Effects of Farm Scale on Land, Labor, and Energy Efficiency in Organic Crop Production

Michael Bomford, Tony Silvernail, Jon Cambron, and Joni Nelson
Objectives

• Compare sweet sorghum and sweet potato to corn in terms of
  – Yield (land use efficiency)
  – Energy use efficiency
  – Labor use efficiency

• Compare efficiencies at three small organic farm scales
  – Biointensive
  – Market garden
  – Small farm
## Methods: Crops

<table>
<thead>
<tr>
<th>Common name</th>
<th>Image</th>
<th>Latin name</th>
<th>Food</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td><img src="image" alt="Corn" /></td>
<td>Zea mays</td>
<td>Sweet corn, grain</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Soybean</td>
<td><img src="image" alt="Soybean" /></td>
<td>Glycine max</td>
<td>Edamame, grain</td>
<td>Biodiesel</td>
</tr>
<tr>
<td>Sweet sorghum</td>
<td><img src="image" alt="Sorghum" /></td>
<td>Sorghum bicolor</td>
<td>Sorghum syrup, grain</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Sweet potato</td>
<td><img src="image" alt="Potato" /></td>
<td>Ipomoea batatas</td>
<td>Sweet potato</td>
<td>Ethanol</td>
</tr>
</tbody>
</table>

- 4 year rotation
- Winter cover crop of rye/vetch each year
- 5 year study (2008-2012)
Small Farm Scales

• Biointensive
  – Human-powered; no fossil fuels
  – Smallest scale

• Market garden
  – Walk-behind tractor is largest fossil fuel powered machine

• Small farm
  – Conventional 4-wheeled tractors and implements
Biointensive mini-farming techniques make it possible to grow food using

- 99% less energy in all forms - human and mechanical,
- 66-88% less water, and
- 50-100% less fertilizer, compared to commercial agriculture.

They also produce two to six times more food and build the soil.”


John Jeavons
Rep 1
Small farm
Bio-intensive
38 m
22 m
2008

Rep 2
Small farm
Bio-intensive
34 m
6 m

Rep 3
Small farm
Bio-intensive
18 m
7 m

Rep 4
Small farm
Bio-intensive
34 m
6 m

Market garden

Corn
Soybean
Sweet potato
Sweet sorghum
Farm scales

Small farm

Small farm

Market garden

Market garden

Biointensive
Data Collection

• Labor
  – Every minute in field by scale and crop
  – Labor intensity (for conversion to metabolic energy input)

<table>
<thead>
<tr>
<th>Task</th>
<th>Metabolic Equivalent of Task</th>
<th>Metabolic Energy Input (kJ/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digging, cutting sorghum cane (moderate to vigorous effort)</td>
<td>5.0</td>
<td>28</td>
</tr>
<tr>
<td>Weeding, hoeing (light to moderate effort)</td>
<td>3.5</td>
<td>20</td>
</tr>
<tr>
<td>Driving tractor (light effort)</td>
<td>2.8</td>
<td>16</td>
</tr>
</tbody>
</table>

Data Collection

- **Fuel**
  - Every mL of gasoline (34.6 kJ/mL, US-DOE) or diesel (38.7 kJ/mL, US-DOE) by scale and crop

- **Yield**
  - **Corn**
    - Fresh ears of sweet corn (3.5 MJ/kg, USDA)
    - Dried kernels of field corn (15.2 MJ/kg, USDA)
  - **Sweet sorghum**
    - Fresh cane (2.3 MJ/kg, Univ. of Kentucky)
  - **Soybean**
    - Edamame pods (6.1 MJ/kg, USDA)
    - Dried and shelled field beans (18.7 MJ/kg, USDA)
  - **Sweet potato**
    - Fresh tubers (3.6 MJ/kg, USDA)
Results: Annual labor input by farm scale and phase, 2008-2012

Labor input (min/m²)

<table>
<thead>
<tr>
<th></th>
<th>Biointensive</th>
<th>Market Garden</th>
<th>Small Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prep</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manage</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Harvest</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

A: Prep: 6, Plant: 6, Manage: 6
B: Prep: 2, Plant: 1, Manage: 1
C: Plant: 1
Results: Annual direct energy input by farm scale, 2008-2012

Energy input (MJ/m²)

- **Biointensive**: B
- **Market Garden**: A
- **Small Farm**: A

**Energy Types**:
- **Metabolic E** (light green)
- **Fossil E** (dark green)
Results: Annual energy yield by farm scale and crop, 2008-2012

<table>
<thead>
<tr>
<th>Farm Scale</th>
<th>Energy Yield (MJ/m²)</th>
</tr>
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<tr>
<td>Biointensive</td>
<td></td>
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<td>Market Garden</td>
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<td>Small Farm</td>
<td></td>
</tr>
</tbody>
</table>

- Sweet potato
- Soybean
- Sweet sorghum
- Corn

Note: The chart shows the percentage contribution of each crop to the total energy yield.
Results: Energy output/input by farm scale, 2008-2012

- Biointensive: A
  - Sweet potato: 3
  - Soybean: 1
  - Sweet sorghum: 8
  - Corn: 2

- Market Garden: B
  - Sweet potato: 2
  - Soybean: 1
  - Sweet sorghum: 4
  - Corn: 1

- Small Farm: B
  - Sweet potato: 2
  - Soybean: 1
  - Sweet sorghum: 4
  - Corn: 1
Conclusions

• Scaling up saves time
  – Market Garden used 80% less time per unit area than Biointensive
  – Small Farm used 57% less time than Market garden and 91% less time than Biointensive

• Move from metabolic power to internal combustion power has energy cost
  – Market Garden and Small Farm plots used about 50% more energy per unit area than Biointensive
  – Indirect energy cost of machinery and tool manufacturing not included
Conclusions

• Yield independent of scale, overall, but some interaction between scale and crop:
  – Sweet sorghum best at small scale
  – Corn and sweet potato best at larger scale

• Net energy gain at all scales
  – Overall energy return similar to that of US organic corn production (Gomiero et al. 2011)
  – Biointensive gave greatest energy return
    • Advantage mainly due to sweet sorghum
    • Overall EROI of 13 similar to Mexican traditional human-powered corn production (Pimentel & Pimentel 1997)
Thanks!

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