Towards guidelines which data to collect for detailed empirical yield gap analysis

Example: Annual variability in actual rainfed durum-wheat yields in Spain

- The yield gap varies from field to field and from year to year!

by: Kees de Bie
Wageningen University, Aug. 2017
To study:

**Firstly:** Why do yields (impacts) vary (remain sub-optimal) between fields *(Biophysical)*? → Needs good/complete Land Use System data-sets

**If known, then*:** Why are farmers not adopting available remedial technology *(Socio-Economical)*? → Needs good/complete Farming System (Holding & Context) data-sets

• Assuming, of course, that the specific Land Use System is (economically) suitable and (biophysically) sustainable.
• This PPT limits itself to the biophysical (first) part.

**Example:** Annual variability in actual rainfed durum-wheat yields in Spain

![Graph showing annual variability in actual rainfed durum-wheat yields in Spain. The yield gap varies from field to field and from year to year!](image-url)

**Why?**
Yield Gap studies address:
- growth limiting
- yield reducing
- land modifying
aspects of a specific Land Use Systems.

They relate differences in land and in (remedial) management to (+/-) differences in system performances.

They require survey data from many plots (farmers’ fields) located in pre-selected map-units (within one recommendation domain).

A CGMS will provide the potential/benchmark yield
The biophysical basics of Yield Gap studies

Yields of 63 paddies varied
From ‘0’ to almost 5500 kg/ha.

**EXAMPLE**

![Graph showing yield distribution](image)

**WHY?**

- **Paddies with low cropping intensity** (one crop per annum)
- **Paddies with high cropping intensity** (two or three crops per annum)
Performance = \( f(\text{land, land-use}) \)

Yield
(a land use purpose)

Impact on land
(e.g. erosion, bulk density, or salinity data)

Observations on land (crop) by the surveyor/land user

Management data
(operation sequence data)

RS/Sensor data

Observation data

Interview data

Function defining the performance (+/-) of a LUS
### Regression output

<table>
<thead>
<tr>
<th>Linear Multiple Regression</th>
<th>8 steps model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable = Rice Yield (kg/ha)</td>
<td>S.E. = 482</td>
</tr>
<tr>
<td>N = 63</td>
<td>Adj. $R^2$ = 86%</td>
</tr>
<tr>
<td>Stepwise forward solution</td>
<td></td>
</tr>
</tbody>
</table>

**Constant:**

<table>
<thead>
<tr>
<th>Coeff.</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2283</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independents</th>
<th>R² when entered</th>
<th>Coeff.</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidence of Rice Blast (%)</td>
<td>41.3</td>
<td>-43.22</td>
<td>0.0%</td>
</tr>
<tr>
<td>If water shortage during Heading/Flowering</td>
<td>61.1</td>
<td>-607.66</td>
<td>0.0%</td>
</tr>
<tr>
<td>Lodging at Yield Formation stage (%)</td>
<td>69.1</td>
<td>-52.93</td>
<td>0.0%</td>
</tr>
<tr>
<td>If 3 sequential crops grown (H2O-avail.)</td>
<td>74.7</td>
<td>937.76</td>
<td>0.0%</td>
</tr>
<tr>
<td>Lodging at Heading/Flowering stage (%)</td>
<td>79.1</td>
<td>-13.58</td>
<td>0.1%</td>
</tr>
<tr>
<td>If the farmer considers his soil &quot;good&quot;</td>
<td>81.7</td>
<td>386.75</td>
<td>0.4%</td>
</tr>
<tr>
<td>Incidence of Brown Leaf Spots (%)</td>
<td>84.1</td>
<td>-32.65</td>
<td>0.5%</td>
</tr>
<tr>
<td>Length of the crop growing period (days)</td>
<td>85.7</td>
<td>13.01</td>
<td>1.7%</td>
</tr>
</tbody>
</table>

**General Notes**
- Very often 8 to 10 significant explanatory variables pop-up
- Explained variability is often 60 to 90%

**Specific Notes**
- In this case NPK use failed to provide sign.impacts (v.poor NPK management etc.)
- Problems related to: location (land), management (early planting), diseases (rice blast), variety (lodging), and access to water
- Many defined variables were mutually correlated, e.g.: good soil $\leftrightarrow$ infiltration rate, planting date $\leftrightarrow$ growing period, cropping system $\leftrightarrow$ location

Yield (kg/ha) = 2283 – 43 . RiceBlast-% – 608 {if H2O deficit during Heading/Flowering} – etc.
Further details:

Land Use System (LUS) = Land + Land Use
Land Use = Land Use Purpose(s) + Operation Sequence

Performance of land use purpose-\(x\) = 

\[ f(\text{land observation-y, land-use specification of operation-z}) \]
Further details:
Land Use Purpose(s) = Aimed at [Species/Services] + [Products/Benefits] combinations

Land-Use is what happens, i.e. the WHY, HOW and WHEN (between \( t_y \) and \( t_z \))

e.g.:
the land service is: [Recreation - Sports - Canoeing],
for the benefit: [Pleasure],
through the operation: [Peddling].

Example of a multi-purpose land use:

Further details:

The Operation Sequence → full inventory and details of actual management
The Observation Sequence → inventory of noteworthy land conditions (states and occurrences)

Illustrating land use operations

Illustrating land use observations

Typically the land user is your BEST/ONLY information source

Links to Citizen Science and to Crowd Sourcing
The Operation Sequence ➔

full inventory and details of actual management

e.g. Sticky rice, Phrao

The crop is photosensitive.
The Observation Sequence →
inventory of noteworthy land conditions (states and occurrences)

Example:

### Impact of Water Shortage on Yield

<table>
<thead>
<tr>
<th>Establishment</th>
<th>Vegetative</th>
<th>Heading + Flowering</th>
<th>Yield formation</th>
<th>Count</th>
<th>Average yields (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>9</td>
<td>2893</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>2</td>
<td>2109</td>
</tr>
<tr>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>3</td>
<td>2069</td>
</tr>
<tr>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>12</td>
<td>2605</td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>5</td>
<td>2019</td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>13</td>
<td>2101</td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>19</td>
<td>3932</td>
</tr>
</tbody>
</table>

### Impact of Lodging on Yield

<table>
<thead>
<tr>
<th>Period of lodging</th>
<th>Freq.</th>
<th>Average rice yields (kg/ha)</th>
<th>Average lodging-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>During Heading/Flowering</td>
<td>15</td>
<td>2300</td>
<td>34 (7.5-60.0)</td>
</tr>
<tr>
<td>During Yield Formation</td>
<td>9</td>
<td>1988</td>
<td>21 (12.5-27.5)</td>
</tr>
<tr>
<td>During Ripening</td>
<td>8</td>
<td>3585</td>
<td>20 (12.5-27.5)</td>
</tr>
<tr>
<td>None</td>
<td>31</td>
<td>3187</td>
<td>0</td>
</tr>
</tbody>
</table>

### Impact of Pests and Diseases on Yield

<table>
<thead>
<tr>
<th>Pests / Disease</th>
<th>Freq.</th>
<th>Correlation with yields</th>
<th>Inter-Correlations</th>
<th>Use in M. Regr.?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice Blast</td>
<td>63</td>
<td>-64</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>Leaf blight</td>
<td>10</td>
<td>-34</td>
<td>37% with RB</td>
<td>Exclude</td>
</tr>
<tr>
<td><strong>Brown Leaf Spot</strong></td>
<td>18</td>
<td>-17</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>False smut</td>
<td>41</td>
<td>-12</td>
<td>20% with RB</td>
<td>Exclude</td>
</tr>
<tr>
<td>Stem Borers</td>
<td>17</td>
<td>-12</td>
<td>None</td>
<td>Try</td>
</tr>
<tr>
<td>Black bugs</td>
<td>7</td>
<td>-8</td>
<td>None</td>
<td>Try</td>
</tr>
<tr>
<td>Sheath rot</td>
<td>12</td>
<td>0</td>
<td>-</td>
<td>No effect</td>
</tr>
<tr>
<td>Foot rot</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>No effect</td>
</tr>
</tbody>
</table>
Overview of land and land-use data to collect in the field

Interview data with the land-user
- holding/holder information (profile)
- site aspects (tenancy arrangement, cadastral no., distance to holding)
- land use system (plot) aspects for the period considered:
  - a-priori land use class:
    - Purpose: crops grown / services provided (% of area, quantities obtained of products/benefits)
    - Selected Operation Sequence classifiers
  - operations (crop calendar):
    - operation name; species involved; % of plot involved; period / periodicity / duration and task times; main power source
    - labor and material inputs and implements / infrastructure used
    - products / benefits obtained
  - observations (by land user):
    - soil related (workability, infiltration rate, fertility status, etc.)
    - weather related (hail storm, dry period, etc.)
    - crop related (pests, diseases, lodging, wilting, etc.)

Observations by surveyor
- plot size, coordinates, slope, position, etc.
- crops (residues) and infrastructure present in / around the plot (with relevance to the plot)
- land cover data (crop condition, growing stage, weed incidence, biomass, height)
- ground cover status (bare soil, mulch, crop residues)
- specific observations (soil characteristics, tillage condition, erosion status, hydrological aspects, pests / diseases incidence, evidence of grazing, burning, etc.)

Use also to validate other info
End with: Expected yield, and reasons why lower!!
The results of the Yield Gap study (1)

e.g. Sticky rice, Phrao

### Tabular interpretation

<table>
<thead>
<tr>
<th>Independents</th>
<th>coefficient (c)</th>
<th>measured values (v)</th>
<th>Yield gap</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>avg.</td>
<td>best</td>
<td></td>
</tr>
<tr>
<td><strong>constant</strong></td>
<td>2283</td>
<td>1</td>
<td>2283</td>
</tr>
<tr>
<td>If 3 sequential crops grown (H2O avail.)</td>
<td>937</td>
<td>0.079</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>938</td>
</tr>
<tr>
<td>Length of the crop growing period (days)</td>
<td>13.01</td>
<td>120</td>
<td>1572</td>
</tr>
<tr>
<td>Incidence of Rice Blast (%)</td>
<td>-43.22</td>
<td>15.8</td>
<td>-216</td>
</tr>
<tr>
<td>If the farmer considers his soil &quot;good&quot;</td>
<td>386</td>
<td>0.44</td>
<td>172</td>
</tr>
<tr>
<td>If H2O shortage during Heading/Flowering</td>
<td>-607.66</td>
<td>0.32</td>
<td>-193</td>
</tr>
<tr>
<td>Lodging at Yield Formation stage (%)</td>
<td>-52.93</td>
<td>3.0</td>
<td>-158</td>
</tr>
<tr>
<td>Lodging at Heading/Flowering stage (%)</td>
<td>-13.58</td>
<td>8.1</td>
<td>-110</td>
</tr>
<tr>
<td>Incidence of Brown Leaf Spots (%)</td>
<td>-32.65</td>
<td>3.2</td>
<td>-104</td>
</tr>
</tbody>
</table>

**Estimated yields (kg/ha):** 2856 5434  
**Actual yields (kg/ha):** 2855 5437  
**Estimated yield gap (kg/ha):** 2578

**Expected yield at Sampatong Rice Research Station:** 4378  
**Potential yield at Sampatong Rice Research Station:** 6253

![Graph showing yield gap, actual yield, average yield, and potential yield](image)

A CGMS will estimate the potential yield.
The results of the Yield Gap study (2)

The yield constraints and their relative importance:
- Water shortage (41%) ... a ‘location’ problem
- Diseases incidence (22%; rice blast & brown leaf spot)
- Late planting (18%) ... a ‘labor availability’ problem
- Lodging (10%) ... a ‘variety’ problem
- Poor soil condition (8%) ... a ‘location’ problem

Advise to organizations:
- Plant breeders must concentrate on resistance to drought, diseases, and lodging.
- Extension services are best concerned with water management, timely planting, and control of diseases.

Relevant land characteristics:
- Water-loss from paddies, defined by the soil infiltration rate (= site specific)
- Water shortage, defined by the distance from weirs (= map unit specific) // can still be ‘optimized’ through LUP

A CGMS will provide the potential yield

e.g. Sticky rice, Phrao
By 2050, we need about 70% more food, so let’s get some yield gaps closed!!

Questions ??

For supporting details see:
- Land use concepts (SIGMA PPT)
- CPA of Agro-Ecosystems