Biological carbon cycling and biosequestration by terrestrial plants
Global terrestrial carbon uptake and storage

GPP $\approx$ 120 Gt C yr$^{-1}$

Plant Respiration $\approx$ 60 Gt C yr$^{-1}$

Decomposition $\approx$ 50 Gt C yr$^{-1}$

Disturbance $\approx$ 9 Gt C yr$^{-1}$

Short-Term Carbon Uptake

NPP $\approx$ 60 Gt C yr$^{-1}$

Medium-Term Carbon Uptake

NEP $\approx$ 10 Gt C yr$^{-1}$

Long-Term Carbon Uptake

NBP $\approx$ 1-2 Gt C yr$^{-1}$

Adapted from Science 280, 1393-94
Global terrestrial carbon uptake and storage

GPP \approx 120 \text{ Gt C yr}^{-1} \quad \text{Plant Respiration} \quad \approx 60 \text{ Gt C yr}^{-1}

\begin{align*}
\text{Decomposition} & \approx 50 \text{ Gt C yr}^{-1} \\
\text{Disturbance} & \approx 9 \text{ Gt C yr}^{-1}
\end{align*}

- Short-Term Carbon Uptake
  - NPP \approx 60 \text{ Gt C yr}^{-1}

- Medium-Term Carbon Uptake
  - NEP \approx 10 \text{ Gt C yr}^{-1}

- Long-Term Carbon Uptake
  - NBP \approx 1-2 \text{ Gt C yr}^{-1}
Global annual NPP

\( (g \text{ C m}^{-2}\text{y}^{-1}) \)

Field et al. 1998 Science 281: 237-240
## Annual NPP of the major units of the biosphere

<table>
<thead>
<tr>
<th>Ocean NPP (Pg C)</th>
<th>Land NPP (Pg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oligotrophic</td>
<td>Tropical rainforests</td>
</tr>
<tr>
<td>Mesotrophic</td>
<td>Broadleaf deciduous forests</td>
</tr>
<tr>
<td>Eutrophic</td>
<td>Broadleaf and needleleaf forests</td>
</tr>
<tr>
<td>Macrophytes</td>
<td>Needleleaf evergreen forests</td>
</tr>
<tr>
<td></td>
<td>Needleleaf deciduous forest</td>
</tr>
<tr>
<td></td>
<td>Savannas</td>
</tr>
<tr>
<td></td>
<td>Perennial grasslands</td>
</tr>
<tr>
<td></td>
<td>Broadleaf shrubs with bare soil</td>
</tr>
<tr>
<td></td>
<td>Tundra</td>
</tr>
<tr>
<td></td>
<td>Desert</td>
</tr>
<tr>
<td></td>
<td>Cultivation</td>
</tr>
</tbody>
</table>

| Total           | 56.4             |

Modified from Field et al. 1998 Science 281: 237-240
Global terrestrial carbon uptake and storage

Adapted from Science 280, 1393-94
Global terrestrial carbon uptake and storage

$\text{CO}_2$

GPP $\approx 120 \text{ Gt C yr}^{-1}$

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Long-Term Carbon Uptake

NBP $\approx 1-2 \text{ Gt C yr}^{-1}$
The concentrations of gases (e.g., CO$_2$, H$_2$O, CH$_3$, N$_2$O) or temperature of the eddies
Eddy Covariance Measures Net Ecosystem Exchange

[Diagram showing the flow of atmospheric CO2, production, ecosystem respiration, heterotrophic respiration, plant respiration, DOC leaching, and carbon storage.]
Fluxes:
- CO₂
- H₂O
- S

Meteorology:
- wind
- Air Temperature
- Net radiation
- Humidity
- Canopy Temp
- PAR

Photos:
- phenology

Soil:
- Heat flux
- Temperature (to 1 m)
- Moisture (to 1 m)
Online everyday at: http://www.flickr.com/photos/energy_farm/
"Carbon fingerprints" (NEE=-NEP)

Corn:
- NEE = -283 g cm\(^{-2}\) y\(^{-1}\)
- GPP/R\(_{eco}\) = 1.33

1\(^{st}\) season Miscanthus:
- NEE = 71 g cm\(^{-2}\) y\(^{-1}\)
- GPP/R\(_{eco}\) = 0.9
Carbon Sequestration for 10 years of corn/soybean “no-till”

Modified from Bernacchi et al., *GCB*, 11, 1867-1872
Conversion to 100% no-till could offset 2% of U.S. anthropogenic carbon emissions

Table 2  Net biome productivity (NBP) summed for current corn/soybean agricultural ecosystems with 10% of agric-

<table>
<thead>
<tr>
<th>Current practices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No-till</td>
<td>-1.28</td>
</tr>
<tr>
<td>Conventional till</td>
<td>9.37</td>
</tr>
<tr>
<td>Total</td>
<td>8.09</td>
</tr>
<tr>
<td>Future scenario</td>
<td></td>
</tr>
<tr>
<td>100% no-till</td>
<td>-12.68</td>
</tr>
<tr>
<td>0% conventional-till</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>-12.68</td>
</tr>
<tr>
<td>Net potential sequestration</td>
<td>-20.77</td>
</tr>
</tbody>
</table>

Net potential sequestration is the net change in C flux between the two scenarios. Positive values represent fluxes of C from the ecosystem into the atmosphere.

Modified from Bernacchi et al., GCB, 11, 1867-1872
Global terrestrial carbon uptake and storage

$\text{CO}_2$

GPP $\approx 120 \text{ Gt C yr}^{-1}$

Plant Respiration
$\approx 60 \text{ Gt C yr}^{-1}$

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Short-Term Carbon Uptake
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NEP
$\approx 10 \text{ Gt C yr}^{-1}$

Long-Term Carbon Uptake
NBP
$\approx 1-2 \text{ Gt C yr}^{-1}$
Growth at elevated CO$_2$ stimulates respiration in soybean

Global terrestrial carbon uptake and storage

Adapted from Science 280, 1393-94

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NBP $\approx 1-2$ Gt C yr$^{-1}$
C3 Potential $\varepsilon_c = 0.046$
Maximum observed $\varepsilon_c = 0.024$
Average observed $\varepsilon_c = 0.007$

C4 Potential $\varepsilon_c = 0.060$
Maximum observed $\varepsilon_c = 0.037$
Average Observed $\varepsilon_c = 0.012$

Atmospheric CO₂, ppm

- Years below 280 ppm, 395,000 (96%)
- Years below 240 ppm, 280,000 (67%)
- Years below 200 ppm, 83,500 (20%)

Time before present, 10^3 years
There is a trade off between ability of rubisco to discriminate between \(CO_2\) and \(O_2\) rubisco catalytic rate.

\[
k_c^c = \left( \frac{e^{5.16}}{\tau} \right)^{\frac{1}{0.69}}
\]

\[r^2 = 0.89\]

\(k_c^c = \text{Catalytic rate per active site (s}^{-1}\text{)}\)
## Adding 'foreign' Rubisco

<table>
<thead>
<tr>
<th>Species</th>
<th>AC' = CANOPY PHOTOSYNTH. (mmol m⁻² day⁻¹)</th>
<th>EC (% inc.)</th>
<th>Asat (µmol m⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current average C3 crop</td>
<td>1040</td>
<td>0%</td>
<td>14.9</td>
</tr>
<tr>
<td>(k_c = 2.5, τ = 92.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amaranthus edulis</em></td>
<td>1250</td>
<td>17%</td>
<td>28.3</td>
</tr>
<tr>
<td>(k_c = 7.3, τ = 82)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amaranthus edulis</em> /current</td>
<td>1360</td>
<td>31%</td>
<td>28.3</td>
</tr>
<tr>
<td>(k_c = 7.3/2.5, τ = 82/92.5)</td>
<td></td>
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The image represents the C₃ Cycle, a process in photosynthesis that occurs in the chloroplast stroma. The cycle involves the fixation of CO₂ to form 3C Sugar, which is then reduced to form ATP and NADPH. These energy molecules are then used for further reactions in the chloroplast stroma, leading to the synthesis of starch and sucrose.
2050 versus 2005 CO2 levels

Change needed for re-optimization

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

RuBisco  GAPDH  Aldolase  FBPase  SBPase

Zhu et al. 2007 Plant Physiology 145: 513-526
Over expression of SBPase improves photosynthetic efficiency at elevated [CO$_2$]

Rosenthal et al. unpublished
Trade off between efficiency and photoprotection
Typical change in quantum yield of $CO_2$ uptake over a sunny day and recovery resulting from a sudden drop in light level (e.g., clouds).

Modified from Zhu et al. 2004 J. Exp. Bot. 55: 1167-1175
What would be the impact of increasing photosynthetic efficiency on managed agricultural lands by 25%?
NPP for global managed agricultural lands compared to all terrestrial ecosystems and compared to fossil fuel emissions

# NPP of global managed agricultural lands


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<tr>
<th>Land Type</th>
<th>Area (Mha)</th>
<th>Mean NPP (t C ha(^{-1})y(^{-1}))</th>
<th>Total NPP (Pg C y(^{-1}))</th>
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<td>1,696</td>
<td>4.8</td>
<td>8.1</td>
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<tr>
<td>Pasture</td>
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NPP of global managed agricultural lands with 25% improvement in photosynthetic efficiency

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<tr>
<td>Returned to Crop</td>
<td>386</td>
<td>3.2 6</td>
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<td><strong>20.9 26.9</strong></td>
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Global terrestrial carbon uptake and storage with 25% improvement in photosynthetic efficiency on managed agricultural lands

\[ \text{GPP} \approx 120 + 6 \text{ Gt C yr}^{-1} \]

Plant Respiration
\[ \approx 60 \text{ Gt C yr}^{-1} \]

Decomposition
\[ \approx 50 \text{ Gt C yr}^{-1} \]

Disturbance
\[ \approx 9 \text{ Gt C yr}^{-1} \]

Short-Term Carbon Uptake

NPP
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NBP
\[ \approx 1-2 \text{ Gt C yr}^{-1} \]
Global terrestrial carbon uptake and storage with 25% improvement in photosynthetic efficiency on managed agricultural lands

GPP \approx 120 + 6 \text{ Gt C yr}^{-1} \quad \text{Plant Respiration} \approx 60 + 2.4 \text{ Gt C yr}^{-1} \quad \text{Decomposition} \approx 50 \text{ Gt C yr}^{-1} \quad \text{Disturbance} \approx 9 \text{ Gt C yr}^{-1}

Short-Term Carbon Uptake

NPP \approx 60 + 3.6 \text{ Gt C yr}^{-1}

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\[ \text{NBP} \approx 1 - 2 \text{ Gt C yr}^{-1} \]
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\[ \text{GPP} \approx 120 + 6 \text{ Gt C yr}^{-1} \quad \text{Plant Respiration} \approx 60 + 2.4 \text{ Gt C yr}^{-1} \quad \text{Decomposition} \approx 50 + 3 \text{ Gt C yr}^{-1} \quad \text{Disturbance} \approx 9 + 0.48 \text{ Gt C yr}^{-1} \]

- **Short-Term Carbon Uptake**
  - **NPP** \( \approx 60 + 3.6 \text{ Gt C yr}^{-1} \)

- **Medium-Term Carbon Uptake**
  - **NEP** \( \approx 10 + 0.6 \text{ Gt C yr}^{-1} \)

- **Long-Term Carbon Uptake**
  - **NBP** \( \approx 1 - 2 + 0.12 \text{ Gt C yr}^{-1} \)

\( \text{CO}_2 \)
Global terrestrial carbon uptake and storage with 25% improvement in photosynthetic efficiency on managed agricultural lands could offset 7% of global anthropogenic carbon emissions.

**GPP**: 120 Gt C yr\(^{-1}\) + 6 Gt C yr\(^{-1}\)
- **Plant Respiration**: 60 Gt C yr\(^{-1}\) + 2.4 Gt C yr\(^{-1}\)
- **Decomposition**: 50 Gt C yr\(^{-1}\) + 3 Gt C yr\(^{-1}\)
- **Disturbance**: 9 Gt C yr\(^{-1}\) + 0.48 Gt C yr\(^{-1}\)

**Short-Term Carbon Uptake**: NPP ≈ 60 + 3.6 Gt C yr\(^{-1}\)
**Medium-Term Carbon Uptake**: NEP ≈ 10 + 0.6 Gt C yr\(^{-1}\)
**Long-Term Carbon Uptake**: NBP ≈ 1 - 2 + 0.12 Gt C yr\(^{-1}\)