Applying Systems Thinking to World Hunger: Seeking Solutions in Agriculture, Food Production, and Sustainability

By Hank Roark, SDM ‘10
Disclaimer

These views are my own and do not represent the views of any other individual or organization.
National Academy of Engineering
Grand Challenges related to agriculture

Manage the nitrogen cycle
Provide access to clean water
Develop carbon sequestration methods
The agriculture engineering systems are connected to nearly every other engineering system type

In world where systems are becoming increasingly connected, the interactions with the agricultural system will become more numerous and boundaries less well defined.

In this world, for example, agricultural becomes more reliant on communication, is a major contributor to energy, is driven by preventative health care, and is shipped globally and locally.

---

deweck et al

Additional interactions with agricultural systems

---

Presentation Overview

1. Trends
2. History and current situation
3. Future systems
4. Value from systems thinking

Strong focus on crop production

Not covered: fisheries, forests, consumer availability, agri-biotechnology
Trends

- Population growth and calories per capita
- Land available for crops
- Water usage
- Climate impacts
Population and wealth increases means at least 60% increase in crop production needed by 2050

Population  
6.6B (2007) → 9.1B (2050)

Cereals  
2 billion tonnes (2007) → 3 billion tonnes (2050)

Meat production  
260 million tonnes (2007) → 455 million tonnes (2050)

Calories / Person / Day  
2772 (2007) → 3070 (2050)

These are the most conservative estimates; some report needing to increase production by up to 110% over today.

Alexandratos and Bruinsma 2012
Arable land will increase by 10% by 2050

Figure 4.5  Arable land and land under permanent crops: past and future

Alexandratos and Bruinsma 2012
Arable land per capita will decrease by 10% by 2050

Figure 4.3  Arable land per cap (ha in use per person)

Alexandratos and Bruinsma 2012
Agriculture will increasingly put pressure on fresh water resources

<table>
<thead>
<tr>
<th></th>
<th>Renewable water resources*</th>
<th>Water use efficiency ratio</th>
<th>Irrigation water withdrawal</th>
<th>Pressure on water resources due to irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>42 000</td>
<td>50</td>
<td>51</td>
<td>2 761</td>
</tr>
<tr>
<td>Developed countries</td>
<td>14 000</td>
<td>41</td>
<td>42</td>
<td>550</td>
</tr>
<tr>
<td>Developing countries</td>
<td>28 000</td>
<td>52</td>
<td>53</td>
<td>2 211</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>3 500</td>
<td>25</td>
<td>30</td>
<td>96</td>
</tr>
<tr>
<td>Latin America</td>
<td>13 500</td>
<td>42</td>
<td>42</td>
<td>183</td>
</tr>
<tr>
<td>Near East/North Africa</td>
<td>600</td>
<td>56</td>
<td>65</td>
<td>311</td>
</tr>
<tr>
<td>South Asia</td>
<td>2 300</td>
<td>58</td>
<td>58</td>
<td>913</td>
</tr>
<tr>
<td>East Asia</td>
<td>8 600</td>
<td>49</td>
<td>50</td>
<td>708</td>
</tr>
</tbody>
</table>

Alexandratos and Bruinsma 2012
Temperature and rainfall variability increase will likely increase yield variability.

History and Current Situation

• Historical Technology Impacts
• Yield gaps
• Post harvest loss
Adoption of technology leads has previously improved yields

Hybrid corn

Improve genetics
Nitrogen fertilizer
Pesticides
Mechanization

Transgenic hybrids?

Current yield trends are insufficient to double production by 2050

Solid line – current trend line

Dashed – needed to double global crop production by 2050

Ray DK, Mueller ND, West PC, Foley JA (2013)
Global Yield Gaps Exist Across the Globe

Precision agriculture technology helps us understand variability exists at all geospatial extents

Fields
Rows
Individual Plants

Variability means loss yield

Hendrickson
Another approach to delivering food and protecting water is to improve the proportion of produced calories which make it to the consumer.

Future systems examples

- Sustainable intensification
- Improved water utilization
- Data intensive and precision agriculture
Sustainable intensification through integrated crop-pest management is one path to yield improvement.

Adoption of technologies can improve crop production water use efficiency

https://upload.wikimedia.org/wikipedia/commons/1/17/PivotIrrigationOnCotton.jpg
http://serc.carleton.edu/eslabs/drought/8d.html
Increasingly data and decisions on data will be needed for ecologically improved production.
Examples of applying systems thinking to agricultural production

• Sugar cane, India
• Biofuels, United States
• Cotton
Value network analysis provides an improved understanding of sugar cane production system

Sugar cane value starts to degrade as soon as it is harvested

Sugar cane mills have limited production capacity

Coordination is required among multiple harvest operations and multiple mills in a region

Joshi and Jayant (2012)
Value network, manual harvesting

Money flow

Value flow

Farmer

1MT Sugarcane

~ INR 1900

Society

100 kg Sugar

INR 2500

INR 120 - 160 (avg.)

(depends on distance)

Mill

Labour contractor

Transport contractor

Labour

Can go upto
INR 700

= INR192 + 18% commission

INR227

= INR192

Cutting & loading: 1MT cane

Food, drinks, fodder

Tips ~ INR 25 (~ INR1000/acre)

Transport: Field to field

Diesel & maintenance

Driver + cleaner

1MT  Sugarcane

INR 192

Cutting & loading: 1MT cane

INR 192

Cutting & loading: 1MT cane

INR 192

INR 227

= INR192 + 18% commission

INR 1900

INR 2500
Value network, mechanized harvesting

Farmer

- 1MT Sugarcane
- ~ INR 1900

Support labourers

- Edge cutting, collecting billets
- ~ INR 23

Interest
- ~ INR 220

Depreciation
- ~ INR 200

Maintenance
- ~ INR 18

Mill

- Transport: 1MT cane
- ~ INR 120 - 200 (avg.)

Harvester / infielder drivers

- Service
- ~ INR 10.5

Society

- 100 kg Sugar
- INR 2500

Transport contractor

- Diesel & maintenance
- Driver + cleaner

Support labourers

- ~ INR 10.5

MITsdm

Copyright Hank Roark, 2013, All Rights Reserved
Tradespace exploration gives insights into how biofuel industry structure might benefit from technology

Bernstrom, Johnson, Roark, Schlichtmann (2010)
Ethanol
Ethanol Dedicated Pipeline

![Graph showing cost versus utility with Gen 1 and Gen 2 data points]

Copyright Hank Roark, 2013, All Rights Reserved
Butanol
Butanol Using Existing Pipelines

![Diagram showing cost and utility with Gen 1 and Gen 2 labeled]
Cotton harvesting improvements came from application of lean thinking

Optimizing the cotton harvest required a new form of cotton harvester...

...a new interface, the cotton module...

...new machines at the gin to process the module.

Module traceability is provided via RFID tag in module wrap and wireless information from the harvester.
Summary

Efficient agriculture production is needed to feed the growing global population

Technology and its adoption by society has historically led to increased agricultural productivity

Agriculture is a set of socio-technical systems that can benefit from systems thinking tools and processes
system design and management

Thank you

Hank Roark
hroark@alum.mit.edu
http://www.linkedin.com/in/hankroark