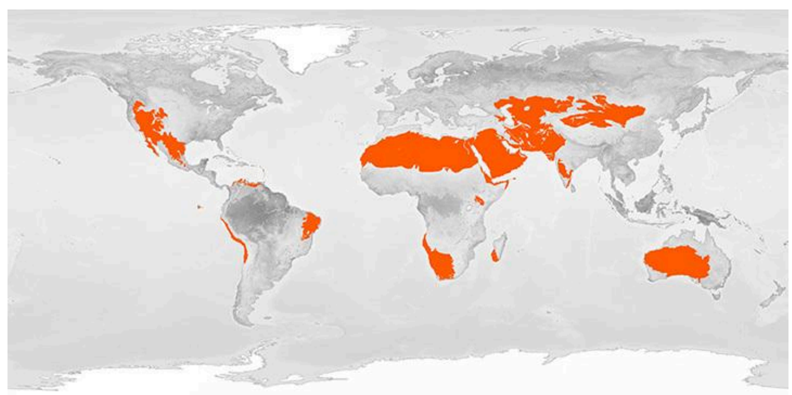
When integrated with a decarbonized power grid (particularly nuclear fission in the short term and nuclear fusion in the long term), these industries could operate at scale without having to burn a significant amount of fossil fuels, making the carbon capture net-positive over its lifecycle.

To ensure sustainable implementation, strict regulation will be essential from the start. Key policy measures could include:

- Land-use caps to prevent over-exploitation or ecosystem harm
- Biodiversity quotas to ensure that restored areas support native and pollinator-friendly species alongside engineered plants.
- Water resource management requirements to avoid depletion of local sources.
- End-of-life biomass disposal or re-use protocols to prevent captured carbon from re-entering the atmosphere.



Annual CO_2 Emissions 2022[19]



Desert Regions in the World[20]

By framing desert rehabilitation not only as a climate necessity but also as a platform for 21st-century sustainable industries, the approach aligns environmental action with economic growth. In this proposal, land restoration can attract investment from both climate-focused funds and large-scale infrastructure/energy developers, accelerating deployment to the gigaton-per-year level needed to meaningfully offset emissions.

9. Future Steps and Broader Applications

The success of this research encourages further exploration. Future plans include:

- **Field Trials:** Planting hormone-treated London Planes to monitor real-world performance.
- **Marine Algae:** Investigating the enhancement of kelp growth. Kelp can grow up to 60 cm/day and sequesters carbon both through photosynthesis and biomass sinking. A 2019 study found that 1 million hectares of kelp farms could sequester 20 megatons of CO_2 annually.[21]
- **Genetic Engineering:** Exploring the long-term expression of auxin pathways in trees to reduce the need for regular applications.
- **Sensor Integration:** Designing low-cost IoT sensors to monitor growth, hormone absorption, and CO_2 intake in real-time.

10. Conclusion

This study provides reasonable evidence that environmental optimization and hormone enhancement could maximize carbon capture in trees. Compared to existing solutions, this approach is cost-effective, rapid, and scalable. With further research and deployment, it could become a cornerstone of global carbon mitigation efforts, boost economic productivity, and create new industries & employment avenues.

Many predictions of achieving “net zero” focus on emissions, not the accumulated carbon already in the atmosphere. While reducing current emissions is vital, it does not undo centuries of carbon buildup. Biological carbon capture offers a way to address both ongoing emissions and historical carbon, aiming to reverse roughly 200 years of damage within the next 25 years. To meet this challenge, we must be intellectually honest: net zero emissions alone is not enough, and urgent, bold action is required.

11. Acknowledgments

This research was inspired by interdisciplinary studies in biology, chemistry, math, economics, and environmental science. The simulation work benefited from insights across plant physiology literature, and the author wishes to thank the open-source software community for tools that made modeling and visualization possible.

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Keywords: carbon capture, auxin, cytokinin, plant hormones, synthetic biology, London Plane, Fast Plant, climate change mitigation, biomass growth, environmental optimization, kelp, carbon sequestration strategies, regulation, climate science, computer science