(Soil) Carbon Sequestration in the Urban Environment

Central Park and Mid-town Manhattan
Photo: S. Cornwell, 2208

Row crops and forest buffer, Roxbury Farm, Hudson Valley, NY
Photo: Alison Powell, October 2008

Cynthia Rosenzweig
World Bank
May 13, 2009
Carbon Sequestration in Cities

- Street trees
- Parks
- Green roofs
- Compost
- Urban agriculture
Implementing Green or Living Roofs

Green or living roofs are lightweight, thin (4 – 6” growing medium), and planted with hardy, drought-resistant plants to minimize weight, cost, and maintenance. This type of green roof is generally referred to as “extensive.”

A green roof system typically consists of several layers including a waterproof membrane, drainage layer, growing medium, and vegetation.

Hamilton City Apartments, Portland OR.
Source: Environmental Services of Portland
Intensive Living Roofs / Roof Gardens

Green roofs can also be designed to support grass, flowers, trees, shrubs, and/or crops and thus serve as an additional urban outdoor space, food-producing area, and amenity. This type of green roof is generally referred to as “intensive.”

Solaire Building Intensive Green Roof, Battery Park City, New York
Soil Characteristics of Green Roofs

• On an extensive green roof, growing medium must be able to retain water (to mitigate stormwater runoff) while at the same time easily allowing excess water to drain

• Can hold between half their weight in water to about twice the soil mass

• Additional water sometimes held in a drainage mat beneath the growing medium

• Growing medium must be low density

• Mineral content is generally expanded slate, clay, or shale (example: perlite)

• Organic content tends to be low

• ~50% pore space

Example from Bauder in the UK:
Combination of recycled brick, expanded shale and composted pine bark
Vegetation Characteristics of Green Roofs

- Vegetation should be drought-tolerant, needing irrigation only to help the plants become established (up to two years)

- Vegetation should grow and spread rapidly, have fibrous roots to protect roofing membranes, and have no special nutrient requirements

- Sedums, and other succulents, thrive in thin green roof growing medium

- Other plant choices include low-growing herbs, grasses, and mosses

- Plants with airborne seeds should be avoided to prevent green roof plants from invading other areas

- Small amounts of carbon can be sequestered
Regional summertime temperatures are projected to rise 2.12 – 2.75°C by the 2050s.

Precipitation projections range from a 1.3% decrease to an 8.8% increase by the 2050s.

Climate change is projected to bring increased heat waves and more frequent droughts and floods to the NY Metropolitan Region.

Green roofs could help to reduce summertime temperatures and energy demand and improve air quality and public health.

Green roofs can sequester small amounts of carbon.

GISS, 10 years; MM5, 5 years

NASAGISS Climate Impacts Group

MM5 Regional climate projections
Rosenzweig et al.
## Cost-Benefit Analysis

<table>
<thead>
<tr>
<th>Private (Building-Level)</th>
<th>Public (City-Level)</th>
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</thead>
<tbody>
<tr>
<td><strong>Tier I Benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Increased service life for roof membrane</td>
<td>Reduced stormwater runoff expenditures</td>
</tr>
<tr>
<td>Reduced energy use for cooling</td>
<td>Reduced urban heat island</td>
</tr>
<tr>
<td><strong>Tier II Benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Sound insulation</td>
<td>Improved air quality</td>
</tr>
<tr>
<td>Food production</td>
<td>Reduced greenhouse gas emissions; carbon sequestration</td>
</tr>
<tr>
<td>Aesthetic value</td>
<td>Improved public health</td>
</tr>
<tr>
<td></td>
<td>Aesthetic value</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Net cost of green roof</td>
<td>Program administration and setup</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>Program maintenance</td>
</tr>
</tbody>
</table>

Acks et al., 2007
Green roof infrastructure could be a cost-effective way to help address urban environment, human health, and climate change when multiple private and public benefits are considered together.

-10% of NYC’s surface area is flat roof space

## Cost-Benefit Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Performance Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tier I</strong></td>
<td></td>
</tr>
<tr>
<td>Benefit-Cost Ratio Tier I, Private</td>
<td>Low</td>
</tr>
<tr>
<td>Benefit-Cost Ratio Tier I, Private &amp; Public</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Tier I &amp; II</strong></td>
<td></td>
</tr>
<tr>
<td>Benefit-Cost Ratio Tier I &amp; II, Private</td>
<td>Low</td>
</tr>
<tr>
<td>Benefit-Cost Ratio Tier I &amp; II, Private &amp; Public</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Acks et al., 2007
Acreage of farm parcels in Hudson Valley

Developing Carbon Sequestration Programs for Urban-Rural Bioregions

Hudson Valley
A small diverse agricultural region with many smallholders
Near large urban area

Row crops and forest buffer
Roxbury Farm, Hudson Valley, NY
Photo: Alison Powell, October 2008
Objectives

• Explore development of carbon trading system for cities and their surrounding agricultural regions.
• Calculate the carbon sequestration potential of the Hudson Valley.
• Define challenges and opportunities for bioregion-scale carbon linkages between urban residents and farmers.
R.E.A.L.* Urban-Rural Program
Reduced Emissions on Agricultural Lands in Urban Bio-Regions

INITIAL FUNDER: Philanthropy Donor Grant

VERIFIER: University NY-DEC

ASSEMBLER & ALLOCATOR: Non-Profit

OFFSET BUYER: Individuals Associations Businesses Corporations

Measurement
Modeling
Monitoring

$\text{carbon sequestration & emission calculations}$

$\text{education; funding allocation to farms; brokerage}$

$\text{transparency; local foodshed support; regional pride}$

GHG EMISSION REDUCER & SEQUESTERER:
Hudson Valley FARMS

*Erick Fernandes
Determining Land Use which affects carbon sequestration

Distribution of land use in Hudson Valley Counties. The yellow-shaded areas represent areas of cultivated crops and pasture land.
Determining Soil Type

Distribution of soil textures in the Hudson Valley

Created by Sarah Bartges
December 1st, 2008
Using data from the Soil Geographic Survey SSURGO Database
obtained from the US Dept. of Agriculture, NRCS
## Ranking Farmland’s Sequestration Potential

<table>
<thead>
<tr>
<th>Soil</th>
<th>Rank</th>
<th>Vegetation</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>1</td>
<td>Cropland</td>
<td>1</td>
</tr>
<tr>
<td>Muck</td>
<td>2</td>
<td>Woody/forest</td>
<td>2</td>
</tr>
<tr>
<td>Loam</td>
<td>3</td>
<td>Herbaceous</td>
<td>3</td>
</tr>
<tr>
<td>Silt loam</td>
<td>4</td>
<td>Shrubs</td>
<td>4</td>
</tr>
<tr>
<td>Fluvaquent s</td>
<td>5</td>
<td>Sparse veg.</td>
<td>5</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>6</td>
<td>Waterlogged veg.</td>
<td>6</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>7</td>
<td>Developed</td>
<td>7</td>
</tr>
<tr>
<td>Rocky</td>
<td>8</td>
<td>Water</td>
<td>8</td>
</tr>
<tr>
<td>Water/developed</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Farm Size (acres)</th>
<th>Rank</th>
<th>Farm Type</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A &gt;= 300</td>
<td>1</td>
<td>Dairy</td>
<td>1</td>
</tr>
<tr>
<td>A &gt;= 200 &amp; &lt;300</td>
<td>2</td>
<td>Crops</td>
<td>1</td>
</tr>
<tr>
<td>A &gt;= 100 &amp; &lt;200</td>
<td>3</td>
<td>Cattle, calves, hogs</td>
<td>2</td>
</tr>
<tr>
<td>A &gt;= 50 &amp; &lt;100</td>
<td>4</td>
<td>Sheep</td>
<td>3</td>
</tr>
<tr>
<td>A &gt;= 10 &amp; &lt;50</td>
<td>5</td>
<td>Vacant Ag land</td>
<td>4</td>
</tr>
<tr>
<td>A &gt;= 0 &amp; &lt;10</td>
<td>6</td>
<td>“Other” livestock</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Orchard</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vineyard</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poultry</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horse Farm</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beeswax &amp; honey</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Other” fruits</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nursery</td>
<td>9</td>
</tr>
</tbody>
</table>

Bartges, 2009
Determining Promising Areas for Carbon Sequestration

Carbon sequestration potential of Hudson Valley farms based on soil type, farm size, farm type, and vegetation.
# Site-specific Inputs for Comet-VR and Sources

<table>
<thead>
<tr>
<th>LOCATION &amp; SOIL</th>
<th>LAND USE HISTORY</th>
<th>TILLAGE</th>
<th>FUTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT</td>
<td>SOURCE</td>
<td>INPUT</td>
<td>SOURCE</td>
</tr>
<tr>
<td>Address and county</td>
<td>Real Property Data (GIS)</td>
<td>Landscape position &amp; land management 1880 to 1970</td>
<td>1900s Ag. Census</td>
</tr>
<tr>
<td>Area of actively farmed land</td>
<td>Real Property Data (GIS)</td>
<td>Land management 1970 to mid 1990</td>
<td>1987 Ag. Census</td>
</tr>
<tr>
<td>Soil surface texture</td>
<td>SSURGO soil data (GIS)</td>
<td>Conserv. Reserve Program (CPR)?</td>
<td>1985 Ag. Census</td>
</tr>
<tr>
<td>Presence of hydric soil</td>
<td>SSURGO soil data (GIS)</td>
<td>Current Land Management</td>
<td>2007 Ag. Census</td>
</tr>
</tbody>
</table>

Bartges, 2009; Paustian et al.
CO2 Sequestered in Hudson Valley for Three Scenarios in Comet-VR

**Current Practices**
- Conventional Tillage or Heavy Grazing
- Conservation Reserve Program Grass/legume Pasture

**Best Practices**
- No-Till, Rotational Grazing

Under the best scenario, a market based on conservation tillage and rotational grazing would consist of ~620,000 tons CO2 = $1,023,000 (based on Chicago Climate Exchange value of $1.65 per ton CO2)

Bartges, 2009
R.E.A.L. Urban-Rural Program
Reduced Emissions on Agricultural Lands in Urban Bio-Regions

There is potential for development of regional-scale REAL Urban-Rural Programs
For cities and their surrounding agricultural regions
Even with diverse smallholder agricultural systems

Programs need to address additionality, permanence, duration and leakage
NCAR CCSM 3.0 GCM A1b

Annual temperature change 2050s (°C) (2040-2069) minus (1970-1999)

0.75 1.5 2.25 3.75 3 4.5 5.25 6 6.75 7.5 10

C40 Large Cities Climate Summit and Urban Climate Change Research Network Symposium

May 2007

Working with City Experts on Mitigation and Adaptation
Results

• An 1000 sq. ft. building with a green roof and cooled with an AC system of 10 EER will save $16.92 in cooling costs over the summer and decrease CO2 emissions released into the atmosphere by 138.19 lbs. of CO2 from being

• 10% of all flat roof buildings in NYC covered with AC systems of 10 EER
  – CO2 emissions will decrease by 1771149 lbs. over one summer
  – Altogether 1781794 lbs. of combined emissions (CO2, Hg, CO, NOx, SO2, PM 2.5 µm and 10 µm) will be prevented from release into the atmosphere over one summer

• 50% of all flat roof buildings in NYC covered with AC systems of 10 EER
  – CO2 emissions will decrease by 8855746.302 lbs. over one summer and combined emissions will decrease by 8908971.216 lbs. over one summer

• If all buildings owned by NYC (19403028 sq. ft.) are covered and have 10 EER AC, the government would save $246,249.72 over one summer

Rosenzweig, Parshall, and Solecki, eds., 2007
Key Findings from Research Report I

**Energy**: Surface temperatures in July 2003 were 19°C higher on standard roofs than on green roofs during the day and 8°C cooler at night based on analysis of Penn State Data.

**Urban Heat Island**: A 50% extensive green roof scenario reduced New York City’s average surface temperature by 0.1 -- 0.8°C.

**Hydrology**: Green roofs captured 80% of rainfall during rainstorms compared to 24% for standard roofs at Penn State. A 50% extensive green roof scenario reduced runoff by up to 10%.

Rosenzweig, Parshall, and Solecki, eds., 2007
## Possible Acres of Carbon Sequestration

<table>
<thead>
<tr>
<th>Hudson Valley Counties</th>
<th>CROPLAND (acres)</th>
<th>PASTURE (acres)</th>
<th>TOTAL (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albany</td>
<td>40,870</td>
<td>6,421</td>
<td>47,291</td>
</tr>
<tr>
<td>Columbia</td>
<td>77,838</td>
<td>7,416</td>
<td>85,254</td>
</tr>
<tr>
<td>Dutchess</td>
<td>59,255</td>
<td>12,492</td>
<td>71,747</td>
</tr>
<tr>
<td>Greene</td>
<td>31,841</td>
<td>5,120</td>
<td>36,961</td>
</tr>
<tr>
<td>Orange</td>
<td>70,753</td>
<td>9,704</td>
<td>80,457</td>
</tr>
<tr>
<td>Putnam</td>
<td>1,780</td>
<td>290</td>
<td>2,070</td>
</tr>
<tr>
<td>Rensselaer</td>
<td>53,912</td>
<td>6,192</td>
<td>60,104</td>
</tr>
<tr>
<td>Rockland</td>
<td>581</td>
<td>28</td>
<td>609</td>
</tr>
<tr>
<td>Ulster</td>
<td>39,358</td>
<td>9,449</td>
<td>48,807</td>
</tr>
<tr>
<td>Westchester</td>
<td>2,462</td>
<td>1,270</td>
<td>3,732</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>378,650</strong></td>
<td><strong>58,382</strong></td>
<td><strong>437,032</strong></td>
</tr>
</tbody>
</table>

Bartges, 2009
Whole Farm Planning

EXAMPLE:
50-acre Vegetable Farm in Dutchess County

FARM ASSESSMENT:
  silt loam, lowland, non-hydric soils
  CSA farm, produce delivered weekly to NYC via truck (25 weeks/year)

EMISSIONS CALCULATION:
  1970-present – intensive tillage – 7.7 CO₂ tons emitted/year by soils
  CSA delivery transportation (diesel truck) – 3.7 CO₂ tons emitted/year by truck

BMiP OPTIONS:
  Option 1: switching to **minimum tillage** would **REDUCE EMISSIONS** by 62.4%
             (4.8 CO₂ tons emitted/year)
  Option 2: switching to **no-till** would lead to **SEQUESTRATION**
             (15 CO₂ tons sequester/year)
  Option 3: utilizing **biodiesel** in diesel truck
             (1.85 CO₂ tons emitted/year)
Whole Farm Planning

EXAMPLE:
200-acre Grazed Pasture in Columbia County

FARM ASSESSMENT:
Soil: clay, lowland, non-hydric
Production: free-range beef cattle

EMISSIONS CALCULATION:
1970-present – non-irrigated, continuous pasture/hay/legume mix, reduced tillage
intensive grazing on allotted pasture land (not rotational)
31 CO₂ tons emitted/year by soils

BMIP OPTIONS:
Option 1: switching to no-till hay/corn production only would INCREASE emissions
(45 CO₂ tons emitted/year)
Option 2: switching to rotational grazing would lead to SEQUESTRATION
(160 CO₂ tons sequestered/year)
Option 3: switching to seasonal, heavy grazing would lead to SEQUESTRATION
(215 CO₂ tons sequestered/year)
Connecting Farmers with Climate Change Mitigation

Planning and Implementation Team Actions

Adapted from Watershed Protection Plan Whole Farm Planning Program

Powell, 2009
Soil Carbon Sequestration

Challenges of Claiming Soil Carbon Credits

- **Additionality**: credits generated must be additional to any reduction in carbon that would have occurred under a "business as usual" scenario.

- **Permanence**: the length of time that carbon is sequestered and maintained in a sink (e.g. forest or agricultural soil).

- **Duration**: the length of the contract.

- **Leakage**: the problem of project activities inducing economic agents to take actions that would increase greenhouse gases emissions elsewhere.