Producer's Guide to Developing Prescription Maps Using Various Inputs

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Jan. 12-13 2016
2016 Cropping Systems Conference
Three Rivers Convention Center
Kennewick, WA
Site-Specific Climate-Friendly Farming

- Erin Brooks
- Kate Painter
- Kate Reardon

- Jan Eitel
- Lee Vierling
- Dave Brown
- Claudio Stockle
- Jeff Smith
- Dave Huggins

Remote sensing, soil sensing & mapping, simulation modeling, cropping systems, hydrology, microbiology, biogeochemistry, economics, simulation modeling

Palouse

$4.6 million, 5 years
What is Precision Agriculture?

Precision agriculture (PA) or satellite farming or site specific crop management (SSCM) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. (Wikipedia)

4 R’s of precision agriculture

• **Right input (at the)**
• **Right time (in the)**
• **Right amount (in the)**
• **Right location**

It’s a learning process!!!
Why do variable rate application of fertilizer?

• Decrease input costs
• Improve grain quality
• Maximize profit

• Avoid yield losses/increase yield
• Meet protein goals
What do these cropping patterns mean?
How can we improve nitrogen management in this landscape?

Ward (2015)

Managing Spatial Variability
How can we improve nitrogen management in this landscape?

Ward (2015)

Managing Temporal Variability/Resilience
In the information age it sometimes might feel like you are...

Drinking from the Digital Data Fire Hose
2012 Precision Ag Survey on the Palouse
REACCH (Wulfhorst et al., 2014)
900 surveys sent, 46% response rate

Most growers have GPS guidance

Over half growers do not have a yield monitor
How do we improve N management?

• Fundamentals
  – Nitrogen management
  – Creating Rx Fertilizer Map
  – Post-Harvest Evaluation

• Understanding processes that drive variability
  – Soils & Hydrology
  – Remote sensing

• What models tell us
  – Cropping systems modeling
  – Economic implications
How do we improve N management?

• **Fundamentals**
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• **What models tell us**
  - Cropping systems modeling
  - Economic implications
Nitrogen Cycling 101

• How much nitrogen in the soil is available?
• How is nitrogen lost (groundwater/atmosphere)?
• How do I apply fertilizer to minimize losses?
• Pools, fluxes, transformations...

Inorganic Nitrogen Balance

Input - Output = Change in Storage

• Inputs
  • Fixation + Mineralization + **Fertilization**

• Outputs
  • Plant Uptake(Immobilization) + Leaching + (Volatilization + Denitrification)
Calculating Fertilizer Requirements

• Local Fertilizer guides provide good initial estimates
Calculating Fertilizer Requirements

• Fertilizer Required = Plant Uptake + Leaching + Volatilization – Fixation – Mineralization – (Inorganic N in soil)

Unit N Requirements (UNR)***

UNR for the Palouse:
Soft white winter wheat = 2.7 lbs N/bu (2.5-2.9)
Hard red wheat = 2.9 – 3.7 lbs N/bu

***Assumed N Uptake efficiency of 50% !!!
Calculating Fertilizer Requirements

- Fertilizer Required = Plant Uptake + Leaching + Volatilization – Fixation – Mineralization – (Inorganic N in soil)

Requires knowledge of Soil Organic Matter

Can range from 10-100 lbs N per acre!!!

In the Palouse:
- 1% SOM \(\rightarrow\) \(~20\) lbs N / acre
- 3% SOM \(\rightarrow\) \(~60\) lbs N / acre
How do we improve N management?

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  – Economic implications
Variable rate fertilizer application technologies

**Require**

Field specific management zones

- Crop Yield Monitor Data
- Pre-plant soil sampling
- Experience

**Methods to establish zones**

**what is happening**

- Soil Electrical Conductivity mapping
- Satellite Imagery

**Improved spatial resolution**

**Better understanding of why it is happening**

[SCF: Site-specific Climate-friendly Farming]
Steps to create Rx Fertilizer Map

1.) Set realistic crop yield goals
- How does crop yield vary across the field?
- How do soil moisture levels this year compare with previous years?
- Should I expect relative low yields (drought year) or good yields?
Steps to create Rx Fertilizer Map

With multiple years of crop yield maps you can create a relative crop yield map.

\[
Y_{rel} = \frac{\sum_{i=1}^{N} Y_i}{N \times Y_{avg,i}}
\]

- \(N = \text{number of years}\)
- \(i = \text{specific year}\)
- \(Y = \text{yield at a point in year } i\)
- \(Y_{avg,i} = \text{field average yield for year } i\)

Caution: Must calibrate your yield monitor each year and crop!
Steps to create Rx Fertilizer Map

Using a relative yield map you can create a potential yield map from historic field average yield data.

\[ Y_{act} = Y_{avg\ field} \times Y_{rel} \]

<table>
<thead>
<tr>
<th>Year</th>
<th>Field Average Yield (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>110</td>
</tr>
<tr>
<td>2010</td>
<td>80</td>
</tr>
<tr>
<td>2011</td>
<td>42</td>
</tr>
<tr>
<td>2012</td>
<td>80</td>
</tr>
<tr>
<td>2013</td>
<td>93</td>
</tr>
<tr>
<td>2014</td>
<td>105</td>
</tr>
<tr>
<td>2015</td>
<td>90</td>
</tr>
<tr>
<td>Average</td>
<td>85.7</td>
</tr>
<tr>
<td>Std. dev.</td>
<td>22.4</td>
</tr>
</tbody>
</table>

Do I use the average?

Do I use the maximum?

I may compare this year to the most similar previous year.
Steps to create Rx Fertilizer Map

With a relative yield map you can create an actual field average yield by the relative yield.

\[ Y_{\text{act}} = Y_{\text{avg field}} \times Y_{\text{rel}} \]

I used the long term field average.

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<td>93</td>
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Steps to create Rx Fertilizer Map

2.) Creating Management Zonees

- Often created in mapping software from potential crop yield map
- Can also be created from soil or remote sensing maps (less common)

Three zones using “natural breaks”

<table>
<thead>
<tr>
<th>Potential Yield</th>
<th>bu/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>65 - 98</td>
</tr>
<tr>
<td></td>
<td>99 - 114</td>
</tr>
<tr>
<td></td>
<td>115 - 137</td>
</tr>
</tbody>
</table>
Steps to create Rx Fertilizer Map

2.) Creating Management Zones...

- Often created in mapping software from potential crop yield map
- Can also be create from soil or remote sensing maps (less common)

Three zones using “equi-interval”

Potential Yield
bu/ac

- 65 - 90
- 91 - 116
- 117 - 137
Steps to create Rx Fertilizer Map

2.) Creating Management Zones...

- Often created in mapping software from potential crop yield map
- Can also be created from soil or remote sensing maps (less common)

Potential Yield

bu/ac

- 65 - 84
- 85 - 102
- 103 - 122
- 123 - 137

Four zones??
Steps to create Rx Fertilizer Map

2.) Creating Management Zones...
   - Often created in mapping software from potential crop yield map
   - Can also be created from soil or remote sensing maps (less common)

Five zones??

<table>
<thead>
<tr>
<th>Potential Yield</th>
<th>bu/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 - 80</td>
<td>red</td>
</tr>
<tr>
<td>81 - 96</td>
<td>yellow</td>
</tr>
<tr>
<td>97 - 110</td>
<td>light green</td>
</tr>
<tr>
<td>111 - 126</td>
<td>light blue</td>
</tr>
<tr>
<td>126 - 137</td>
<td>dark blue</td>
</tr>
</tbody>
</table>
Steps to create Rx Fertilizer Map

• Number of zones
  • The uncertainty in the potential yield goal will be large (~10-20 bu/ac)
  • Little confidence that multiple zones represent significant differences
  • Most growers use 2-4 zones
3.) Soil Sampling

- Zone sampling (most common)
  - Pre-plant inorganic nitrogen (most common)
  - Post-harvest inorganic nitrogen (for evaluation)

Soil Organic Matter sampling every 5-10 years
Steps to create Rx Fertilizer Map

4.) Calculate the amount of Fertilizer for each zone

Fertilizer amount = Yield Goal x UNR – Mineralizable N – Preplant Inorganic N in root zone

Adjust with experience and understanding of crop response in each zone!!

How good are these numbers???
Need some way to evaluate this...
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- **Understanding processes that drive variability**
  - Soils & Hydrology
  - Remote sensing

- **What models tell us**
  - Cropping systems modeling
  - Economic implications
Post-Harvest Evaluation

1) Did I meet my yield goals?
2) Did I meet my protein goals?
3) How efficiently is my nitrogen being used?
4) Should I adjust my strategies?
<table>
<thead>
<tr>
<th>Zone</th>
<th>Fertilizer Rate</th>
<th>Protein Goal</th>
<th>Yield Goal</th>
<th>Efficiency Goal</th>
<th>Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Consider boosting fertilizer rates, ran out of fertilizer during grain filling</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Cut fertilizer rates, may check to see if nitrogen fertilizer is still in soil or whether it was lost to leaching</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Good! Consider boosting fertilizer rates, used all the fertilizer that was available, maybe unrealistic yield goal</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Likely a timing issue where you lost excess N to leaching: Less fall application and more spring application or consider legume rotation</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Likely over-application of N or very poor soil</td>
</tr>
<tr>
<td>6</td>
<td>Low</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Likely the crop was water stressed, poor year</td>
</tr>
<tr>
<td>7</td>
<td>Low</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

*N balance Index* = $\frac{N_g}{N_f} = \frac{N \text{ in grain (protein)}}{N \text{ fertilizer applied}}$

Performance Class Analysis
Brown (2015); Brown et al. (2014); Huggins et al. (2010)
Most commonly available measurements:

- Grain weight (yield monitor)
- Applied N (fertilizer) (Rx or as-applied map)
- Pre-plant soil N (soil sampling)

Useful but not readily available measurements:

- N biomass (from remote sensing)
- Grain N (protein) (protein sensor)
- Post harvest soil N (soil sampling)
- Mineralizable N (estimate from SOM)
Post-Harvest Evaluation

- Control strips crossing multiple zones provide less expensive quantification of yield response
How do we improve N management?

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  – Remote sensing

• What models tell us
  – Cropping systems modeling
  – Economic implications
Why high yield here?

Why low yield here?
Clay layers can route water laterally!
There are legacy issues if you farm on the Palouse!!
What are these patterns telling us?

May 9th

July 15th
Site-Specific Climate-Friendly Farming Research Sites

Colfax Site

Pullman Site

Troy Site

Leland Site

Genesee Site

Mean Annual Precipitation

- 336 - 441 mm
- 442 - 506 mm
- 507 - 563 mm
- 564 - 618 mm
- 619 - 677 mm
- 678 - 746 mm
- 747 - 823 mm
- 824 - 917 mm
- 918 - 1,050 mm
- 1,060 - 1,280 mm

Colfax Site Map

Elevation (m)

- 40
- 480
Terrain Modeling

- elevation
- slope (gradient)
Terrain Modeling

aspect

insolation

Colfax
Terrain Modeling

- **Topographic Wetness Index (TWI)** is a useful to map soil moisture patterns

\[ TWI = \ln \frac{a}{\tan(b)} \]

**where:**
- \( a \) = upslope catchment area
- \( b \) = slope steepness (degrees)

- **Assumes uniform soil thickness and hydrologic characteristics!**
Soil Maps

- **Key Stable Soil Properties**
  - Texture, Soil Organic Matter
  - Bulk Density
  - Depth to restrictive layer

- **Mapping Technologies**
  - Electromagnetic Induction
  - VisNIR penetrometer
  - Terrain modeling

- **Dynamic Soil Properties**
  - Ammonium & Nitrate N

*Soils influence hydrology*
In low rainfall zones of eastern Washington, every inch of additional water stored in the soil produces from 5 to 7 bushels of grain per acre. (Leggett, 1959; Schillinger et al., 2009)
Soil Maps – Electromagnetic Induction

• Tip resistance vs. bulk density

Robinson et al., SSSAJ, 2004
Soil Maps – Electromagnetic Induction

• Apparent electrical conductivity (ECa)
• Clay content and mineralogy
• Water
• Salinity
Soil Maps – Electromagnetic Induction

**Spring ECa**

**Fall ECa**

*Often high Electrical Conductivity (ECa) → shallow soils*

*Captures more complex soil/water differences elsewhere*
Soil Maps – VisNIR Penetrometer

Visible and Near-Infrared Spectroscopy
• Clay
• Soil Organic Matter
• Moisture
• ...

Tip Resistance
• Bulk Density
• Clay
• Soil Organic Matter
• Moisture
• ...

White Light
Detected Reflectance
Soil Material
Soil Maps – VisNIR Penetrometer

• Tip resistance

• Palouse soils commonly have 1-2 restrictive layers
  ✓ Plow pan ~ 30 cm (1 foot)
  ✓ Argillic/Fragipan at depth of 60+ cm (2+ feet) -- if present
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Remote Sensing – Drying Patterns

Daily resolution from time lapse camera
Remote Sensing – NDVI

• Normalized Difference Vegetation Index (NDVI)
• Ranges from 0 to 1
• Higher value → more green leaf area
  ✓ Canopy closure
  ✓ Senescence
Remote Sensing – NDVI (RapidEye Satellite)
Crop drying patterns correlate well with both soil and topographic variability.

Soil ECa Map
4/21/2012
Crop drying patterns correlate well with both soil and topographic variability.
Remote Sensing – NDRE

• Nitrogen Deficiency in Spring Wheat

<table>
<thead>
<tr>
<th>NDVI</th>
<th>NDRE</th>
<th>Leaf Chlorophyll Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

Rick Engel, Montana State University
Above ground crop N at harvest correlated with NDRE at peak greenness.

\[ y = 220.71x + 1.06 \]
\[ R^2 = 0.81 \]
\[ \text{RMSE} = 15.94 \text{ kg/ha} \]
Soil water storage is primary control on N uptake – particularly for spring wheat.
Palouse wheat & NDRE

- Notice fence line in 2013
- Patterns vary by year and crop
• NDRE is generally correlated with yield.

• NDRE is correlated with N uptake, which is correlated with grain protein.

• Comparing yield maps and NDRE maps can help identify areas with relatively low or high grain protein (or bad yield data).
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An Economic Analysis of Precision Ag Strategies with Crop Modeling
Economic Analysis

• Evaluation of variable rate zones should be based on profit
  • Most common strategies:
    1.) Cutting rates in lowest yielding locations
        • reduces costs and can increase yield (e.g. minimize ‘haying off’)
        • Weather/moisture dependent
    2.) Increasing rates in high yielding areas increases profit
    3.) Maximizing yield ≠ Maximizing profit
Annual cropping (CAF, Pullman, WA)
Crop Net Returns, 2006 (Painter et al., 2007)

Useful for evaluating Spatial Variability and Temporal Persistence Profit
Economic Analysis

Requires

- Farm Level cost of production ($/ac)
- Variable Rate Rx Map
- Yield Map

\[
\text{Returns to Risk ($/acre)} = \left[ \text{Crop Yield} \left( \frac{\text{bushels}}{\text{acre}} \right) \times \text{Crop Price} \left( \frac{\$}{\text{bushel}} \right) \right] - \left[ \text{Fertilizer} \left( \frac{\text{lbs}}{\text{ac}} \right) \times \text{Fertilizer price} \left( \frac{\$}{\text{lb}} \right) \right] - \text{Cost of Production} \left( \frac{\$}{\text{acre}} \right)
\]
3D CropSyst-Microbasin Model (Stockle et al., 2014; Ward, 2015)

**INPUTS**
(Each 10x10m pixel in basin can have unique input parameters)

- Microbasin (watershed) characteristics
- Farm Management Practices
- Crop Characteristics
- Soil Characteristics
- Weather

**OUTPUTS**
(10x10m pixel with daily and hourly time series data)

- Water Balance Parameters (ET, Runoff, Leaching, Precip)
- Nutrient Parameters (NO₃ & NH₄ leaching and concentration in soil layers, mineralization, etc)
- Crop Parameters (Yield, biomass, Nitrogen Uptake)
- Soil Parameters (water content, temperature, lateral flow)

Allows investigation of yield variability and economic response

Ward (2015)
Soil Moisture Field Patterns

Model assessment to observed field data (Ward, 2015)

Spatial & Temporal
- 12 locations
- Fall, Spring, & Summer dates

RMSE = 0.0371
Soil Moisture Changes with time

Model assessment to observed field data (Ward, 2015)

NSE = 0.61

Soil Water Content

Garbonzos

Winter wheat (shading?)

Change color of probes to make easier to see

Water Content (m$^3$/m$^3$)

Date

Foglia et al. (2009): 0.6 – 0.8 “very good” > 0.8 “excellent”
Model assessment to observed field data (Ward, 2015)

Soil Moisture Changes with time

NSE = 0.61

WW NSE = 0.89
Crop Yield & Crop N Uptake

<table>
<thead>
<tr>
<th></th>
<th>Simulated</th>
<th>Observed</th>
<th>RMSE</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield (bu/ac)</strong></td>
<td>87</td>
<td>91</td>
<td>14</td>
<td>15.5</td>
</tr>
<tr>
<td>(Yield Monitor)</td>
<td></td>
<td>(NDRE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>N uptake (Kg-N/ha)</strong></td>
<td>138</td>
<td>137</td>
<td>28</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Model assessment to observed field data (Ward, 2015)
Apply economic metrics to CropSyst-Microbasin outputs

Uniform Profit – Precision Profit

Returns to Risk ($/ac)
Hillslope Scenario Testing (Ward, 2015)

- Garfield Soil ‘Clay Knob’ (0.3 m)
- Southwick Soil (1 m)
- Palouse Silt Loam Soil (1.5 m)
Soil Type & Hillslope Position

Winter Wheat Crop Yield (bu/ac)

- Toeslope
- Foot Slope
- Back Slope
- Shoulder
- Crest

Garfield (Shallow)
Southwick (Moderate)
Palouse (Deep)
Temporal Stability in Yield Goal

Crop Yield (bu/ac) vs. Probability of Exceedance

- Shallow Crest
- Moderate Backslope
- Deep Toeslope

(Probability that crop yield will meet or exceed a specific amount)
Fertilizer Rates to Maximize Profit (2013 prices)

Maximum Profit ≠ Maximum Yield

“Law of Diminishing returns”

How will optimal fertilizer rates change if wheat prices drop???
Maximizing profit with $4.00/bu wheat ($2.75 drop in grain price)

Optimal fertilizer rates drop as wheat prices drop on all soils

How will optimal fertilizer rates change if fertilizer price doubles???
Maximizing profit with $1.54 per unit N fertilizer (doubling of fertilizer price)

Optimal fertilizer rates decreases on all soils as the fertilizer price increases

How will optimal fertilizer rates change if fertilizer prices drop???
Maximizing profit with $0.38 per unit N fertilizer (50% reduction in fertilizer price)

Optimal fertilizer rate increases on Southwick and Palouse Soils

- **Soft White Winter Wheat Yield (bushels/acre)**
  - **Fertilizer Rate (Fall plus Spring, lbs/acre)**

- **Graph:**
  - Garfield
  - Southwick
  - Palouse
Returns per acre with $330 cost of production

Garfield Soil (0.3 m depth)

Not breaking even on shallow clay knob soils even under the optimum wheat and fertilizer prices!
Returns per acre with $330 cost of production

**Palouse Soil (1.5 m depth)**

Making money under all scenarios except a drop in wheat prices to $4 per bu

- $8/bu; $0.77/lb N
- $6.75/bu; $0.38/lb N
- $6.75/bu; $0.77/lb N
- $6.75/bu; $1.54/lb N
- $4/bu; $0.77/lb N
Apply economic metrics to CropSyst-Microbasin outputs

- 180 kg-N/ha

- 68 bu/ac
- 75 bu/ac
- 96 bu/ac
- 104 bu/ac
- 97 bu/ac
Apply economic metrics to CropSyst-Microbasin outputs

40 kg-N/ha

+$61/ac

+$33/ac

-$22/ac

180 kg-N/ha

-$21/ac

-$2/ac

Average: +$10/ac

Precision is profitable!
Cautions regarding variable nitrogen application

• Many variables interact to determine nitrogen use efficiency
  • Weather
  • Soil
  • Application forms, timing, rates
• Many additional variables determine crop price and yields
  • Markets, exchange rates
  • Weather
    • Precipitation
    • Temperature
Summary

• Developing Rx maps is a learning process!
• Each field is unique
• Start simple
• A wide range of tools are becoming available to help with exploring what is causing variability
• Invest the time for post-harvest evaluation!
Precision Ag Survey on the Palouse
REACCH (Wulfhorst et al., 2014)
900 surveys sent, 46% response rate

Reasons for not using Precision Ag Technology

- Equipment is too expensive: 62.0%
- Not cost-effective for operation: 59.9%
- Do not want to invest in new capital: 25.7%
- Difficult to operate and maintain: 24.1%
- Equipment lacks reliability: 17.1%
- Lack of cost-share programs: 12.8%
Returns per acre with $330 cost of production

Southwick Soil (1 m depth)

Making money on moderate soils if the price of wheat does not drop to $4/bu or the price of fertilizer does not double to $1.54/lb