I. How Has Agriculture Evolved?

A. Characteristics of “Traditional” Farming Systems  

1) Types
   - Cropping systems
     - "Extensive" (slash & burn agriculture)  
       Def. Move farm every few years  Why?
     - “Mixed cropping”  
       Def. Plant several crops together in a field  Why?
   - Livestock systems
     - Extensive pastoral/nomadic systems  
       Def. Move cattle in search of grass  Why?

2) Farming practices are based on "local knowledge" passed from one generation to the next

3) Farm family provides all inputs (original "organic" farming system)
4) Farms are small (< 5 acres), farming is labor intensive  

5) Family mainly produces & processes food for own use (subsistence), but sell crops in good years when there’s a surplus  

6) Throughout history, farmers have increased food production by:
   o Planting more land **How?**
   o Using traditional technology to increase yields **Examples?**

7) Farmers using traditional farming systems are "**Poor but Efficient**"  
   Def. (India, YouTube, 1 min)

8) **Limitations** of traditional systems--can’t meet future food needs of growing population:
   o New & productive land not available for area expansion
   o Can’t rapidly increase yield using traditional technologies

B. Characteristics of “Modern” Farming Systems in DCs

1) Types  
   o Crop/livestock systems
      ✓ “Sedentary” and capital intensive  
      Def.
      ✓ Highly specialized, typically "monoculture"  
      Def.

2) Farming practices are **based** on “modern science”:
   o Genetics (Mendel, hybrids)
   o Chemical fertilizer (post-WW II)
   o Plant protection (pesticides since WW II, IPM now)
   o Power/equipment (mfg. tools, equipment, pumps)
   o Transport/processing/storage technologies

3) Farmers **purchase** most inputs from the market

4) Farms are large & mechanized
5) Farmers produce for the market (profit oriented)

6) Farmers increase production by increasing yields (use more inputs)

7) Farmers produce low cost food, but often receive subsidies from the government (Europe, US, Japan)

8) Limitations of modern farming systems—growing concerns about environmental impacts of input intensive agriculture
   - Pesticides contamination
   - Fertilizer (nitrate) in groundwater, oceans (dead zones)
   - Wildlife habitat loss

C. How Can LDCs Modernize their Farming Systems?
1) How traditional/modern are farming systems in LDCs?
   - Varies greatly by country, due to crops grown, growing environment (rainfed vs. irrigated), governmental policies & programs, etc.

   Many farmers in LDCs plant new/improved crop varieties, apply some fertilizer & insecticide, but few use machinery

2) Since the early 1970s, most of the increase in food production in LDCs (especially in Asia) has been due to higher yields (1980-90)
   - Higher yields (+27%)
   - More cropped area (4.5%)

3) Should LDCs follow the “intensification strategy” (i.e., increase yields) that DC used to “modernizing” their agriculture?

Yes/No—Limitations?
   - More fertilizer?
   - More machinery?
   - More irrigation?
   - More improved crop varieties (including GM varieties)?
   - More pesticides?
Implications:
- LDCs must intensify their agriculture to develop **BUT** a second "double green revolution" is needed!

- Future technologies must:
  1. Increases crop yield (limited potential to increase planted area)
  2. **But** be more "environmentally friendly" than past technologies, (e.g., IPM, YouTube, 2 min) (IPM Photos)

- LDC farmers need “appropriate technologies”
  **Def:** technologies that:
  - Solve farmer’s problems (in all growing environments)
  - Are simple to use (due to farmers’ limited education)
  - Are compatible with farmers’ limited resources (i.e., inexpensive)

4) Successful agricultural development in necessary to: (Figure)
- Increase in per capita food production
- Reduce food prices (which especially benefits the urban poor)
- Increase the demand for industrial goods **Why?**

II. How is Int. Agric. Research Organized?

A. Consultative Group for International Agricultural Research (CGIAR)--established in 1971)

1) History
- Created in response to the fear of famine—esp. in Asia
  - Rockefeller/Ford Foundation, wheat in Mexico (1940s)
  - IRRI, targeted rice, located in the Philippines (1960)
- Now supports 15 CGIAR-funded "IARCS", located throughout the world (Figure)
- Each Center has a mandate to focus on specific crops/livestock species and/or environments
- Now has 64 members (DCs, LDCs, Int. organizations)
2) CGIAR Centers’ agricultural research priorities:

- Reduce hunger/malnutrition through genetic improvement, (e.g., increase yields, reduce inputs use, reduce crop risk) (Photo)
- Sustain biodiversity by collecting plant genetic resources (Photo)
- Promote diversification & high-value commodities/products
- Promote sustainable management & conservation of water, land, and forests (Photo)
- Improve policies & facilitate institutional innovation, and
- Help to strengthen national research program by training LDC scientists—key to strengthening national research programs (e.g., IRRI & Cambodia, post-genocide)

Note: CGIAR research is shared via international research networks at no cost to LDCs (public good!)

3) CGIAR Centers focus on the major food crops & livestock species, and environmental problems facing LDCs

- Staple food crops: rice, maize, wheat, barley, cassava, yams, millet, sorghum, potatoes, sweet potato, cowpea, banana
  Note: NOT export crops (e.g., coffee, cocoa, oil palm, sugarcane)

- Livestock: focus on improving local breeds of cattle & goats
  Why local breeds?
  ✓ Can tolerate heat/high temperatures
  ✓ Resistant to diseases
  ✓ Can survive on low quality grasses

- Fish (aquaculture/inland fish ponds): focus on increasing growth rate, disease resistance (Photo)

- Agroforestry (trees & soil conservation): focus on developing
  ✓ Quicker-growing trees for firewood
  ✓ Technologies (terracing) to reduce soil erosion
4) CGIAR System’s budget & staff are very small! (2009)
   o Funded by donors—DCs, LDCs, Int. organizations/foundations
   o Budget—$520 million/year
   o Employs about 8,000 scientists, based in >100 countries
   o Focus—SS-Africa (46%), Asia (30%), LAC (14%), other (10%)

   **Note:** MSU’s agricultural research budget = $100 million (2007); US has >23,000 agricultural & ag-related scientists

B. The international agricultural research system is a **partnership** between developed & developing countries

   **Collaborators include:**
   o LDC’s national research institutes (e.g., EMBRAPA) & universities
   o DC’s national research institutes & universities
   o Private research firms (Cargill, Montsanto, Pioneer, ADM)
   o National governments, NGOs, private businesses
   o CGIAR centers
   o Key players—award-winning agri. scientists—[World Food Prize](#)

C. Recent Agricultural Research Successes Benefiting LDCs
   o Biological control of **cassava** mealy bug/green mite
   o New **rice** varieties for Africa—resistant to local pests/diseases
   o Drought-tolerant **maize** varieties for Africa
   o Flood-tolerant **rice** varieties (Bangladesh)
   o Zero tillage system for **rice-wheat** system in South Asia
   o “Fertilizer tree” fallows that renew fertility in Southern Africa
   o Information/tools to monitor **forests**, promote better management
   o New methods to detect/reduce **aflatoxin** in Southern Africa
   o New approaches for predicting the impact of **climate change**
   o Improved methods of small-holder **dairy** production in Kenya
   o Mapped **rice & maize** genome
   o Deep-rooting **beans** that are tolerant to drought & low fertility

   ➔ Increased food production, income, food security, sustainability²
III. What is the "Green Revolution"?
A. Key Features of GR Technologies

1) **Def:** use of science & technology to increase food production in developing countries

2) Emphasized biological (genetics), not mechanical technology

   **Why?**

   - Land:

   - Labor:

3) Not really a "revolution", but rather an "evolution"

4) What crops and regions did the GR benefit?

   - **First** (1960s)—rice & wheat—mainly in Asia

   - **Later, but less impact**—corn, cassava, sorghum, millet, etc. in other regions

5) How do agricultural scientists **develop** new crop varieties?

   - Set breeding **goals** (based on traits desired in new variety)

   **Rice—Example**

   - * High yield
   - * Shorter growing time
   - * Drought tolerance
   - * Better nutritional characteristics
   - * Pest/disease resistance
   - * Characteristics consumers prefer (seed color, taste, cooking time)
   - * Submergence/flood tolerance
   - * Other?

   **Traditional Plant Breeding**

   - **Select** from the seed bank germplasm (seed) with the desired traits/genes

   - **Cross, evaluate, screen** offspring (takes 7 generations)

   - **Test** "best" lines around the world (networks)
6) “Modern rice varieties”: an example of a GR success story

Traits & Benefits to LDC farmers?

<table>
<thead>
<tr>
<th>Trait</th>
<th>Benefit?</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short in height, fertilizer responsive</td>
<td>Benefit?</td>
<td>(Photo)</td>
</tr>
<tr>
<td>Mature in less time (100 vs. 160 days)</td>
<td>Benefit?</td>
<td></td>
</tr>
<tr>
<td>Genetically resistant to diseases/pests</td>
<td>Benefit?</td>
<td>(Photo)</td>
</tr>
<tr>
<td>Photoperiod insensitive--can plant in any month</td>
<td>Benefit?</td>
<td></td>
</tr>
</tbody>
</table>

IV. What Was the Impact of the Green Revolution?

A. Impact/Success of the Green Revolution Varied by crop, country, region

1) Crops—greatest impact on rice & wheat; less impact on maize, etc. Why?

2) Region—mainly benefited Asia Why?

3) Environment—mainly benefited irrigated farms Why?

4) Country—depended on govt. policies, land tenure situation (e.g., Indonesia, small farmers vs. India, large farmers)

5) Region within a country--varied by type of farming system Why?
B. Overall Impact Green Revolution in Wheat & Rice (1960-1990)
   - Farmers adopted new varieties (70%)
   - Yields doubled
   - Production doubled (while population increased by 60%)
   - Prices declined (especially benefited the urban poor)
   - Strengthened the rural economy
     (e.g., > farmer income, more purchases, more non-farm jobs)
     - Vietnam—Honda rice
   - Improved nutrition (i.e., more income, cheaper grain)
     - Other?

Example: Asia, Rice, 1965-91 (Production = area x yields)

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (m.ha)</th>
<th>Yld (t/ha)</th>
<th>Prod (mil. m. tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>114</td>
<td>2.0</td>
<td>232</td>
</tr>
<tr>
<td>1991</td>
<td>133</td>
<td>3.6</td>
<td>477</td>
</tr>
<tr>
<td>(+16%)</td>
<td></td>
<td>(+80%)</td>
<td>(+106%)</td>
</tr>
</tbody>
</table>

C. Asian Success was Due to Several “Complementary” Factors
   - Fertilizer
   - New variety
   - Irrigation
   - Government policies:
     (e.g., Asian farmers had good access to credit for buying inputs—seed, fertilizer, pesticides—extension, markets)

D. Criticisms of the Green Revolution in Asia
   - Benefited better growing environments (irrigated farms)
   - Benefited richer farmers who could afford fertilizer
   - Caused environmental damage
     (i.e., overuse of fertilizer, insecticide)
   - India—success, but a revolution reversed? (India, YouTube, 6 min)

Future research needs to address these 2nd generation problems,
But, What if there hadn’t been a Green Revolution?

**A key lesson:** technology alone isn't sufficient!!!
E. Recent Green Revolution Successes in Africa
   o Hybrid maize/wheat—Kenya, Zimbabwe, Ghana

   o But impact of the GR technology has been limited in Africa, due to:
     ✓ Diversity of crops grown—not just rice & wheat
     ✓ Many different farming systems—need specific technologies for each farming system
     ✓ Rainfed growing conditions (farming is risky)
     ✓ Poor government policies (weak research & extension systems, farmers have limited access to credit & markets)
     ✓ Widespread poverty—farmers can’t afford to buy inputs
     ✓ DC’s/donors resistance to providing loans for input subsidies

   o Africa—Meeting the Challenge of increasing Food Production
     ✓ Alliance for a Green Revolution in Africa (AGRA)—need a “Comprehensive Farm Support Package” (Mali, YouTube, 6 min)

V. New, Greener” Revolutions: Emerging Technologies

A. Genetic Engineering—very different from Traditional Plant Breeding

  1) What is biotechnology?
     o Tissue culture—used to produce disease free planting material (e.g., banana in the Honduras/Philippines, potatoes in Peru)
     o DNA-based techniques/GMOs most controversial—transfer genes across species to add new traits to crops (e.g. bt, flounder)
     o Diagnostic kits—used to identify presence of seed diseases
     o Agro-industrial applications—change characteristics of products (e.g., less fat in coconut oil)

  2) What are the potential benefits from biotechnology/GMOs?
     o Reduces years needed to develop new varieties
     o Introduce exotic genes into plants (e.g., bt for pest resistance)
     o Improve food quality (e.g., Golden rice, > vitamin A)
1) What are some benefits of Genetic Engineering?

- Safer/better environment (e.g., less pesticide use, less deforestation if farmers can grow more food on existing fields)
- Higher farmer profits (e.g., higher yields, less pesticides)

3) What are some concerns of LDCs/Critics of Genetic Engineering?

- Cost—requires expensive infrastructure, trained scientists
- Intellectual property rights—private sector owns most patents
- Biosafety—will genes escape (superweeds)?
- Food safety—is GMO food safe? (e.g., food allergens, Brazil nut)
- Biodiversity—will success displace all local varieties, reduce genetic diversity?
- Market concerns—will EU countries buy GMO crops?

**Bottom line**—Most LDCs (e.g., China, S. Africa, Brazil) are more concerned about increasing food production

4) Promising GMO-based technologies for food crops in LDCs

- **Rice**: “Super” Rice (less straw, fertilizer, water); “Golden” Rice (vitamin A); flood/submergence tolerance varieties (reduce yield losses); bt (natural pesticide)
- **Corn**: higher yield, drought & acid soil tolerant (can grows in poor environments, reduces risk), bt (natural pesticide, [Phil YouTube, 2 min.](#))
- **Potatoes**: “True seed” potatoes (virus free, higher yields, grow quicker)
- **Cattle**—vaccine (protects against East Coast Fever)
- **Soybeans**—herbicide tolerance (apply herbicide w/o killing crop)
- **Tomatoes**—salt tolerance gene (can grow in water with high salt levels, hope to later introduce into other crops)

Is organic farming (no chemical fertilizer/pesticides) an alternative to GMOs?

**Note**: 1 cow = only 41 kg of N/year
5) Will haven’t the Promises of GM Varieties been Realized?

- Concerns in Europe, US, LDC regarding:
  - Food safety (Bt corn, Roundup Ready soybeans)
  - Environmental impact of GMOs (gene escape—super weeds)
  - Export market impact (EU won’t buy GM crops)
  - Corporate control of biotechnology (a few multinationals own the key genes, processes)

**Note:** In US, most soybeans & corn are GMOs

- Increasingly complex/expensive regulatory environment
- GMO research has focused on major crops grown in DCs (corn, cotton, soybeans), neglecting many “orphan crops” grown in LDCs
- Private biotech firms in DCs not likely to develop GM varieties for poorer LDCs—farmers can’t afford to buy the seed

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B. **New opportunities** for LDC farmers: Non-Traditional Crops for Niche Markets

1) Mexico—“exotic” crops—avocados, spices (**Kalsec**) Why?

2) Kenya/India/C. America—horticultural/organic crops for export to Europe/US Why?

3) Colombia—flowers/roses to the US Why?

4) Fair trade—coffee, cocoa, rice, bananas for sale to ethical consumers (**TransfairUSA**) Why?

5) Peru—endangered *paiches* (fish species) Why?
VI. Future Challenges

A. Need a 2nd GR that’s “Greener”/Smarter—many Mini-GRs
   o Must “focus” on:
     ✓ Developing technologies for poor environments (dry, poor soils)
     ✓ Improving neglected crops (not just rice, wheat, corn)
     ✓ Improving infrastructure, marketing systems
     ✓ Increasing farmer access to inputs (seed, fertilizer)

   o Future technology must be more “environmentally friendly”
     Examples—IPM, technologies to control erosion, crop varieties that are more disease/pest/drought resistant, technologies that use water more efficiently (e.g., Kenya—water harvesting, Senegal—drip irrigation, Moneymaker pump [Rap!!!, YouTube, 5 min])

   o Addressing Asia’s rice crisis—challenges & solutions (Dr. Zeigler, BBC-IRRI, YouTube, 4 min)

   o Addressing Africa’s food crisis—Kofi Annan ([An African Green Revolution, YouTube, 6 min])

B. BUT........

Science Alone Can’t Solve the Food Problem!

   o Developing countries should:
     ✓ Improve rural infrastructure—roads, dams
     ✓ Invest more $ in agricultural research
     ✓ Target neglected groups (women & the poor) to insure that they benefit from new agricultural technologies
     ✓ Implement policies to promote agriculture—access to credit, extension, markets (e.g., Kenya, phone based marketing), subsidized inputs (e.g., fertilizer & seed)—controversial
     ✓ Eliminate restriction on GMOs?—controversial
     ✓ Expand South-to-South collaboration ([EMBRAPA])

   o Developed countries should:
     ✓ Provide more aid for agriculture—now recognized by World Bank, EU, and US => Global Agricultural & Food Security Program
     ✓ Open up markets to LDC’s crops (e.g., sugar)
     ✓ Reduce agricultural subsidies (FAO, cheap food dependence)
SORGHUM (to be harvested in Dec)
PEANUTS (harvested in Sept, removed)
SESAME (planted in Oct)
YAM HEBPS (made in Oct, to be planted in Feb)
MILLET (harvested in Aug)
Animal manure

Legumes (e.g. cowpea) fixes nitrogen

Traditional irrigation
The CGIAR System: Institutes Agricultural Research Institutes

- IFPRI
  Washington, D.C., United States
- CIMMYT
  Mexico City, Mexico
- CIAT
  Cali, Colombia
- CIP
  Lima, Peru

- IPGRI
  Rome, Italy
- ITA
  Itali, Nigeria
- ICRAF
  Nairobi, Kenya
- ICRISAT
  Patancheru, India
- IWMN
  Colombo, Sri Lanka
- ILRI
  Nairobi, Kenya
- ISNAR
  The Hague, Netherlands
- ICLARM
  Manila, Philippines
- IRRI
  Los Baños, Philippines
- CIFOR
  Bogor, Indonesia
The response to nitrogen fertilizer of two semi-dwarf rice varieties—IR8 and Taichung Native 1—and of Petu, a tall, traditional variety. In the 1966 dry season on IRRI's experiment farm.
**Genetics—Mendel**
- Discovered how plants inherit traits
- Foundation of plant breeding & the Green Revolution

**Fertilizer—A Short History**

**Guano**
- Incas applied to corn
- Commercially mined/exported to Europe/US (1840-1860)—25x more potent than manure, source of ammonia/nitrate for munitions
- Response to growing demand for food/munitions for war

**Chilean nitrate**
- Darwin observed mining (1835) in Atacama Desert
- Commercial mining exploded 1970s as guano supplies ran out
- Cheap source saltpeter for gunpowder & nitrogen fertilizer

**Ammonia**
- Haber-Bosch process (early 1900s) made ammonia from air, reduced cost of fertilizer/munitions
- One of most important invention is 20th century (Nobel Prize)—prevented famine, prolonged WW II