Spatially variable application of nitrogen for cereal crops (wheat)
Objectives

The aim is to develop practical guidelines for implementing precision farming by:

- Developing a method for identifying the causes of within-field variation.
  Focusing on soil/water/nutrient/plant interaction.
- Exploring the use of remote sensing methods to make 'real time' decisions during the growth of the crop.
- Determining the potential economic benefits.
- Collaborating with farmers to ensure that the research findings are appropriate.
Approach in three phases

• Harvests of 1995 - 1997: blanket application of inputs to determine in-field variability and to develop the remote sensing and "Real Time" techniques.

• Harvests of 1998 - 2000: controlled spatial application of inputs compared with control strips including canopy management.

• 2000-2001: analysis and reporting.
Variable Nitrogen Experiments

<table>
<thead>
<tr>
<th>Year</th>
<th>Trent</th>
<th>12 Acres</th>
<th>Far Sweetbrier</th>
<th>Seedrate / Canopy studies</th>
<th>Hydro N-Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>w barley</td>
<td>w wheat</td>
<td>w wheat</td>
<td>w wheat</td>
<td>Shortwood</td>
</tr>
<tr>
<td>1999</td>
<td>w barley</td>
<td>w wheat</td>
<td>s wheat*</td>
<td>w wheat (Waterlogging)</td>
<td>w wheat*</td>
</tr>
<tr>
<td>2000</td>
<td>w barley</td>
<td>w wheat</td>
<td>w wheat*</td>
<td>w wheat</td>
<td>w wheat*</td>
</tr>
</tbody>
</table>

Similar soils

Related soils
Determining within-field variability

- Soil survey and targeted profile pits.
- Plant and soil-nutrient status (grid sampling).
- Crop Structure
  - Plant populations; tiller counts; crop height; spikelet counts; grains per ear; grain weight.
- ADP calibrated derivatives (targeted sampling).
- Soil moisture status (targeted).
- Yield mapping (from harvest ‘95).
1. Variable nitrogen experiments

- To test N management strategies of:
  1. *More* on the ‘good’, and *less* on the ‘poor’

- Need to identify ‘**good**’ and ‘**poor**’ areas

Two methods:

1. Historic yield maps,
2. Aerial digital photography (ADP) of crop canopy.

2. Seed rate/canopy experiments

- Vary nitrogen rate depending upon crop canopy using ADP.
Historic yield maps

100% = Contour of Grand Mean

1995

1996

1997

High

Ave.

Low
Airborne Digital Photography

Cessna 177 ‘Cardinal’

Cameras and Mount

Trigger

PC-Card hard Disk

Camera Port Holes red 640nm (½max10.4nm)
Normalised Difference Vegetation Index (NDVI) = \((\text{NIR} - \text{RED})/ (\text{NIR} + \text{RED})\)
Yield maps

- Yield maps are indispensable for targeting areas for investigation and treatment.
- They provide a valuable basis for estimating the replenishment levels of P and K fertilisers.
- They were not found to provide a basis for determining variable nitrogen application.

* P off-take* (kg.ha⁻¹)

* grain only
Assess the canopy size

Canopy measurement

- Above target
- On-target
- Below target

Growth Stages in Cereals
- Stem Extension
- Heading
- Ripening

Seed rate match sowing date

- <GS20
- GS27-30
- GS31
- GS39
- GS61

Plant density
- 300/m²

Shoot density
- 1000 shoots/m²
  - 300/m²
  - GAI=1.2

GAI
- GAI₁₁ = 1.9
- GAI₂₂ = 5.9
- GAI₃₃ = 6.0

GAI = Green Area Index
Calculating N requirement

- Measure and take account of Soil Mineral Nitrogen
- Determine the current canopy size
  - 1 unit-GAI equates to 30 kg N/ha.
- Determine amount of N fertiliser to augment the current supply to achieve a GAI of 6.5

  Typically, only 60% of applied fertiliser is recovered
‘Planned nitrogen’

First N application to manage shoot numbers
GS 23-29

Main N application to achieve canopy required for optimum yield
GS 30-32

Final N application for canopy survival
GS 37

Below shoot target
Increase the first dose and subtract this amount from the main dose.

eg. 65 kg N/ha

On-target
Apply ‘planned’ dose as determined.

eg. 50 kg N/ha

Above shoot target
Reduce or omit first dose and add to the main dose.

eg. 0 - 35 kg N/ha

Above-target for growth stage
Reduce main dose.

88

On-target for growth stage
Reduce main dose.

88

Below-target for growth stage
Apply ‘planned’ main dose.
Check nitrogen availability.

125

Apply ‘planned’ main dose.

125

Increase main dose.

162

Increase main dose.

162

Above-target for GS 37
Omit final dose.

0

On-target for GS 37
Apply ‘planned’ dose.

40

Below-target for GS 37
Increase dose. If the earlier main dose was increased, apply the ‘planned’ dose.

40 - 52
1. Calibrated ADP image – canopy size

2. Image processed into management zones according to canopy size

Canopy Size
- Above-target
- On-target
- Below-target

3. Management zones imported into Fieldstar Software and application rates assigned

4. Application plan implemented

5. Economic Benefit - £22/ha
The spatially variable application of nitrogen can improve the efficiency of cereal production through managing variations in the crop canopy.

Between 12% and 52% of the area of the fields under investigation responded positively.

7 out of 8 treatment zones gave positive economic returns to spatially variable variable nitrogen.

With an average benefit of £22 ha.
Gross margins: Variable v uniform nitrogen

Average benefit £22/ha

SEED RATE (seeds/sq m)

GROSS MARGIN (Pounds/ha)

OnionField Far Highlands
Spatially variable application of nitrogen reduced the nitrogen surplus by one third.
Cost effectiveness

A farm of 250 ha of cereals where 20% of the area could respond positively to spatially variable nitrogen would need to achieve a yield increase of

- 1.1 t ha\(^{-1}\) on that 20% for a system costing £11,500.
- 0.25 t ha\(^{-1}\) for a basic system costing £4,500.
## Economic Analysis

<table>
<thead>
<tr>
<th>Cost – capital depreciation</th>
<th>Other - associated costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine mounted hardware</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Tractor mounted hardware</td>
<td>Training</td>
</tr>
<tr>
<td>Implement mounted hardware</td>
<td>Cost of capital</td>
</tr>
<tr>
<td>Software</td>
<td>Bought in services</td>
</tr>
</tbody>
</table>

- **Cost – capital depreciation**
  - Combine mounted hardware
  - Tractor mounted hardware
  - Implement mounted hardware
  - Software

- **Other - associated costs**
  - Maintenance
  - Training
  - Cost of capital
  - Bought in services
### Assumptions

<table>
<thead>
<tr>
<th>PF equipment Cost</th>
<th>Full system</th>
<th>Basic system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class 1</td>
<td>Class 2</td>
</tr>
<tr>
<td><strong>Initial capital cost</strong></td>
<td>£11,363</td>
<td>£14,100</td>
</tr>
<tr>
<td><strong>Cost of capital</strong></td>
<td>8.5%</td>
<td>8.5%</td>
</tr>
<tr>
<td><strong>Depreciation all equipment</strong></td>
<td>13% for 5 yr replacement</td>
<td>13% for 5 yr replacement</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combine</td>
<td>3.5% for 150 hrs use pa</td>
<td>3.5% for 150 hrs use pa</td>
</tr>
<tr>
<td>Tractor</td>
<td>8% for 1000 hrs use pa</td>
<td>0</td>
</tr>
<tr>
<td>Seed drill</td>
<td>7.5% for 150 hrs use pa</td>
<td>0</td>
</tr>
<tr>
<td>Fertiliser distributor</td>
<td>7.5% for 150 hrs use pa</td>
<td>0</td>
</tr>
<tr>
<td>Training</td>
<td>£60 pa (£300 over 5 yr)</td>
<td>£60 pa (£300 over 5 yr)</td>
</tr>
</tbody>
</table>

£1 = Aus$ 2

- **Fieldstar**: Combine, Tractor, Seed drill, Fertiliser distributor
- **Virtual Implement**: Training

- **Fieldstar**
  - Combine: 3.5% for 150 hrs use pa
  - Tractor: 8% for 1000 hrs use pa
  - Seed drill: 7.5% for 150 hrs use pa
  - Fertiliser distributor: 7.5% for 150 hrs use pa
  - Training: £60 pa (£300 over 5 yr)

- **Virtual Implement**
  - Training: £60 pa (£300 over 5 yr)
Breakeven analysis
for a £11,500 system

Breakeven yield t/ha

Area of field likely to respond to variable inputs

Area/combine ha
### Answer to 4 key questions

1. **How large is my cereal area?** 250ha
2. **What is my potential investment?** £11000
3. **What % of the farm might respond to spatially variable inputs?** 20%
4. **What is the expected yield increase?** 1.5t/ha

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#### Level of Yield Increase (t/ha) Needed to Justify Investment

<table>
<thead>
<tr>
<th>System (investment)</th>
<th>% area responding</th>
<th>250 ha</th>
<th>500 ha</th>
<th>750 ha</th>
<th>1000 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic entry level</td>
<td>5%</td>
<td>1.44</td>
<td>0.72</td>
<td>0.48</td>
<td>0.36</td>
</tr>
<tr>
<td>(£4,500)</td>
<td>10%</td>
<td>0.72</td>
<td>0.36</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>(£11,000)</td>
<td>20%</td>
<td>0.36</td>
<td>0.18</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>(£16,000)</td>
<td>30%</td>
<td>0.24</td>
<td>0.12</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Fully integrated</td>
<td>5%</td>
<td>3.81</td>
<td>0.91</td>
<td>1.27</td>
<td>0.95</td>
</tr>
<tr>
<td>(£11,000)</td>
<td>10%</td>
<td>1.91</td>
<td>0.95</td>
<td>0.64</td>
<td>0.48</td>
</tr>
<tr>
<td>(£16,000)</td>
<td>20%</td>
<td>0.64</td>
<td>0.32</td>
<td>0.21</td>
<td>0.16</td>
</tr>
<tr>
<td>(£25,000)</td>
<td>30%</td>
<td>0.95</td>
<td>0.48</td>
<td>0.32</td>
<td>0.24</td>
</tr>
<tr>
<td>Multiple units</td>
<td>5%</td>
<td>5.68</td>
<td>2.84</td>
<td>1.89</td>
<td>1.42</td>
</tr>
<tr>
<td>(£16,000)</td>
<td>10%</td>
<td>2.84</td>
<td>1.42</td>
<td>0.95</td>
<td>0.71</td>
</tr>
<tr>
<td>(£25,000)</td>
<td>20%</td>
<td>1.42</td>
<td>0.71</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td>(£35,000)</td>
<td>30%</td>
<td>0.95</td>
<td>0.47</td>
<td>0.32</td>
<td>0.24</td>
</tr>
</tbody>
</table>

*Based on wheat at £65/t

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*Shaded areas: sustainable improvements of this magnitude were not generated during the project.*

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The expected yield increase needed to justify investment is **0.95 t/ha**.
Precision farming systems

The benefits from spatially variable application of nitrogen outweigh the costs for cereal farms greater than:

- 75 ha if basic systems costing £4,500 are purchased, and

- 200-300 ha for more sophisticated systems costing between £11,500 and £16,000.
Field management

- Water-logging and fertiliser application errors, can result in crop yield penalties.
- Precision farming enables these to be identified, the lost revenue to be calculated, the cost/benefit to be determined.
- It is critical that these are corrected prior to the application of other inputs.
1. Consider variation while:
   - Field Walking
   - Combine Driving
   - Spraying/Fertilising

2. Dig/auger holes in good/bad areas
   - Texture/Structure
   - Rooting depth
   - Compaction

3. Identify pest effects
   - Rabbits
   - Slugs

4. Identify waterlogging during wet periods

5. Assess machinery operation quality
   - Drill misses
   - Spreader calibration
   - Sprayer operations

6. Commission aerial digital photography of crop variation in March/April

7. Commission EMI survey

Note reasons for variation and assess impact at field scale

1. Causes:
   - Pests
   - Disease
   - Soil type
   - Topography
   - Excess water
   - Drought stress
   - Operator error

2. Use aerial photography and EMI to assess crop and soil variability at field scale

3. Assess the yield impact by field walking and sampling the crop prior to harvest with the aid of the aerial photography and/or EMI to locate areas with variation
Both Sensors performed well
• Reduced Nitrogen application rates
• Benefit of Active sensors
• Improved Nitrogen utilisation
• >Cost Neutral

Results of Strip Experiments in UK and Slovakia

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After: Havrankova (2007) with thanks to Soilessentials, Yara and AGCO
SOYL Farm Study

- 10 farms ~ with variable rate and GPS capability
- ½ normal practice; ½ variable rate @ 30m resolution
- Mini satellites cover 90% of England in a 300km swath width, with 2 day turn around period
- Cost £6/ha imagery for 3 flights + £2/ha capital investment
- Average return £24/ha (Aus$50/ha)
Field management

Precision farming demands a high level of good husbandry prior to spatially variable fertilizer and agrochemical application:

- Water-logging - up to £190/ha, Aus$ 380/ha
- Fertiliser errors - up to £ 65/ha, Aus$ 135 /ha
- Rabbit damage - up to £ 10/ha, Aus$ 20/ha

can result in significant crop yield penalties

It is critical that these are corrected prior to the application of other inputs.
Conclusions

– The economic advantages linked to the environmental benefits should improve the longer term sustainability of cereal production.

– Precision Farming is a State of Mind,
  • the concept works for all sizes of farm,
  • once committed no one will ever go back.

– It does not take huge financial investment- Just good farm practice and sensible tools for good management.

– Practical Guideline Booklets are available.