Terrestrial Carbon Sequestration: Processes, Practices, Potential

Peter Reich and Ed Nater
Cinzia Fissore, Javier Espeleta, Sarah Hobbie
The Goal:

Minnesota’s Next Generation Energy Act targets ambitious CO₂ emission reductions:

<table>
<thead>
<tr>
<th>Reduction</th>
<th>Year</th>
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<tbody>
<tr>
<td>15%</td>
<td>2015</td>
</tr>
<tr>
<td>30%</td>
<td>2025</td>
</tr>
<tr>
<td>80%</td>
<td>2050</td>
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Strategies to mitigate CO$_2$ emissions

**DIRECT**
- Reduce use of fossil fuel
  - i.e.
  - Increase conservation,
  - Use of alternative energy sources

**INDIRECT**
- Terrestrial C sequestration
  - i.e.
  - Land use & management changes
Policies rely heavily on terrestrial C sequestration to offset CO$_2$ emissions

ID Soil Conservation Commission:
Near-total CO$_2$ offset.

MN Climate Change Advisory Group:
38% CO$_2$ emission reduction in MN by 2025.

- MT Climate Change Action Plan:
  11% CO$_2$ emission reduction in MT by 2020.
What is Terrestrial Carbon Sequestration?

• Accumulation of C (carbon) in a terrestrial “pool” at the expense of the atmospheric pool
Carbon exchange

- Plant photosynthesis
- Plant respiration
- Biomass production
- Biomass harvest
- Litterfall, root death
- Root respiration, decomposition
Terrestrial Carbon Cycle

C accumulates when inputs > outputs

- CO₂ Plant respiration
- CO₂ Soil respiration
- Photosynthesis
- Litter
- Roots
- Microbes
- Soil Organic Carbon
- Harvest, Fire, Erosion
- Groundwater transport
To sequester C we need to:

• Increase biomass or
• Increase soil organic matter
• Requires changes in land use or management
Carbon-depleted landscapes

% Organic Carbon

land use change

land use change
ATMOSPHERIC CO$_2$ ≈ Row Crop 
> Perennial grassland
Processes Responsible for Terrestrial Sink

- Enhanced sinks due to atmospheric changes:
  - CO$_2$ fertilization
  - N fertilization (effective for biomass, but not necessarily for soils)

- Enhanced sinks due to land use/land management
  - Fire suppression
  - Woody encroachment
  - Forest regrowth following agricultural abandonment

- Enhanced sinks due to climate change
  - longer growing season
Processes Countering Terrestrial C Sink Now and in the Future

- Ozone
- Climate change: drought - reduce plant growth
- Climate change: warming - enhanced respiration of soil C
- Permafrost melting: 400 Mt C in permafrost
- Peatland drainage due to climate or agriculture
- Deforestation/biomass burning
Short rotation woody crops
Afforestation
Prairie pothole restoration
Grassland restoration
Turfgrass to urban forest
Optimal forest stocking
Peatland restoration
Introduction of cover crops
Annual crop to pasture
Conventional to conservation tillage
Low to high diversity grassland

C sequestration rate (Mg C ha\(^{-1}\) yr\(^{-1}\))
## Minnesota Land Use

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Million Acres in 1990 (% of Total)</th>
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<tbody>
<tr>
<td>Urban</td>
<td>1.47 (2.7)</td>
</tr>
<tr>
<td>Cultivated</td>
<td>22.69 (42.0)</td>
</tr>
<tr>
<td>Pasture / Hay</td>
<td>4.98 (9.2)</td>
</tr>
<tr>
<td>Brushland</td>
<td>1.33 (2.5)</td>
</tr>
<tr>
<td>Forested</td>
<td>14.43 (26.7)</td>
</tr>
<tr>
<td>Bog / Marsh / Fen</td>
<td>5.73 (10.6)</td>
</tr>
<tr>
<td>Mining</td>
<td>0.15 (0.3)</td>
</tr>
<tr>
<td>Water</td>
<td>3.21 (6.0)</td>
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<tr>
<td>Total</td>
<td>53.99 (100.0)</td>
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Minnesota Land Use

<table>
<thead>
<tr>
<th>Land Use or Cover</th>
<th>Area (million acres)</th>
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<tbody>
<tr>
<td>Cultivated</td>
<td>22</td>
</tr>
<tr>
<td>Forested</td>
<td>15</td>
</tr>
<tr>
<td>Bog/Marsh/Fen</td>
<td>7</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>5</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
</tr>
<tr>
<td>Urban</td>
<td>1</td>
</tr>
<tr>
<td>Brushland</td>
<td>1</td>
</tr>
<tr>
<td>Mining</td>
<td>0.5</td>
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Can we really offset CO$_2$ emissions by changing the way we use the land?

(if yes, how much?)

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Dept of EEB
Dept of Forest Resources
Scenario 1

• Land area required to achieve the MNCCAG recommendations of 38% of the 2025 reductions coming from terrestrial C sequestration
  – 50% from afforestation
  – 50% from prairie (perennial grasslands)
Scenario 2

- Relative percent of the 2025 reductions that can be obtained by converting 10% of MN agricultural lands to prairie or forest as ecologically appropriate.
  - 50% to forest
  - 50% to prairie
Results: Scenario 1

• To achieve 38% of the 2025 targeted reductions would require the conversion of:
  • 1.56 million acres of row crop land to forest
  • 5.38 million acres of row crop land to prairie

• the combined acres would represent 25.8% of Minnesota’s 22.69 million acres of cropland
Results: Scenario 2

- Conversion of 5% of Minnesota row crop land to forest and 5% to prairie would sequester:
  - 6.24 million metric tons of CO$_2$ by afforestation
  - 1.81 million metric tons of CO$_2$ by prairie restoration

- the total quantity of CO$_2$ sequestered (8.05 MT) by converting 2.27 million acres (10%) of row crop lands represents 5.3% of Minnesota’s 2002 emissions of 151 MT CO$_2$
Is this acceptable?
Direct or indirect C mitigation strategies?

**INDIRECT**

ca. 5.3% CO₂ emission reduction

Conversion of 2.3 million acres of agricultural land into other uses.

**DIRECT**

ca. 5.3% CO₂ emission reduction

Increase fleet fuel efficiency in the region from 20 to 24 mpg.
What About No-till and Conservation Tillage?
Short rotation woody crops
Afforestation
Prairie pothole restoration
Grassland restoration
Turfgrass to urban forest
Optimal forest stocking
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C sequestration rate (Mg C ha\(^{-1}\) yr\(^{-1}\))
No-till and Conservation Tillage

- **Advantages:**
  - Agricultural lands remain working lands
  - Can be applied to extensive acreages

- **Problems:**
  - Burgeoning evidence that no-till simply re-distributes C compared to conventional tillage, but that the overall C balance is not significantly different, if at all
  - Reversals
Peatlands: A Special Case

- Globally, peatlands comprise only 3% of soils
- However, they contain ~33% of all C stored in soils
- Minnesota peatlands contain roughly 4,250 Mt C, or approximately 745 tonnes of C per acre
- Protecting peatlands should be a high priority
Conclusions

CO₂ Emission reduction goals for MN:
15% by 2015
30% by 2025
80% by 2050

Achievable through land use change: 3 - 5 %

Land use change can help sequester C, but other measures have to be undertaken to reach Minnesota’s goals, first of all reduction of CO₂ emissions.
Conclusions

CO$_2$ mitigation plans that rely heavily on terrestrial C sequestration are overly optimistic.

Offset > 5% of CO$_2$ emission by land use change is unrealistic.
• Efforts should be made to protect existing C sinks
• peatlands and forests in Minnesota contain enormous C stocks; their loss will only exacerbate the problem
• C sequestration should be tied to land use / land management practices that provide other ecosystem services, such as increased wildlife habitat and enhanced biodiversity, erosion reduction, and water quality improvements
• These land uses typically sequester carbon

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<tbody>
<tr>
<td>CRP and WRP (million acres)</td>
<td>0.54</td>
<td>0.91</td>
<td>1.26</td>
<td>1.63</td>
<td>1.93</td>
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