Crop sensing for nitrogen management

- Why use crop sensors?
- How do crop sensors work?
- What do crop sensors measure?
- Different types of optical crop canopy sensors
- International commercial practice
- Algorithm development for nitrogen application
- Field scale research
- Plot scale research
**Introduction**

Crop sensing uses reflected light to measure crop biomass and chlorophyll content. It captures in-field variability, providing growers with information which can then be used to adjust inputs such as nitrogen and plant growth regulators.

This *Crop Sensing for Nitrogen Management* project was set up to investigate whether fertiliser efficiency in wheat crops could be improved by the use of crop sensing technologies. The project had two distinct elements; one based on replicated trials examining how best to use the link between crop reflectance and nitrogen status of the crop canopy, and the other exploring how different manufactured sensors can be applied in the paddock for zonal management (e.g. variable rate fertiliser within the paddock).

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Foundation for Arable Research

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1. Why use crop sensors?
Tractor mounted crop sensors may provide the following advantages in better nitrogen (N) fertiliser management for crops:

- Instant assessment of canopy N status.
- Indication of biomass and/or N status across the whole paddock (Figure 1).
- Objective measurement of crop response to applied N (i.e. Nitrogen rich strips).
- Better indication of N supply to the plant than soil testing, since the plant can be an indicator of available N on a spatial basis.
- More easily linked to variable rate fertiliser application.
- Form the basis of a change map where the grower could use the sensor to record the degree of change or crop growth following an earlier N application.
- Management of other inputs linked to crop canopy size and N status such as plant growth regulator linked to lodging risk, disease control linked to canopy density and green leaf area.

Regularly monitoring a crop with a crop sensor allows a cropping farmer to measure the effect of decisions made earlier in the season through assessing the crop’s growth response. Depending on the management decisions taken, the results of action can be seen when the crop is harvested and yields are less variable than they otherwise would have been. This crop knowledge can also be built up with information from other sources, such as soil maps and previous yield maps, to help with future management decisions.

Accurately recording and mapping sensor data will also capture in-field variability, allowing a farmer to manage specific areas of the crop differently. Application rates of products such as plant growth regulators and fertilisers, can be adjusted based on the crop’s status. This can be done either through the creation of prescription maps prior to application, or by linking the sensors directly to on-the-go variable rate application. This will increase efficiency of inputs and maximise profits.

Figure 1. Map produced from CropSpec sensor data recorded over a Barley crop at Zadoks growth stage 32. Lighter areas have less biomass or chlorophyll and darker areas more biomass or chlorophyll.
2. How do they work?
Measurements taken from the crop canopy are used to produce a value, or vegetative index, which gives an indication of biomass and chlorophyll content at that particular location. Crop sensors measure crop canopy reflectance at specific electromagnetic wavelengths (red (VIS) and near infrared (NIR)). As with any material, vegetative material has a spectral signature and the characteristics of that signature differ for healthy and stressed vegetation.

Figure 2 shows the reflectance of a healthy and a stressed leaf across the visible and near infrared regions of the electromagnetic spectrum. A healthy leaf absorbs more, (reflects less) visible red light than a stressed leaf. This is generally related to chlorophyll content; the greater the chlorophyll content the less visible red light is reflected. A healthy leaf reflects a much greater portion of the incoming near infrared radiation than a stressed leaf. A stressed leaf absorbs more near infrared radiation. These are the principles used by VIS/NIR sensors to determine the crops status.

Active optical sensors emit a light pulse which is projected onto the target surface, the crop canopy. The light reflected back from the crops’ canopy is detected by the sensor (Figure 3). Reflectance in the red and infrared wavelengths is strongly influenced by the chlorophyll content and/or nutrient concentration (greenness) and biomass (amount of vegetation). The reflectance measurements are converted into a vegetative index. The most common index is the NDVI (Normalised Difference Vegetative Index).

**Figure 2.** The typical spectral signature of a healthy versus a stressed leaf.

**Figure 3.** Diagram representing the basic principles used by a VIS/NIR crop canopy sensor.
3. What do crop sensors measure?
The sensor readings can give an indication of crop condition with two main characteristics: condition or ‘greenness’ and biomass. In figure 4, the photo on the left is a healthy green wheat crop, next is wheat with yellowing leaves in poor condition. The three photos on the right of figure 4 illustrate low, medium and high biomass in maize at an early growth stage. Healthy areas of crop would be expected to give a higher sensor value as would areas of higher biomass.

However sensor readings can be affected by individual or multiple factors. The condition of the crop may not solely be associated to nutrient status but can be influenced by other environmental factors such as poor drainage, water stress or pest and disease pressure.

Moisture on plant leaves, soil, and the presence of weeds can also give readings that are not representative of the target crop’s condition and biomass (Figure 5). Clearly the reasons for differences in the crop need to be investigated.

**Figure 4.** VIS/NIR sensors can give the farmer and indication of the crops condition (two photos on the left, healthy crop on extreme left) and low, medium and high biomass (three photos on the right).

**Figure 5.** Infrared aerial and paddock images of the same maize crop. a) Blue area shows bare soil and red shows vegetation - the maize rows and, circled, an area of ground cover bindweed. b) Maize crop.
4. Different types of optical crop canopy sensors
There are several optical crop canopy sensors on the market. This project compared three, CropCircle™, Greenseeker™ and CropSpec™. The principles of the various canopy reflectance sensors are similar but there are differences in the technical setup including: the electromagnetic wavebands that are measured (and the vegetation indices used), viewing angle, and sensor to crop distance. These different features result in different footprint (field of view) sizes.

The VIS/NIR sensors use a band in the visible red region and one in the near infra-red region, although each of the sensor systems uses slightly different wavebands and waveband resolutions. The wavebands are shown in figure 6 and in summary table 1.

The derivation of vegetation indices used by each of the sensors also differs. No one algorithm is used consistently. Instead each system derives the indices using their own method: Greenseeker uses NDVI from 0 - 1 and this is the only information that is given by the sensor; CropCircle uses a value from 0 - 1 for each of the three wavebands and gives the user some flexibility as to whether they use NDVI or another vegetative index; CropSpec uses a value they term Cs ranging from 0 - 120.

The recommended set up of the sensors also differs. The manufacturer’s instructions for mounting the sensors are similar for CropCircle and Greenseeker as these sensors are both mounted to the sprayer boom and sense the crop from a nadir or vertical position. The CropSpec is mounted to the roof of the tractor cab and senses the crop at an oblique angle out from the side of the vehicle. The sensor design and recommended mounting specifications results in different sized footprints. The technical specifications of the sensors are summarised in table 1.

![Figure 6. Spectra of a healthy and stressed leaf and the wavebands used by the sensors.](image)

**Table 1.** Overview of the technical specifications of Crop Circle™ Greenseeker™ and CropSpec™ sensors.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>CropCircle</th>
<th>GreenSeeker</th>
<th>CropSpec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>ACS470</td>
<td>RT200</td>
<td>IP67</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Holland Scientific</td>
<td>N Tech Indus.Inc.</td>
<td>Topcon</td>
</tr>
<tr>
<td>Data logger</td>
<td>Geo SCOUT GLS400</td>
<td>RT Commander</td>
<td>X20</td>
</tr>
<tr>
<td>Operational Wavebands</td>
<td>670/20 (Red) and 760/LWP (NIR)</td>
<td>660/15 (Red) and 770/15 (NIR)</td>
<td>730/10 nm (Red) and 800/10 nm (NIR)</td>
</tr>
<tr>
<td>Footprint/ Field of view</td>
<td>15 x 57 cm (changes with height)</td>
<td>5 x 60 cm</td>
<td>2 - 3 m (changes with mounting height)</td>
</tr>
<tr>
<td>Viewing angle</td>
<td>32°/6°</td>
<td>32°</td>
<td>45 - 55°</td>
</tr>
<tr>
<td>Operating Height</td>
<td>0.6 - 1.2 m</td>
<td>0.86 m</td>
<td>2 - 4 m</td>
</tr>
<tr>
<td>Number of sensors used</td>
<td>2 - 4</td>
<td>4 - 8</td>
<td>2</td>
</tr>
<tr>
<td>Mount</td>
<td>Handheld or Sprayer boom</td>
<td>Handheld or Sprayer boom</td>
<td>Tractor cab</td>
</tr>
</tbody>
</table>
5. International commercial practice
Crop canopy sensors are most commonly used commercially in Australia, America and Europe. The way sensors are used is often quite different according to the crop and location. The use of these sensors first gained popularity in the USA, mainly in maize crops. Here additional N was often applied to areas of weaker early growth to build canopy in order to create the opportunity to capture greater yield.

Australian users seem more inclined to think about the soil water holding capacity, the actual amount of moisture in the soil and to act on this and soil zoning information.

In Europe, canopy management of winter cereal crops is an important focus. The sensors have been used to base initial spring N application, calculate secondary application on the basis of response to the first, and a third N application based on canopy reflectance and moisture holding capacity of the soil, i.e. “Which areas of crop can I keep going for that little while longer?”

An earlier Canterbury-based project demonstrated that the sensors aided ryegrass seed production by identifying differences in biomass across a paddock and thus allowing variable application of plant growth regulators.

While there is no single recipe for how to act upon the information the sensors produce, they have been shown to consistently identify differences in crop biomass.

Crop sensors are no good on their own. The farm using them must also have suitable software (or access to a data processing service) to transform the data into maps and useful information.

During this project two main software packages were used. In the initial stages SSoolBox was used, then in year 3, Farmworks from Trimble. This was mainly due to issues around support and integration with other parts of the precision agriculture system. Farmers will need to invest in software capable of true mapping, i.e. each location is geo-referenced. Images or pictures of fields are not much use when it comes to using the information in a streamlined and accurate way.

The farmer will also need access to machinery capable of variable rate application (VRA) and that machinery must be compatible with the software being used so that files instructing the machinery on application plans can be downloaded seamlessly. The major software providers have gone to some trouble to make sure their software is compatible with a range of controllers for spreaders and sprayers.

It is important for farmers to consider their options carefully as they do not want to cut corners and head down a blind alley by purchasing a product which will be unsupported in the marketplace.
6. Algorithm development for N application

- 6.1 Algorithm structure
A key objective for this project was the identification of methods and algorithms for informing nitrogen inputs to the crops grown in the project on the basis of the NDVI estimates given by the sensors. While it is mathematically feasible to do this, caution is required in interpreting results from both the plot and field experiments as few of the results were statistically significant. For field trials, areas of paddocks were selected and N application rates changed, but no equipment was available to identify lower biomass areas and then apply additional N to them. In these field experiments the farmer’s own fertiliser spreader was used and an application rate assumed. In some cases additional N was applied with the irrigator which may also have had an effect.

In this project sensor measurement results appear to give a poor explanation of the relationship between early season crop biomass and yield. The relationship between yield and early biomass tends to be positive, but with a low level of correlation. However, canopy management strategies vary so there will not necessarily be a linear relationship between canopy size and final yield.

6.1 Algorithm structure

There are many ways to construct an application equation. Equations developed within SSToolbox and Farmworks software will produce data files informing variable rate application of fertiliser. The programmes will handle conditional statements and some simple mathematical constructs, however if more complex equations are required then these can be developed outside the programme and imported back in. The equations are based on the values of NDVI measurements from the same point on the map. A simple ramp of nitrogen is illustrated in figure 7. This is expressed in a way that could be used with any of the sensors. In the case illustrated if the level of NDVI is at or above 95% of target then a lower or base level of nitrogen is selected. As the measured NDVI of the crop is reduced, the N application rate is increased until a cut-off is reached.

The BaseN fertiliser level is the level of input where the crop is at its most vigorous, in many cases this will be equal to 0.95 of maximum NDVI. SupplN is the maximum level of fertiliser (kg/ha) to be applied (decided by grower) and the NDVI cut-off (the point where there is no merit in applying additional fertiliser). The NDVI cut-off might be the bare soil level of NDVI or something just above it.

The gradient of the line is calculated from:

\[ \frac{\text{SupplN} - \text{BaseN}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{cut-off}}} \]

Consider each location in the map as having an i, and j, positional value. Then the Napp(i,j) (the amount of N applied at any point in the field, kg/ha) can be calculated at any point in the map.

This can be completed using the equation:

\[ \text{Napp}(i,j) = \text{SupplN} - (\text{NDVI}(i,j) - \text{NDVI}_{\text{cut-off}}) \times \text{Gradient} \]

Another way to do it is to apply some conditions that would give you a stepped function, if NDVI(i,j) is between certain values in the range, then apply X amount.

There are more complex algorithms that could be developed, like those of Schepers and Holland (2010) where a non-linear function is used. This could be completed by exporting the (map) data out of the mapping software and using a spreadsheet to calculate the rates that should be applied. Macros could be written to do this, to make it easier and less prone to error. Other factors of interest such as soil available N could be taken into account with the variable rate N application. This could be included in the conditional statements around the N app algorithm developed in the software.

![Figure 7. A linear N fertiliser ramp to supplement N inputs.](image-url)
7. Field scale research

7.1 Sensor comparison
7.2 Relationship with biomass
7.3 Relationship with electromagnetic soil maps and yield maps
7.1 Sensor comparison

An extensive study was conducted over an annual area of around 300 ha on various crops using the three sensors mentioned in table 1. The methods used are described fully in the project report. The Crop Circle and Greenseeker sensors, which view the crop from a vertical position, had the closest agreement, while the Cropspec, which samples from an oblique angle, varied more. However, when all three sensors were compared on sites identified as having high, medium or low biomass, sensor readings gave good correlations with biomass, particularly at the earlier growth stages (Figure 8).

7.2 Relationship with biomass

Biomass cuts were sampled from sites selected as ‘high’, ‘medium’ and ‘low’ levels of dry matter and the relationship between biomass and the sensor measurement was calculated. In all cases sensors correctly identified the area of high, medium and low vegetation biomass (Figure 8). The sensor measurement (vegetative index) increased with increased biomass.

7.3 Relationship with EM and yield maps

The relationship between crop growth, yield and soil electromagnetic (EM) is not an easy one to explain. We would normally expect areas of very low EM to have low soil water holding capacity and therefore lower yield. Areas of high EM could indicate areas of impeded drainage which could also reduce yield, or, alternatively, a deeper, better structured soil with much higher moisture retention capable of supporting higher yields. In the 2012 harvest there was a tendency for EM to be negatively correlated with crop sensed biomass and final yield in the North Island. Areas of lighter soil appeared to produce better crops compared with areas of heavier soil that tended to have significant problems because of the very wet spring and trafficking wet soils with heavy equipment. In the South Island the relationship between yield and soil EM was positive although weak in many cases, again this may be an artefact of the season and the effective irrigation systems in place, i.e. areas of low water retention were never compromised. A range of figures for each paddock in the study comparing these factors is given in the appendices attached to the project report.

The key points from the study demonstrate that:
1. There are a number of factors affecting yield.
2. Sensors can detect biomass differences in the crop canopy.
3. Maps can be configured and interpreted.
4. Maps should not be interpreted without consideration of the farmer’s knowledge of the land.
5. Sensors allow farmers to measure in-season changes and respond within season and monitor response to management.
6. Sensor response will vary in relation to season and site.
7. The sensor data will not always give a clear cut response, for example, additional biomass may be weeds rather than crop and some on-farm experimentation, observation and learning is required.
8. Sensors have the potential to reduce N inputs and increase yields, increasing crop profitability.

![Figure 8. Cut Biomass Sample Dry Matter (low, med, high areas) vs. Sensor Values Wheat - Watson Field 2.](image-url)
8. Small plot trial work

8.1 Normalised difference vegetative index as an indicator of soil nitrogen mineralisation

8.2 NDVI relationship with canopy dry matter, nitrogen concentration and nitrogen content

8.3 Consistency over seasons and sites

8.4 N rich strip/response index

8.5 Does variable rate N pay?

8.6 Digital photos for measuring canopy cover

8.7 Conclusion
8.1 NDVI as an indicator of soil N mineralisation

Key points:

- NDVI values could be a useful spatial indicator of fertility (soil N) in the paddock.
- On a more fertile site the large crop canopy saturated the crop sensor by growth stage 31 so differences in crop canopy were not detected.
- N rich strips or calibration strips are needed to verify that any differences in biomass and chlorophyll content are due to N rather than other nutritional factors, disease or waterlogging.

Crop sensors have the potential to distinguish zones in the paddock with different amounts of soil available N by measuring crop canopy N status. That is, parts of the paddock which have mineralised more N will potentially have a crop canopy with a higher N uptake and higher NDVI (assuming the unevenness in N uptake is not caused by unevenly spread fertiliser N).

This idea was tested in autumn drilled wheat at two trial sites, one at Wakanui and the other at Methven, mid-Canterbury. At the Wakanui site the NDVI of the unfertilised crop ranged between 0.65 and 0.8 through stem extension (Figure 9). The NDVI of both unfertilised and fertilised plots was very similar at GS39 (about 0.8) indicating high fertility and that there would be only a small response to applied N. However, in this trial there was a 3.6 t/ha yield increase with applied N. The crop sensor didn’t detect differences in canopy N status when the canopy got to a certain bulk and N content (the sensor became saturated). In contrast, at the Methven site there was a large NDVI difference, with the unfertilised crop below 0.4 through stem extension while the fertilised crop NDVI increased to 0.7 at GS39. The yield response to applied N was almost double (6.9 t/ha) that in the Wakanui trial. Interestingly both sites had similar soil mineral N contents (Methven trial 70 kg N/ha and Wakanui trial 56 kg N/ha, 0 to 60 cm) in spring, but the nil applied N treatment at Wakanui had a much higher NDVI through stem extension compared with the Methven site. This indicates a higher rate of N mineralisation at the Wakanui site.

![Figure 9. Influence of the optimum amount of applied N and nil N on the NDVI of the wheat crop canopy from GS31 to GS61. Cultivar Phoenix at Methven and Wakanui in 2011-12. Nitrogen applied at 2/3 GS32 and 1/3 GS39.](image-url)
8.2 NDVI relationship with canopy dry matter, nitrogen concentration and nitrogen content in wheat

Key points:
- NDVI gives a good relationship with the nitrogen content of the plant biomass. However NDVI levels out at about 200 kg N/ha (due to saturation of biomass and/or greenness).

NDVI is related to both biomass and the N concentration of the canopy (the higher the N concentration the greener the canopy). Is NDVI more influenced by dry matter or N concentration? In two trials where the first dose of N was applied at GS30, and crop sensor measurements made at GS32, NDVI was more strongly related to N% (N% range was 2.5 to 5.0%) compared with dry matter (dry matter range was 2.5 to 3.7 t/ha).

At GS39 the eight trials in the project were analysed to assess if one variable was more strongly related to NDVI than the other. NDVI was more strongly related to N% than dry matter in all of the trials. For example, at the Dorie 2009-10 trial there was a significant relationship between N% and NDVI but not dry matter and NDVI (Figure 10). Generally, the graphs were curvilinear with NDVI reaching a plateau with increased N%.

Figure 10. Relationship between NDVI and dry matter and N% of the canopy at GS39. Nitrogen applied at 2/3 GS32 and 1/3 GS39. Cultivar Phoenix, Dorie, 2009-10. The correlation between dry matter and NDVI was not significant.
While NDVI clearly relates to applied nitrogen, it is the relationship with nitrogen in the plant that ultimately determines the reflectance signal. Work conducted as part of the project has shown that NDVI gives a good relationship with the nitrogen content of the plant biomass. However, NDVI levels out at about 200 kg N/ha (due to saturation of biomass and/or greenness) (Figure 11).

Two N response trials, run in 2011-12 at Wakanui and Methven, show contrasting ability for the crop sensor to determine canopy N differences. There was a strong relationship between increasing canopy N content and increasing NDVI at the Methven site (Figure 12). In contrast, the NDVI value was maximised with no applied N in the Wakanui trial, where the canopy was thicker and greener (Figures 13, 14 and 15). Therefore, the Greenseeker would not be able to determine canopy N differences at this site. These results suggest NDVI as a measure of canopy N status at GS39 may be limited to thinner and or less green crops. There was a yield response to applied N in this trial.
Figure 13. Trial at GS39 with nil applied N on left and 204 kg N/ha applied at GS32 on right. Cultivar Phoenix, Methven, 2011-12

Figure 14. Trial at GS39 with nil applied N on left and 202 kg N/ha applied at GS32 on the right. Cultivar Phoenix, Wakanui, 2011-12
Nitrogen response trials were run at Wakanui, mid Canterbury over three seasons. For the first two seasons the milling wheat cultivar Conquest was grown and in the third season the feed wheat Phoenix. In the 2009 and 2010 seasons, with the cultivar Conquest, there was a strong relationship between N content and NDVI (the soil N reserve was higher in the 2010 season) (Figure 16). However, in the 2011 season (cultivar Phoenix) the relationship was much weaker. The same N uptake could be represented by NDVIs differing more than 0.3 between seasons for the different cultivars which is not accurate enough for crop N management. For example, in 2010 an N content of 240 kg/ha at GS39 gave an NDVI of 0.59 and in 2011 the same N content gave a NDVI of 0.79.

**Key points:**
- The relationship between NDVI and the N content of the canopy was strong within a trial of the same cultivar in one year but not between different cultivars, paddocks and seasons. This indicates that crop sensors will need to be calibrated to a specific cultivar, site and season.
8.4 N-rich strip/response index

Calculating N rates using the NDVI response index, the N-rich strip and the Wheat Calculator

Can we relate the rate of N input to NDVI values? In some parts of the world growers are applying N on the basis of crop reflectance as outlined in Section 6. The weakness of the method described is that it varies N from a predetermined average application rate rather than calculating an optimum amount of N to apply. Also, a number of complicating factors could influence NDVI readings.

For example:
- Different cultivars and row spacing
- Soil nutrition imbalances e.g. pH, nutrients other than N
- Weed patches
- Disease
- Water-logging

This means that to use crop reflectance to calculate the varying N requirement across a paddock, a specific calibration, or N-rich strip must be used. An N-rich strip is usually one spreader width of early N applied across a representative part of the paddock at a non-limiting, but not excessive amount, to allow comparison with the unfertilised paddock. The comparison of the N-rich strip with the surrounding paddock allows the grower to gauge to how much N is being supplied from the paddock, and also the confidence that the difference in the crop canopy NDVI is due to N uptake.

Websites offering algorithms that match NDVI values to suggested N applications are available (e.g. Oklahoma State University). A simple calculation that has been applied to the N response trials over the past season, which relates to the Oklahoma State University methodology, is to calculate the NDVI response index using plots as N-rich strips which have been treated with 100 kg N/ha at GS30. Taking the NDVI of the unfertilised crop and the crop receiving 100 kg N/ha at GS30, a response index was calculated by dividing the NDVI of the GS30 N by the nil N at GS32. The greater the difference in NDVI between the with- and without-N, the greater the predicted response to N. The yield of the nil N treatment at the Wakanui and Methven trial sites was predicted using the Wheat Calculator. The potential yield with N was obtained by multiplying the response index by the yield from nil N as calculated by the Wheat Calculator. Then the quantity of N to achieve the potential yield was calculated from the nitrogen use efficiency figure from FAR’s publication *Cropping Strategies: Nitrogen Application In Wheat*.

At both the Wakanui and Methven trial sites the response index method incorrectly underestimated the yield increase and consequently the predicted N rate was too low. However, as the following analysis shows it may be possible to improve the accuracy of the method.

In four trials, with an early N dose at GS30, the NDVI response index (N-rich /0 N) was calculated and correlated with the actual yield response with optimal N application. There was a strong relationship between the response index and actual yield response (Figure 17). It appears the relationship between the response index and actual yield response from this series of trials could be used to improve this method of N management. More trials are needed to confirm this.

<table>
<thead>
<tr>
<th></th>
<th>Methven trial site 2011-12</th>
<th>Wakanui trial site 2011-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response index (at GS32)</td>
<td>0.54/0.34 = 1.59</td>
<td>0.65/0.61 = 1.07</td>
</tr>
<tr>
<td>Predicted yield (t/ha)</td>
<td>6.40</td>
<td>9.40</td>
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<tr>
<td>without N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential yield (t/ha)</td>
<td>10.20</td>
<td>10</td>
</tr>
<tr>
<td>with N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N calculated for potential yield (kg N/ha)</td>
<td>122</td>
<td>20</td>
</tr>
<tr>
<td>Optimum applied N (from N rate response curve) (kg N/ha)</td>
<td>250</td>
<td>280</td>
</tr>
<tr>
<td>Actual yield with nil N</td>
<td>4.67</td>
<td>10.80</td>
</tr>
<tr>
<td>Actual maximum yield (t/ha)</td>
<td>12.20</td>
<td>14.40</td>
</tr>
</tbody>
</table>
8.5 Does variable rate N pay? (low and high zone results)

Economics of variable rate nitrogen

Key points:
- There was minimal economic advantage to variable rate N application in this trial.
- High and low potential yield zones were successfully detected by EM measurement.

Is there value in variable rate nitrogen (N) management of a wheat crop with variable soil properties and variable potential yield? Specifically, will the crop N requirements of different yield potential zones be large enough to pay for the variable rate equipment? A nitrogen trial was set up in a paddock of irrigated autumn sown milling wheat cv Sage at Methven in 2010-11. Two N response trials were established in different yield potential zones of the paddock based on soil texture. Lighter and heavier soil zones were selected as identified by an EM survey of the paddock (Figure 18). The EM measurements are related to soil texture and hence water holding capacity. A desktop comparison was made of variable rate N, based on the optimal N rate for each of the two zones with one rate applied to the paddock.

Because the yield and N off-take in the grain on the high zone was higher at a lower N rate compared with the low zone it is probable the heavier soil mineralised more N through the season or that this zone retained its fertiliser N from the previous crop better. This may explain why the higher yield was achieved in the high zone with less soil mineral plus applied N (Figure 19). Revenue, less N cost, was optimal at a total N rate of about 20 kg/ha less than the rate for maximum yield for both trials.

Was there an advantage to variable rate N management based on zones with different potential yields? A desktop comparison was made of variable rate N with one rate applied to the paddock. An assumption was made that the potential yield of the paddock was 10 t/ha with a total N requirement of 30 kg/t of grain, equivalent to 300 kg N/ha as the optimum. A N rate of 300 kg N/ha was the economic optimum on the low potential yield zone. On the high potential yield zone the profit is reduced by about $100/ha because N is applied surplus to requirements. However, the high potential yield zone makes up only a small part of the paddock and therefore variable rate N application from the results of the desktop study would not be viable in a paddock with this level of soil variability.
Figure 18. EM map showing position of low and high yield potential nitrogen trials.

Figure 19. Yield response to nitrogen (soil mineral and applied) on the low and high yield potential zones. LSD = 0.53.
Table 3. Yield, optimal N rates, protein, returns, for a low and high potential yield zone for Sage milling wheat and estimated yield and return at one N rate for the paddock

<table>
<thead>
<tr>
<th></th>
<th>Low potential yield zone</th>
<th>High potential yield zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum yield (t/ha)</td>
<td>9.2</td>
<td>10.7</td>
</tr>
<tr>
<td>Optimal total N for max yield (kg/ha)</td>
<td>320</td>
<td>260</td>
</tr>
<tr>
<td>Optimal total N for max revenue - N cost (kg/ha)</td>
<td>300</td>
<td>240</td>
</tr>
<tr>
<td>Total kg N/t grain at maximum yield</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Protein (%) at maximum yield</td>
<td>12.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Revenue less N cost at maximum yield ($)</td>
<td>3,700</td>
<td>4,400</td>
</tr>
<tr>
<td>Yield with total N 300 kg/ha (t/ha)</td>
<td>9.1</td>
<td>10.7</td>
</tr>
<tr>
<td>Revenue less N cost with total N 300 kg/ha ($)</td>
<td>3,700</td>
<td>4,300</td>
</tr>
<tr>
<td>N off-take in grain at maximum yield (kg/ha)</td>
<td>200</td>
<td>210</td>
</tr>
</tbody>
</table>

8.6 Digital photos for measuring canopy cover

A standard digital camera can also provide a measure of early crop growth which could provide an inexpensive alternative to crop sensors. There is software available to convert digital camera images to green crop cover. Photos were taken from directly above the canopy for each N rate in 1 replicate of 2 trials, cv Phoenix. The images were then converted to % green crop cover using a software programme called GIMP. The process is relatively simple and involves highlighting all of the image that is not crop canopy and changing it to red. The software then calculates the proportion of canopy cover in the image.

The relationship between green crop cover and crop nitrogen content at GS39 was strong at the Methven site, 2011 (Figure 20). In contrast, at the more fertile Wakanui site there was not a significant relationship with almost full canopy cover in the nil N plots at GS32. Generally GS39 will be too late for this analysis as the crop will have covered over. Photos were taken in these trials at GS39 as the N treatments were applied at GS32 and needed time to show differences in the canopy.

Figure 20. Correlation between green crop cover and crop N uptake (kg/ha) of the canopy GS39. Cultivar Phoenix, Methven site, 2011-12.
Crop sensors can give a measure (with a vegetative index called NDVI) of the N status of a crop canopy. Software is available to turn crop sensor measurements into prescription maps to enable variable rate N spreading. However, there are limitations with the technology.

The relationship between NDVI and the N content of the canopy was strong within a trial but not between different cultivars, paddocks and seasons. This indicates that crop sensors will need to be calibrated to a specific cultivar, site and season. Also, there can be complications affecting the measurements, including soil nutrient imbalances (other than N), weeds and diseases.

Therefore, crop sensors need to be calibrated to specific sites and cultivars by applying an early strip of N in a paddock. A method called the NDVI response index based on a calibration strip of N was tested on autumn drilled wheat and is described in this work. The method needs more development in New Zealand conditions and shows more promise in less fertile situations where the sensor does not become saturated by a dense, green canopy.

Crop sensors have the potential to indicate areas of varying soil N mineralisation across a paddock by measuring differences in the crop canopy N status. Again, there is more potential early in the season or on less fertile sites where the sensor does not become saturated.

Three makes of crop sensor: the Greenseeker, CropCircle and CropSpec performed similarly in this research.
Glossary

**Electromagnetic soil mapping (EM mapping):** measurement of the soil profile related to soil texture and hence water-holding capacity.

**N rich strip:** strip of early N applied to the paddock at a non-limiting but not excessive amount to allow comparison with the unfertilised paddock.

**Near infrared (NIR):** electromagnetic wavelength.

**Normalised Difference Vegetation Index (NDVI):** a commonly used index calculated from a ratio of red and NIR light reflected from a crop canopy which is used to analyse crop sensing measurements. NDVI is related to the crop biomass and greenness.

**Response index:** measure of the response of the crop to applied nitrogen compared to unfertilised crop.

**Spectral signature:** the specific combination of emitted, reflected or absorbed electromagnetic radiation (EM) at varying wavelengths which can uniquely identify an object.

References
