Generating Data to Improve Farm Management

(by using precision technology to inexpensively conduct long-term, large-scale field trials on several continents)


University of Illinois College of ACES

Brown Bag Seminar
U of I NCSA CyberGIS Center for Advanced Digital and Spatial Studies
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Fertilizer is great.
But it has its downsides, especially in water:
It leeches into groundwater.
It runs off into fresh water. Resulting algae reduces oxygen and other life.
Hypoxia dead zone in Gulf of Mexico
Too much fertilizer is bad for everybody.

Farmers lose money to increase pollution.
This leads us to some basic questions:

How much fertilizer is “too much?”
When should fertilizer be applied?
What fertilization rate maximizes a field’s profits?
How and why do optimal rates vary site-specifically?
How do management methods affect leaching and run-off?
How does timing of fertilization affect farm profits and run-off?
What’s the trade-off between environmental quality and farm income?
How does that trade-off change with growing conditions?
With better answers:

We give farmers better advice and government better advice.
These questions are basic, but have complicated answers, because...
Every farm field is different, and even small pieces of land within farm fields can be quite different.
Yield response varies greatly, even between neighboring small sites.
Let’s present a conceptual framework and then a little microeconomic theory.
YIELD

ROOT GROWTH

SOIL ENVIRONMENT

CLIMATE

MANAGEMENT DECISIONS

GENETIC POTENTIAL OF THE PLANT

INJURY

Disease & Insects

AVAILABLE WATER

AERATION

Soil Structure & Texture

BULK DENSITY

Soil Strength

CEC ELECTRICAL CONDUCTIVITY

AVAILABLE NUTRIENTS

pH

Organic Matter
Let’s try to get organized a little …

Yield responds to

- Managed inputs \((x)\)
- Spatially dependent *characteristics* \((c)\)
- Unmanaged time-dependent variables \((z)\)

\[
y = f(x, c, z)
\]
Managed Inputs

\[ \mathbf{X} = (x_1, x_2, x_3, \ldots) \]

- Nitrogen fertilizer (pre-plant)
- Herbicide (post-emergence)
- Equipment choices
Spatially-dependent characteristics

\[ \mathbf{c} = (c_1, c_2, c_3, \ldots) \]

- Soil depth
- Soil texture
- Slope of ground
Unmanaged time-dependent variables

\[ Z = (Z_1, Z_2, Z_3, \ldots) \]

- July rainfall
- June temperature
- European corn borer population (possibly also spatially dependent)
The general shape of the curve above, an example of how many researchers believe corn yield responds to N at some locations under typical weather conditions.
Knowing this, let’s see if an N-rate of 100 lbs/ac will make us the most money.

Since the slope of the curve is 1 here, raising N-Rate from 100 to 105 raises yield by 5 bu.
Costs increase by about \((5 \text{ lb.} \times \$0.30/\text{lb}) = \$1.50\)
Revenues increase by \((5 \text{ bu} \times \$4.00/\text{bu}) = \$20.00\).
Response curve is too steep at $N = 100$, so $N = 100$ won’t make us the most money!
Which N rate will make us the most money?  The one at which the slope of the response curve equals the price ratio of \( \frac{\$/lb \text{ N}}{\$/bu \text{ corn}} = w/p = 0.30/4.00 = 0.075 \).

Most money made at \( N^* = 180 \).
But actually, of course, things are a lot more complicated in real life:
Therefore, to use the ACE 100 picture,

Every site in every year will have its own economically optimal input application rates:

\[ f(x_1, c_A, z_{2016}) \]

\[ f(x_1, c_B, z_{2016}) \]

\[ f(x_1, c_C, z_{2016}) \]

\[ f(x_1, c_D, z_{2016}) \]
The Point:

Area A, 2016

Area B, 2016

Area C, 2016

Area D, 2016

WE DON ’T KNOW THE PICTURE!

$y = f(x_1, c^A, z^{2016})$

$y = f(x_1, c^B, z^{2016})$

$y = f(x_1, c^C, z^{2016})$

$y = f(x_1, c^D, z^{2016})$
The real problem: Lack of data
Historically, it was too labor-intensive, too expensive to generate the data:
Laying out small plots using tape measures and orange flags:
Applying inputs by hand or with special equipment:
grad student labor...
But we are hoping to use (cyber) GPS technology to change this situation. A lot.
We want to make fertilizer management depend much more on *science and data*. 

*Getty*
Provide statistically reliable *site-specific* recommendations (and much more).
We want to be the *Moneyball* guys & gals of fertilizer management!!!!
Key: have been running very big “checkerboard” trials very inexpensively,
using software to quickly design randomized field trials.
A 2016 on-farm N rate & seed rate field trial:

Sasse 2014 - Blocks

Sasse 2014 - N Rate (lbs/acre)

Sasse 2014 - Seed Rate (thousand/acre)
VRT allowing participating farmer Alan Sasse to implement our experiment while just doing his usual thing:
Sasse enjoyed taking video of seed rate monitor while he put the experiment in the ground:
Of course, use yield monitor at harvest:
Not small plots.

Experiments on Large fields
(300 ha fields in Brazil)
Begin to see the “yield response map”

Experimental N-rates in 2015:

<table>
<thead>
<tr>
<th>N</th>
<th>Yield</th>
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</thead>
<tbody>
<tr>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>175</td>
<td>225</td>
</tr>
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<tr>
<td>175</td>
<td>100</td>
</tr>
<tr>
<td>225</td>
<td>125</td>
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Yields in 2015:

<table>
<thead>
<tr>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
</tr>
<tr>
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<tr>
<td>150</td>
</tr>
<tr>
<td>175</td>
</tr>
<tr>
<td>200</td>
</tr>
</tbody>
</table>

Each plot provides a piece of data: experimental N-rate and Yield for 2015.
We can get... Data! Lots and lots of data!
Data to answer the questions about

- how yields respond to fertilizer
- how much fertilizer is “too much”
- how these things vary over space and time.
What We’ve Promised to Do with our $4 million from USDA
Main parts of proposal:

- Field Trials
- Field Labs & Water Quality
- Data storage & Maintenance
- Software development
1. Field Trials

- Use precision agriculture technology to design and conduct 100, large-scale, on-farm field trials

<table>
<thead>
<tr>
<th>Location</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Project Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
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</tr>
<tr>
<td>NE</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<td>2</td>
<td>3</td>
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<td>Argentina</td>
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<td>3</td>
<td>12</td>
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<tr>
<td>Uruguay</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14</strong></td>
<td><strong>22</strong></td>
<td><strong>29</strong></td>
<td><strong>35</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Table 2. Planned Project Field Trials
U.S. On-farm Field Trials

<table>
<thead>
<tr>
<th>State</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
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<tbody>
<tr>
<td>Illinois</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
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<td>Nebraska</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Kentucky</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
South American On-farm Field Trials

Uruguay
2016: 3
2017: 3
2018: 3
2019: 3

Sante Fé
2016: 3
2017: 3
2018: 3
2019: 3
In budget:

Compensation to U.S. farmers for any monetary losses due to participation.
2. Big part of project: measuring nutrient run-off.
This will help us better calibrate nutrients/water flow models.
Large-scale Specialized Field Laboratories

To Illinois state budget, Illinois corn growers have paid “check-off” fees to generate revenues for state of Illinois, to be dedicated to corn research. They want to work with our project, using those funds to set up specialized field laboratories.
160-acre U of I-owned field

Tiled so that in each 5-acre area, the water flows to the same point, where it can be chemically analyzed.
Cost of setting up each field lab: $600,000.

By 2019, ICGA wants to have set up five such labs, and wants to give our project the sole right to design and run experiments on those labs.
And measure trade-offs between farm profits and environmental quality.
3. Data Management:

Prof. Shaowen Wang and his group in NCSA for are working with us over long term to develop a “Data Intensive Agriculture” program and accompanying infrastructure.
Our proposal is that NCSA maintain a central database.

- INOPAR (RIAP) researchers contribute.
- INOPAR (RIAP) researchers have access.
Data from farms all over the world, to INOPAR researchers all over the world.
4. Also with NCSA:
Develop two software packages:

- On-farm Research Design (OfRD) software
- Data-intensive Farm Management (DiFM) software
Purpose: Make it possible for researchers all over the world to efficiently design and conduct “checkerboard” field trials, and transfer the data to our Central Database.
Develop “Data-Intensive Farm Management” (DIFM) software

Use DIFM to link research results to individual, site-specific farm management recommendations. Using CyberGIS base—user friendly.
How do we get farm- and site-specific advice to farmers?
Every farmer can’t have someone with a PhD analyze the farm’s data to make recommendations.
We are developing software that

- Can use a farm’s site-specific data with what we know from worldwide data
- Has algorithms that do the statistics/econometrics
- Update analysis yearly with new data
- Consultant-friendly: A trained person with Master’s degree works with the farmer
(DIFM) software

Who: Consultants, crop advisors, extension personnel work with farmers using this tool
Maybe consultant shows farmer something like this?

Plans shown:
- Plan A
- Plan B
- Plan C
- Plan E
- Plan F
- Plan G

Prices of Crop assumed:
- $3.00
- $3.50
- $4.00
- $4.50
- $5.00
- $5.50
- Use econ model forecast

Price of N assumed:
- $0.20
- $0.25
- $0.30
- $0.40
- $0.45
A rare “win-win” situation:
• Improved farm economy
• Better environment
Need to be *international*

- For variability in growing conditions
- For access to farms
- To be pertinent to agriculture worldwide
December Argentina meeting

35 researchers from five countries

Formed *International Network for On-farm Precision Agriculture Research* (INOPAR):
Coordinated trial design to use all the data together.