The Energy and Carbon Conundrum in Sustainable Agricultural Production

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World population

Prospect

Population in billions

year

1950 '60 '70 '80 '90 '10 '20 '30 '40 2050

high

medium

low
The options to meet food demand

Population/Income growth

Agricultural production

Option 1
- Extensification
  - Conversion to agricultural land

Option 2
- Intensification
  - Use of inputs and machinery
## Changes in agricultural land use 1960 - 2000

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed countries</td>
<td>3760</td>
<td>-2</td>
</tr>
<tr>
<td>Developing countries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>2682</td>
<td>19</td>
</tr>
<tr>
<td>Permanent pasture</td>
<td>1973</td>
<td>16</td>
</tr>
<tr>
<td>Arable land</td>
<td>650</td>
<td>22</td>
</tr>
<tr>
<td>Permanent crops</td>
<td>59</td>
<td>81</td>
</tr>
</tbody>
</table>

Smith et al., 2007
Conversion of terrestrial biomes

Fraction of potential area converted

-10 0 10 20 30 40 50 60 70 80 90 100

Medit. forest, woodlands and scrub
Temp. forest, steppe and woodland
Temp. broadleaf and mixed forests
Trop. and sub-trop. Dry broadleaf forests
Flooded grasslands and savannas
Trop. and sub-trop. grasslands, savannas and shrublands
Trop. and sub-trop. coniferous forests
Desert
Montane grasslands and shrublands
Trop. and sub-trop. moist broadleaf forest
Temperate coniferous forest
Boreal forest
Tundra

Source: MEA, 2005
Land degradation in various parts of the world

Source: MEA, 2005
Release of CO$_2$ for agricultural expansion (1980 – 2000) for selected regions

Total: 45 Pg CO$_2$

~ 2.25 Pg CO$_2$ per year or
2250 $10^6$ metric tons yr$^{-1}$

<table>
<thead>
<tr>
<th>Region</th>
<th>Carbon Dioxide (Pg CO$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latin America</td>
<td>20.4</td>
</tr>
<tr>
<td>(West-) Africa</td>
<td>3.8</td>
</tr>
<tr>
<td>(West-) Africa</td>
<td>5.4</td>
</tr>
<tr>
<td>Asia</td>
<td>6.6</td>
</tr>
<tr>
<td>Asia</td>
<td>3.6</td>
</tr>
<tr>
<td>Asia</td>
<td>0.2</td>
</tr>
<tr>
<td>Asia</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Legend:
- **forest**
- **disturbed forest**
- **shrubland**
CO₂ emissions from land use change

Source: Houghton, 2010; GFRA, 2010
CO$_2$ emissions from land use change

Source: Houghton, 2010; GFRA, 2010
The options to meet food demand

Problem Statement

Increasing GHG emissions
Loss of ecosystem services
Pressure on marginal land

Population/Income growth
Agricultural production

Option 1
Extensification
Conversion to agricultural land

Option 2
Intensification
Use of inputs and machinery
What are the consequences and ecological cost of agricultural intensification?

Index of total agricultural output per capita by region (index 1961-2005)

Source: Hazell and Wood, 2008
Tripled World Cereal Production–Areas Spared Through Improved Technology, 1950-2000

Source: FAO Production Yearbooks and AGROSTAT

See also: Rudel et al., 2009: Proc Natl Acad Sci 106(49)20675
Rising energy consumption for agriculture

Energy use in agriculture amounts to ~2% of the total energy use worldwide:
- especially in developing countries a higher demand is expected in the future

Source: IEA, 2010

Total energy use for agriculture:
1990: $197 \times 10^6$ toe
2001: $222 \times 10^6$ toe

![Energy Consumption in Agriculture (Mtoe)]
## Commercial energy consumption in different regions (2001)

<table>
<thead>
<tr>
<th>Region</th>
<th>Commercial energy use (10^6 toe yr(^{-1}))</th>
<th>Commercial energy use in agriculture (10^6 toe yr(^{-1}))</th>
<th>Share of energy use in agriculture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>400</td>
<td>6</td>
<td>1.6</td>
</tr>
<tr>
<td>Latin America</td>
<td>460</td>
<td>17</td>
<td>3.8</td>
</tr>
<tr>
<td>Middle East &amp; North Africa</td>
<td>500</td>
<td>11</td>
<td>2.1</td>
</tr>
<tr>
<td>Asia (incl. China)</td>
<td>2 200</td>
<td>64</td>
<td>2.9</td>
</tr>
<tr>
<td>Developing countries</td>
<td>3 560</td>
<td>98</td>
<td>2.7</td>
</tr>
<tr>
<td>Europe</td>
<td>1 900</td>
<td>50</td>
<td>2.7</td>
</tr>
<tr>
<td>North America &amp; Pacific</td>
<td>3 400</td>
<td>38</td>
<td>1.1</td>
</tr>
<tr>
<td>Others (e.g. Former Soviet Union)</td>
<td>1 200</td>
<td>36</td>
<td>3.0</td>
</tr>
<tr>
<td>World</td>
<td>10 060</td>
<td>222</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Source: IEA, 2005
Food production is dependent on fossil energy

The energy efficiency ratio is the total annual food energy divided by the total energy input.

<table>
<thead>
<tr>
<th>Region</th>
<th>Commercial energy use in agriculture ($10^{13}$ kcal yr$^{-1}$)</th>
<th>Total annual food energy produced ($10^{13}$ kcal yr$^{-1}$)</th>
<th>Fossil energy efficiency (Ef) in agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>6</td>
<td>56</td>
<td>9.3</td>
</tr>
<tr>
<td>Latin America</td>
<td>17</td>
<td>56</td>
<td>3.3</td>
</tr>
<tr>
<td>Middle East &amp; North Africa</td>
<td>11</td>
<td>46</td>
<td>4.2</td>
</tr>
<tr>
<td>Asia (incl. China)</td>
<td>64</td>
<td>346</td>
<td>5.4</td>
</tr>
<tr>
<td>Developing countries</td>
<td>98</td>
<td>480</td>
<td>4.9</td>
</tr>
<tr>
<td>Europe</td>
<td>50</td>
<td>86</td>
<td>1.7</td>
</tr>
<tr>
<td>North America &amp; Pacific</td>
<td>38</td>
<td>43</td>
<td>1.1</td>
</tr>
<tr>
<td>Other</td>
<td>36</td>
<td>105</td>
<td>2.9</td>
</tr>
<tr>
<td>World</td>
<td>222</td>
<td>640</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Source: IEA, 2005
### Total Energy Input and Output and Energy Efficiency (Et) in Agricultural Production Systems

<table>
<thead>
<tr>
<th>Region</th>
<th>Cropping system</th>
<th>Energy (kJ/ha and year)</th>
<th>Total energy efficiency (Et) in agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Guinea</td>
<td>Mixed root crops</td>
<td>41</td>
<td>2.5</td>
</tr>
<tr>
<td>Mexico</td>
<td>Semi-intensive maize</td>
<td>14.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Surinam</td>
<td>Intensive rice</td>
<td>51.5</td>
<td>41.1</td>
</tr>
<tr>
<td>USA</td>
<td>Maize</td>
<td>76.9</td>
<td>29.9</td>
</tr>
</tbody>
</table>
Availability of agricultural land per capita and region

Source: FAOSTAT database, 2008
Increasing dependence on fossil energy

Food security and yield increase

The energy use and carbon conundrum in the agricultural sector

Population/Income growth

Agricultural production

Increasing GHG emissions

Loss of ecosystem services

Pressure on marginal land

Option 1
Extensification

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Use of inputs and machinery

Increasing GHG emissions

Increasing dependence on fossil energy

Food security and yield increase

Problem Statement
### Annual CO₂ Greenhouse gas emissions from agricultural land use

<table>
<thead>
<tr>
<th></th>
<th>CO₂ emissions (10⁶ t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral fertilizer</td>
<td>130</td>
</tr>
<tr>
<td>Farm machinery</td>
<td>69</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
<tr>
<td>Land Conversion</td>
<td>2000+</td>
</tr>
</tbody>
</table>

So what is the best bet?
Options for reducing the climate footprint of agriculture

Cropland includes permanent and shifting cultivation.

Potential for sparing land
Potential for afforestation

Modified after: Grainger A PNAS 2009;106:20557-20558
AFFORESTATION AS AN ADAPTIVE AND MITIGATING LAND USE STRATEGY - Uzbekistan

• Khamzina, Lamers and Vlek 2008 Forest Ecology and Management, 255.
Total annual CO$_2$ emission for 20% additional fertilizer use in the production of rice, maize and wheat and C sequestration on marginal land without loss of overall production

Carbon sequestration (10$^6$ t yr$^{-1}$) CO$_2$ emissions (10$^6$ t yr$^{-1}$)

- CO$_2$ sequestration by forest regeneration
  - high: 218.1
  - low: 92.3

- CO$_2$ balance
  - low: 206.1
  - high: 80.4
  - average: 143.3

<2%
Conclusions

- Agriculture production is fossil fuel depended and carbon intensive
- There is a high demand of agricultural land, especially in developing countries
- The cost in CO$_2$ release in land conversion is substantial - REDD
- The alternative is intensification which is cheaper in CO$_2$ loading
- Sequestration of carbon with afforestation would far outweighs the emissions associated with production of extra fertilizer - CDM
- This route will make agriculture ever more dependent on fossil fuel.
- In the long run, alternative energy sources are needed to sustain agriculture.......