Use of crop sensors for determining N application during stem elongation in wheat

Nick Poole *(Foundation for Arable Research, NZ) and* ***Simon Craig*** *(BCG)*

Take home messages

- *With a soil nitrogen (N) content of 153kg N/ha at sowing, Derrimut wheat yielded just less than 6t/ha with no N fertiliser applied.*
- *Optimum yields and gross margins were recorded with 75kg N/ha (7.9t/ha), though none of the N levels up to 100kg N/ha reached 10.5% protein.*
- *Over the last three years, there has been no difference in yield between N applied all pre drilled, all at GS30 (start of stem elongation) or split 50/50 between GS30 and GS33 (third node).*
- *Over the three years of the project crop reflectance measured in terms of NDVI (normalized difference vegetative index) gave good correlations with crop canopy status over the season and was a useful guide to paddock fertility at the start of spring and grain fill conditions.*
- *At present, it is difficult to suggest how the N rate may be calculated purely from a paddock NDVI, without any form of ground truthing as to what is creating the NDVI differences, particularly since different cultivars give slightly different reflectance readings.*
- *Results clearly show that by providing some form of reference strip, such as an N-Rich strip (small paddock area of excess N at sowing) crop sensors could be employed at stem elongation to give both an indication of likely response to N and provide the basis for adjustments in N rate on a spatial basis.*

Background

Research conducted by BCG and FAR since 2001 has led to a movement away from nitrogen (N) application at sowing (predrilled or deep banded). Common practice in the Wimmera is now to apply most of the crop's needs in crop during stem elongation (GS30 – 39). This change in timing allows inputs to be better matched to seasonal conditions and may allow greater use of crop sensor technology, since the 'appearance', or more specifically reflectance, of the crop itself can be used as an indicator of its need for N.

In this trial, N timings developed from previous canopy management studies were expanded to explore whether crop sensors can be used to support N decisions: in-crop when N is either applied in a single dose at GS30 or split during stem elongation between GS30 (end of tillering) and GS33 (third node).

How do crop sensors work and what is NDVI?

- Crop sensors, such as the Crop Circle® and GreenSeeker® measure light reflectance from the crop canopy at different wavelengths.

- Reflectance in the red and infrared wavelengths is strongly influenced by the chloropyhll content ('greenness') and biomass of the crop. The greater the chlorophyll content of the crop the less red light is reflected.
- With higher biomass content, an increase in near infrared (NIR) reflectance occurs.
- These wavelengths are used to calculate NDVI (Normalised Difference Vegetative Index) for the crop, which is an index of canopy greenness and is one of many indices used in crop sensing.
- $\text{NDVI} = \dfrac{\text{reflectance at red} - \text{near infrared wavelength}}{\text{reflectance at red} + \text{near infrared wavelength}}$
- For most agricultural crop canopies, readings are between 0 and 1. The higher the reading, the greater the canopy greenness.
- Further analysis of this year's trial data is planned to examine the correlation of other vegetative indices of N uptake, biomass and N concentration. This paper brings together three years of data.

Aim

To determine if crop sensors can be used during stem elongation to determine N content of the plant and the need for applied N.

Method

Location:	Mayo Park Farms, Lubeck
Replicates:	4
Sowing date:	14 May (Derrimut and Correll) and 16 May (Gladius) 2010
Seeding density:	150 plants/m² target
Fertiliser:	40kg/ha MAP (10% N, 21.9% P)
Crop type:	Derrimunt, Correl and Gladius wheat
Seeding equipment:	Knife points, press wheels on 22.5cm row spacing

Derrimut wheat was established in a large-plot replicated trial (individual plot 6m x 30m) using farm scale equipment, following wheaten hay in 2009. Soil testing indicated 153kg N/ha available at the start of the season. The crop was fertilised with five different N rates (0, 25, 50, 75 and 100kg N/ha) applied at three different timings (Table 1). The N fertiliser product used was granular urea (46% N). Growing season rainfall for the trial site was 310.5mm (April – Oct). Correll and Gladius were established in unreplicated blocks of the same dimensions.

The trial was assessed at regular stages for crop structure, dry matter and N content analysis, green area index and assessment with a handheld Greenseeker. Yield Prophet® (YP) simulations were run and used to determine the N rate and timing in one of the treatments. The trial was harvested on 22 December 2010. Grain protein and quality were also measured.

Table 1. N timing and rainfall 15 days subsequent to application (mm).

N timing	Description	Date of application	Rainfall following
1. 100%	Single dose - predrilled	30 April	1mm (on the day) 3mm (5 May) 1.5mm (12 May)
2. 100% GS30	Single dose – at start of stem elongation	2 August	4mm (on the day) 11mm (5 August) 20mm (11 August) 15mm (16 August)
3. 50% GS30 50% GS33	Split dose applied at start of stem elongation and third node	2 August 13 September	as above 0.25mm (16 Sept) 0.5mm (28 Sept)

Predicted N rates and timings using Yield Prophet and crop sensor technology

In order to 'road test' two predictive systems for N application, an extra two treatments were set up.

1. Soil, rainfall and crop details from the trial site were fed into Yield Prophet in order to generate recommendations for N application.
2. Constructing an N response index from the crop sensor data at GS30 and GS33.

   Taking the NDVI of the unfertilised crop and the crop receiving 50N pre sowing, it is possible to construct a response index simply by dividing the NDVI of pre sowing N with the zero N. The greater the difference in canopy greenness as measured in NDVI between with and without N, the greater the predicted response to N. This response index can then be plotted against the actual response to N (Figures 4 and 5).

   For example, a NDVI of 0.45 from 50N pre dill versus an unfertilised paddock NDVI of 0.42 would give a response index of 0.45/0.42 = 1.07, indicating very little difference between the fertilised and unfertilised plots.

At GS16 Yield Prophet predicted a 70% chance of yield response to additional N. However, given significant rainfall, at GS33 Yield Prophet predicted a 90% chance of a yield response to additional N and as a consequence 25kg N/ha was applied.

Crop Sensor (Greenseeker) resulted in 25kg N/ha at GS33 (third node). The response index (NDVI 50N predrill/NDVI zero N) was 1.05 at GS30, indicating little difference between the N rich strip and the unfertilised control. However at GS33 this had increased to 1.1, indicating a greater probability of N response. 25kg N/ha was added to cover the extra yield potential, which calculated at that stage to be less than 1 t/ha.

Results

Soil N

Based on soil samples taken on 12 April 153kg/ha of available N was present in the soil (0-100cm) following the previous year's 8t/ha wheat hay crop 111kg N/ha was located in the top 40cm of the profile. These figures were based on both ammonium and nitrate N.

Establishment

No significant differences were found in plant emergence between any of the N rates. All treatments were established at an average 167 plants/m^2. No difference in tiller number was found across the different pre-drill N rates when assessed at GS30 (mean tiller number 530/m^2).

Crop reflectance/ crop canopy greenness (Greenseeker measurements)

N timing

Crop reflectance readings during the season on the 50kg N/ha plots revealed little or no difference in NDVI due to N timing except at flag leaf and flowering when there was a small but significant disadvantage in the split application (Figure 1). There was a greater difference in NDVI when N treated plots were compared with the zero N plots. However these differences were significant only when the crop reached GS33 (third node). Differences were not apparent at GS30 – 32 when stem elongation N application was first considered.

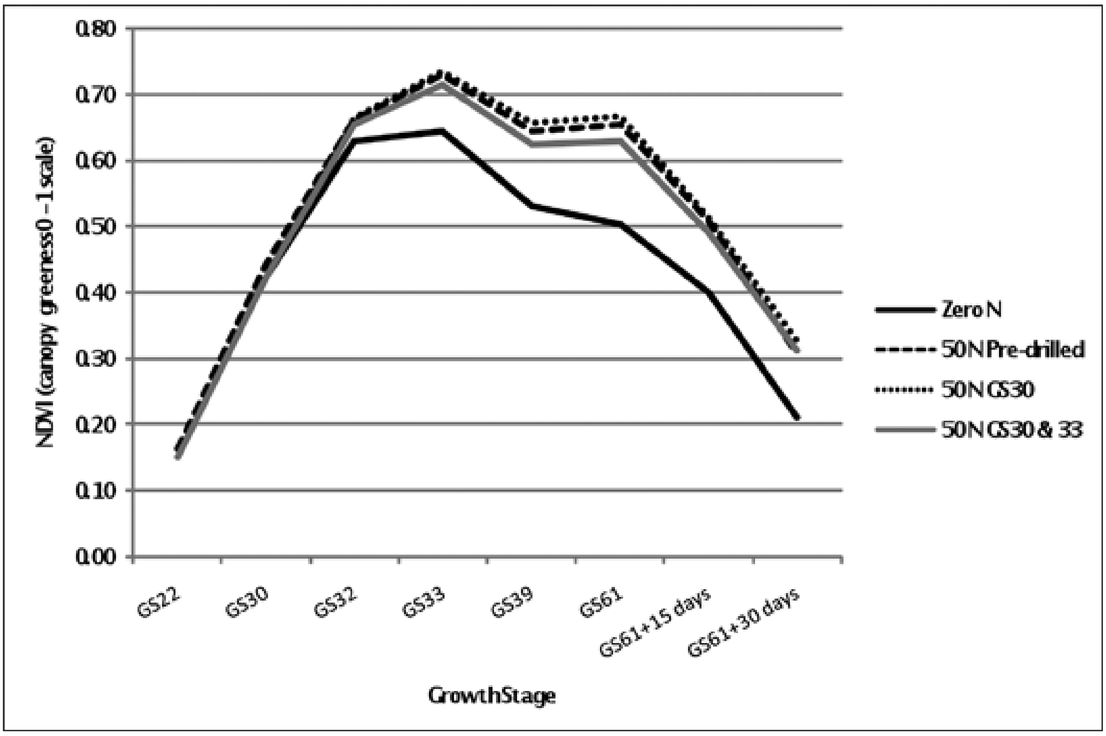

Figure 1. Influence of N application and timing on crop canopy greenness (NDVI reading from Greenseeker) when assessed from tillering to grain fill (GS22 – GS61 + 30days).

N rate

NDVI differences due to N rate were significant from GS32-33 onwards. At GS33, 100kg N/ha predrilled gave significantly higher NDVI than 25kg N/ha predrilled. By flowering (GS61), differences in NDVI were significant between all N rates, a difference maintained through grain fill, with higher N rates staying greener for longer (Figure 2).The differences in N rate NDVI at GS61 were not statistically significant with the stem elongation N timings, though there was the same trend for higher NDVI with more N.

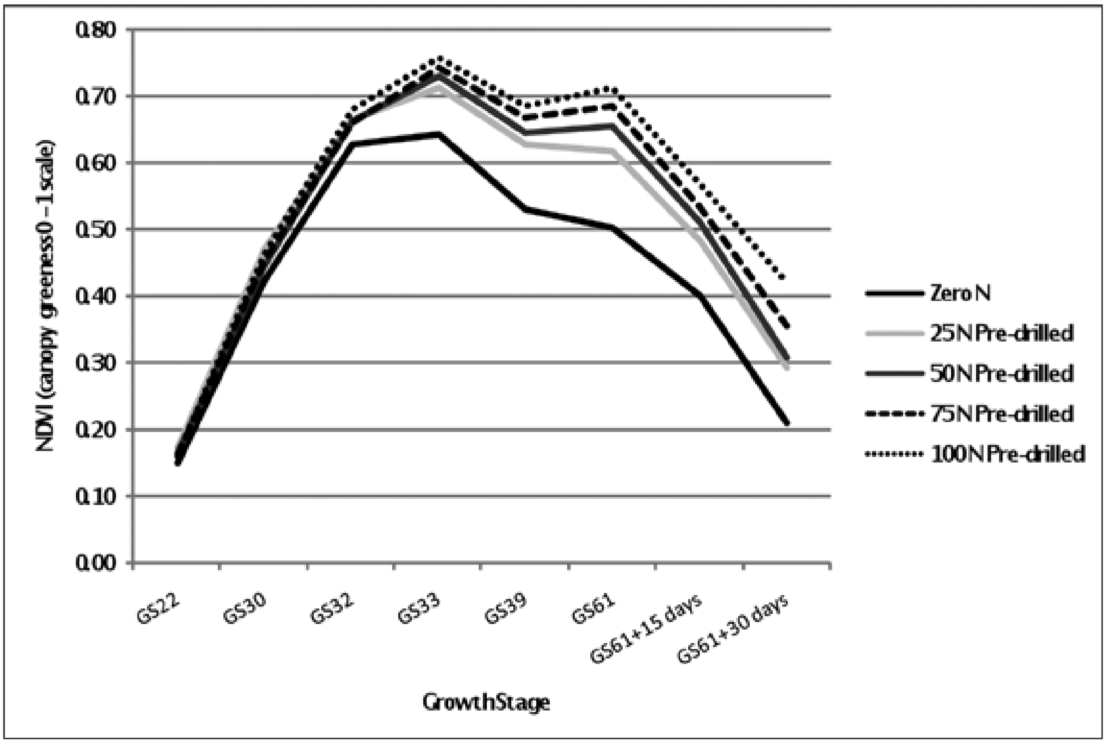

Figure 2. Influence of N rate on crop canopy greenness (NDVI reading from Greenseeker) when assessed from tillering to grain fill (GS22 – GS61 + 30days).

How do these data compare with 2008 and 2009?

Crop reflectance measured in terms of NDVI showed significant differences in the three seasons of the trial (Figure 3):

2008 (Soil N at sowing - 253kg N/ha following lentils)

- NDVIs were above 0.8 at GS30, correlating with the high degree of fertility. There was no indication that plots receiving pre-drilled N had higher NDVI at this growth stage
- NDVI remained high until flowering, with little indication that those plots receiving N exhibited a greater NDVI
- at flowering, severe drought resulted in a rapid decline in NDVI
- there was a negative response to applied N in the trial.

2009 (Soil N at sowing - 60kg N/ha following oaten hay)

- by contrast, 2009 NDVIs never reached 0.4 in the unfertilized crop, while large increases occurred where N was pre drilled, for example, 0.2 in NDVI from an application of 50N by the time crop reached GS32
- the softer finish was mirrored by higher NDVIs at the end of grain fill than had been the case in 2008
- there was a 25% yield increase from the application of N (50kg N/ha).

2010 (Soil N at sowing - 153kg N/ha following wheat hay)

- intermediate fertility was reflected by higher NDVI than recorded in 2009, and later separation of the NDVI lines from N-treated and untreated crops
- the extremely long season led to very high yield potential: 5.8t/ha yield with no N applied
- there was an 18% yield increase with the addition of 50kg N/ha.

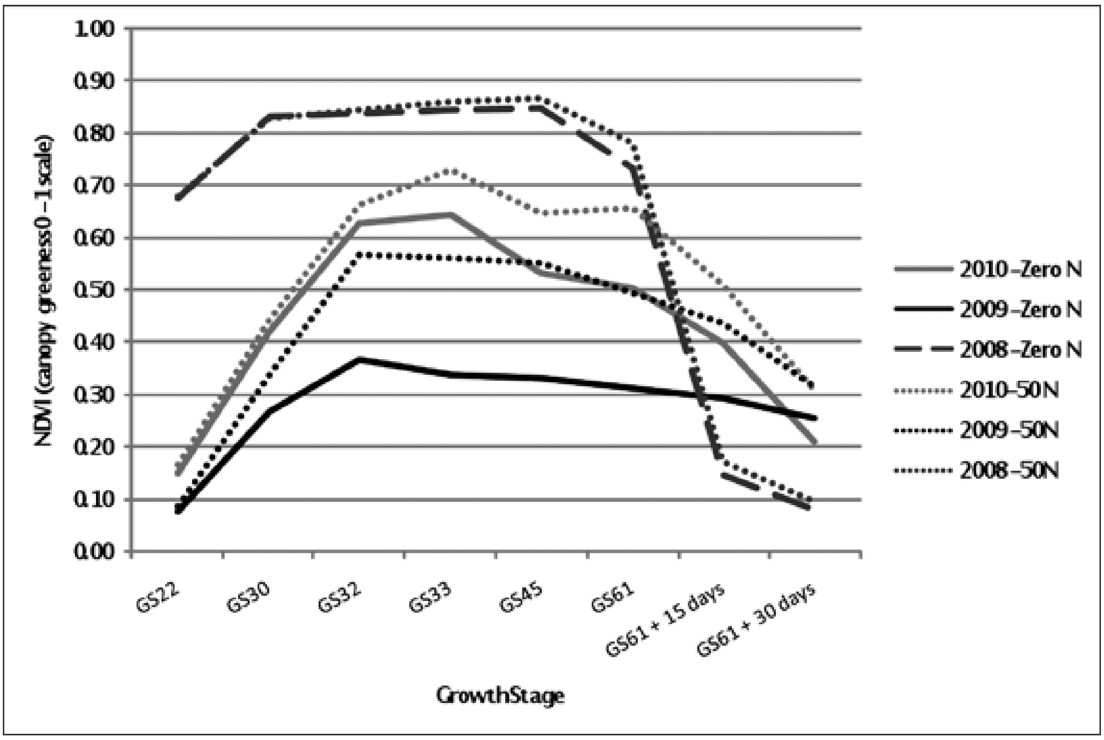

Figure 3. Influence of 50kg N/ha (pre drilled) and unfertilised crop on the NDVI of the wheat crop canopy in the three years of the project (2008 – 2010) assessed from tillering to grain fill (GS22 – GS61 + 30days) (c.v. Derrimut, Lubeck, VIC)

In the three project years, did the NDVI readings give an indication of the likely response to N during stem elongation (GS30 - GS33)?

Using the 2010 data at GS30, the NDVI difference between 50N predrilled and zero N was small (response index 1.05), indicating little need for applied N. However, by the time the crop reached GS33 the NDVI difference was greater (1.1), indicating that a response to N was more likely. In 2008, the NDVI response index never exceeded 1.02 at any stage during stem elongation, indicating little likelihood of a response to N.

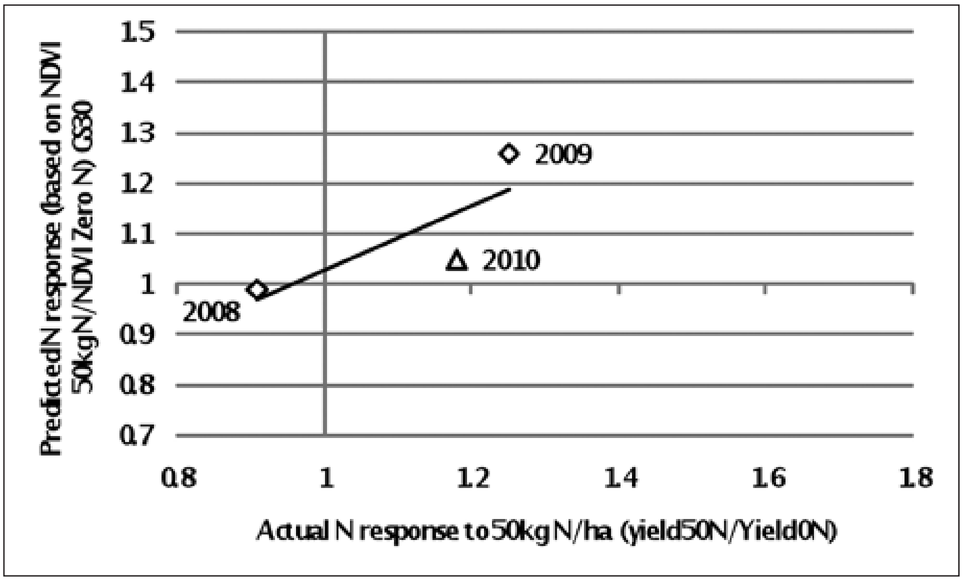

Figure 4. Predicted response to applied N at GS30 comparing NDVI of unfertilised crop with crop receiving 50N pre drill, compared with actual response to N (expressed as a simple ratio fertilised yield/zero N yield).

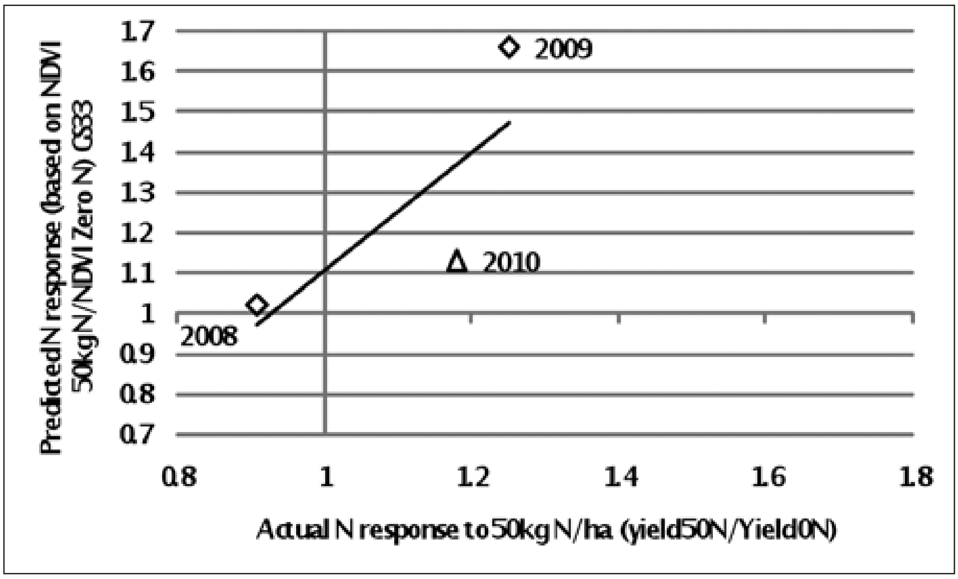

Figure 5. Predicted response to applied N at GS33 comparing the NDVI of an unfertilised crop with a crop receiving 50N pre drill, compared with the actual response to N (expressed as a simple ratio fertilized yield/zero N yield).

2010 Correlation between N uptake and crop reflectance (NDVI)

Since the site was relatively fertile (153kg N/ha in the soil at seeding) the differences in NDVI due to pre drilled N (five N levels) did not start to show up until third node and flag leaf emergence and even then differences were relatively small (Figure 6). The small differences in NDVI due to pre-drilled N relate to small variations in N uptake which became statistically significant only at flag leaf (GS39).

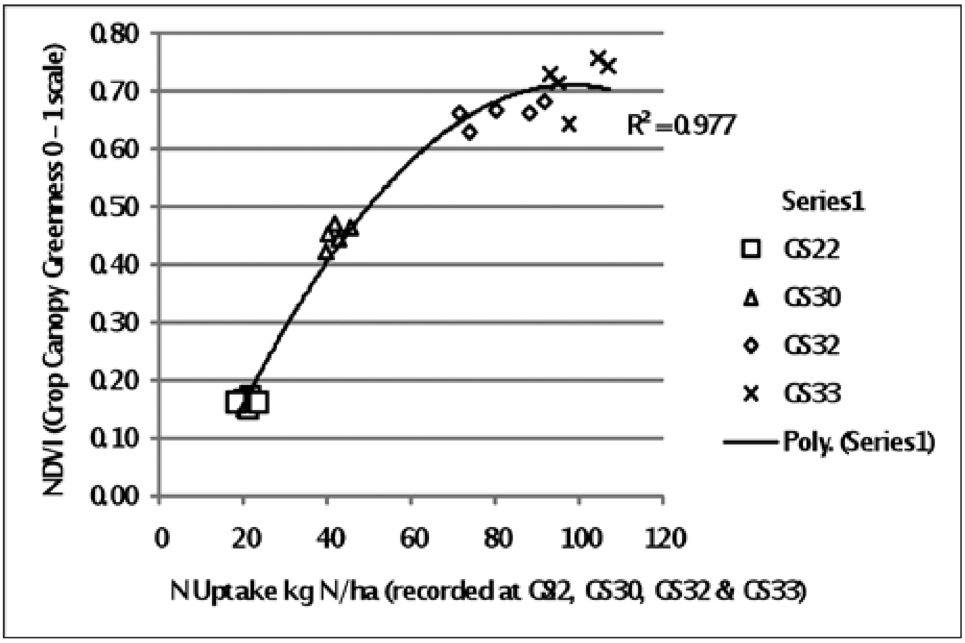

Figure 6. Correlation between N uptake (kg N/ha) in above ground biomass and crop canopy greenness (expressed in terms of NDVI measured with a Greenseeker) at GS22 (□), GS30 (△), GS32 (◇) and GS33 (X) following application of different rates of pre-applied N in 2010 after wheat hay (soil N 0 -100 153kg N/ha) (c.v Derrimut, Lubeck, VIC.)

Over the three years of the project, there has been a general correlation between overall NDVI and N uptake at GS30 for Derrimut. However, the same N uptake could still be represented by the NDVIs differing 0.1 – 0.15 which makes it difficult to predict N uptake for one season based on NDVI readings taken from one season to another. For example in 2009 an N uptake of 42kg/ha at GS30 gave an NDVI of 0.32, but in 2010 the same N uptake gave an NDVI of 0.45 (Figure 7).

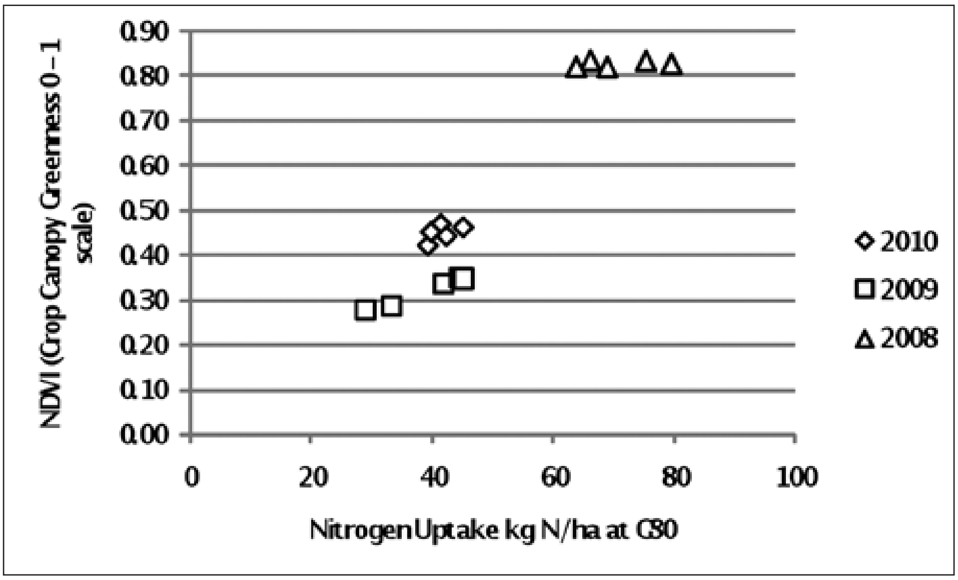

Figure 7. Correlation between N uptake (kg N/ha) in above ground biomass and crop canopy greenness (expressed in terms of NDVI measured) at GS30 (cv Derrimut, Lubeck, VIC, 2008 – 2010).

A further complication is that different varieties can have different NDVI when assessed at the same growth stage (Figure 8).

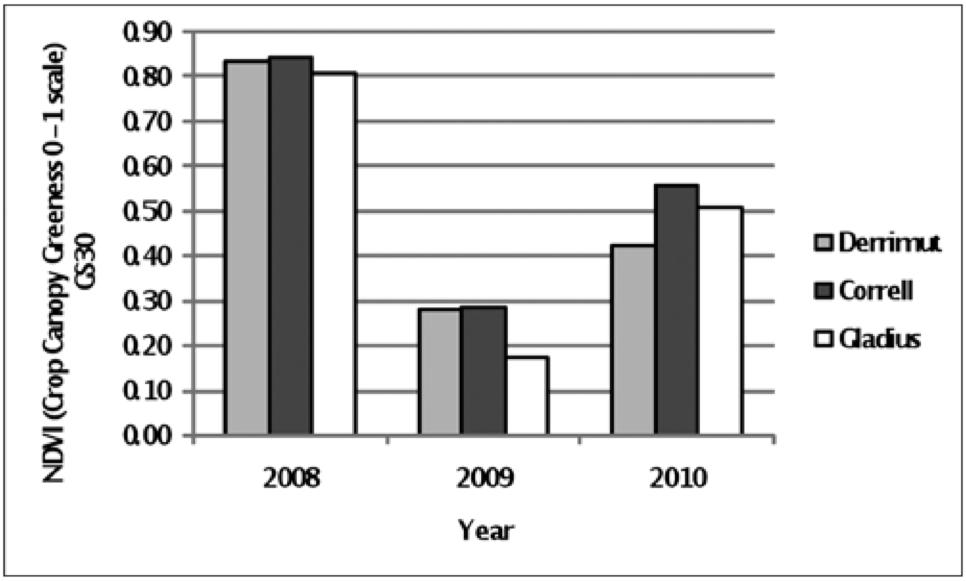

Figure 8. Influence of cultivar on crop canopy greenness (NDVI reading from Greenseeker) when assessed at GS30 in no N plots (cv Derrimut, Lubeck, VIC, 2008 – 2010)

2010 Yield (t/ha) and quality data (protein and screenings)

A significant yield increase associated with N application occurred in 2010, despite the zero N plots yielding 5.79t/ha. Yields were optimised at 75kg N/ha with a mean yield of 7.77t/ha averaged across the three N timings. For the third season in succession, there was no significant difference in yield due to N timing. All three applications: predrill applied N (mean yield 7.39 t/ha), GS30 applied N (mean yield 7.50t/ha) and a split between GS30 and GS33 (third node) (mean yield 7.37t/ha) gave similar results at the four N rates tested.

75kg N/ha gave significantly higher yields than 50kg N/ha (7.77t/ha > 7.31 t/ha averaged across 3 N timings), which in turn was superior to 25kg N/ha (6.76t/ha). No statistical advantage was shown when the N rate was increased to 100kg N/ha, though the protein was higher than at 75kg N/ha (9.88% protein) (Figure 9).

Protein and screenings

There was a significant interaction between protein content and N rate and timing. At N rates up to 50kg N/ha, there was a significant increase in grain protein, but no difference that could be attributed to N timing (Figure 10). At 100kg N/ha, the protein content of GS30 timed N and pre-drilled N was higher than that of the split application. This was unexpected, since in previous years later N has been associated with higher protein content. With a lack of rainfall after N application at GS33 (13th September), it is thought that some of the N was lost and not taken up by the crop.

As N rate increased, also did screenings (Figure 11). N timing had no significant effect on screenings.

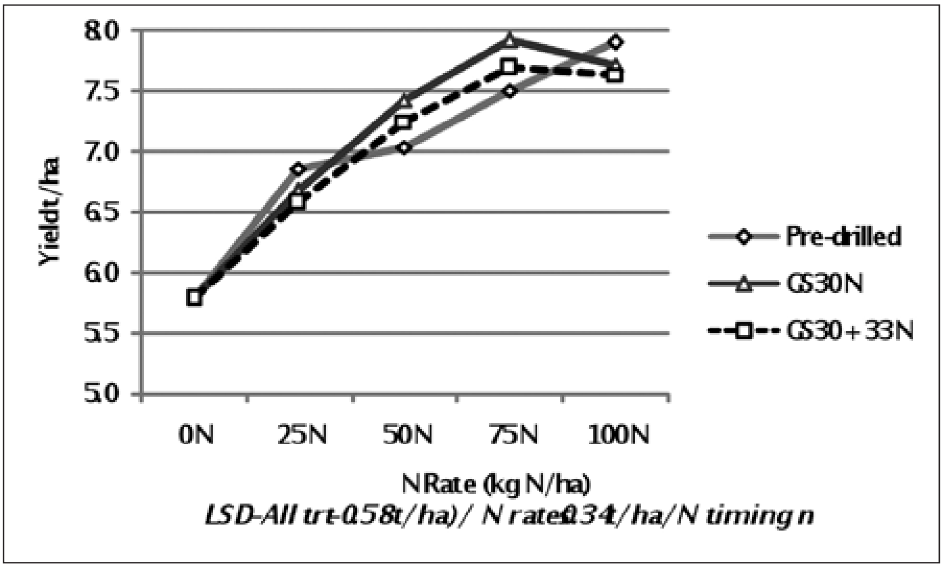

Figure 9. Influence of N rate and timing on yield (t/ha) (c.v Derrimut, Lubeck, VIC)

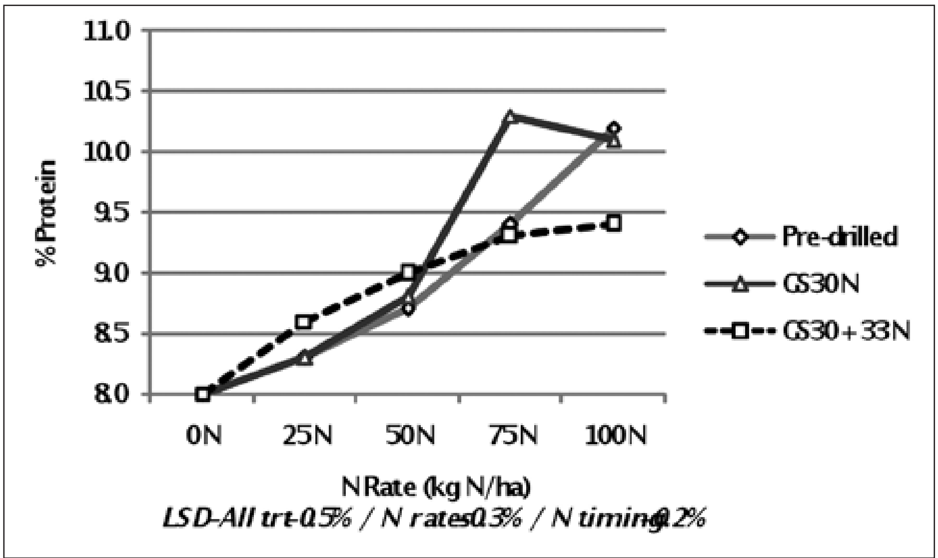

Figure 10. Influence of N rate and timing on % grain protein (c.v Derrimut, Lubeck, VIC).

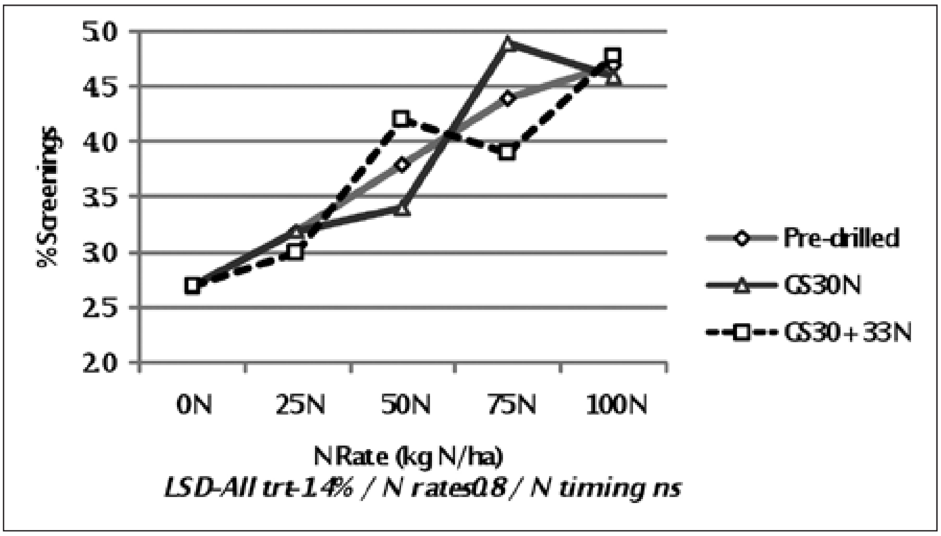

Figure 11. Influence of N rate and timing on % screenings (c.v Derrimut, Lubeck, VIC).

Gross margins

75kg N/ha top dressed at GS30 and 100kg N/ha predrilled gave the highest gross margin (Table 2).

Table 2. Influence of N strategy on yield, quality, quality grade and gross margin after urea cost and application.

N Timing	N Rate (kg/ha)	Yield (t/ha)	Protein (%)	Screenings (%)	Gross Margin ($/ha*)
Nil	0	5.79	8.1	2.9	**1491**
100% Pre drill	25	6.86	8.3	3.2	**1720**
	50	7.04	8.7	3.8	**1750**
	75	7.51	9.4	4.4	**1840**
	100	7.91	10.2	4.7	**1912**
100% GS30	25	6.68	8.3	3.2	**1689**
	50	7.43	8.8	3.4	**1851**
	75	7.92	10.3	4.9	**1946**
	100	7.72	10.1	4.6	**1863**
50% GS30 &	25	6.58	8.6	3.0	**1663**
50% GS33	50	7.25	9.0	4.2	**1804**
	75	7.69	9.3	3.9	**1886**
	100	7.64	9.4	4.8	**1842**
APSIM (100%) GS33	25	7.13	8.8	3.3	**1805**
Crop Sensor (100%) GS33	25	6.72	8.8	3.3	**1700**

Margins are based on gross income minus urea cost (at $575/t). Where yields and proteins are not significantly different, care should be taken when interpreting margins.

Growers should apply their own application costs. The following are guidelines only:

- pre drilling application $33/ha
- top dressing $9/ha
- at sowing (triple bin) $5/ha).

There were no statistical differences in test weights and therefore different price grades were not ascribed where test weights fell below 74kg/hl.

Grain priced as ASW1@ $257.5/t. (AWB Birchip Grainflow - 23 December 2010).

Predictive N treatments

i) APSIM/Yield Prophet

Yield Prophet® simulations resulted in no N being applied at GS30 (start of stem elongation) due to the high level of residual soil N. Over a month later at GS33 (third node), increasing yield potential resulted in the Yield Prophet® plots receiving 25kg N/ha.

ii) Crop Sensor (Greenseeker)

At GS30 the NDVI response index (calculated using 50N predrill plots and the untreated plots) registered 1.05. Since an index this low is regarded as marginal for N application the decision was taken not to apply N at this stage. However at GS33 the NDVI index had increased to 1.1, which indicated soil N reserves were depleting as the crop grew. The decision to apply 25kg N/ha was made using unfertilised YP yield predictions at this stage and then calculating the N required to satisfy a 10% yield increase.

Subsequent rainfall later in the season and cooler conditions during grain fill resulted in sub-optimal N application with these predictive N strategies. However, since the greatest gains in yields were observed with the first two 25kg N/ha increments (ie. moving from zero to 25N and 25N to 50N), the margins reflect reasonable performance (considering the average yield at this site has been 4t/ha, not 8t/ha, over the last 4 years) from both the Yield Prophet® approach and Crop Sensor approach, which in effect are the same treatment (Table 2).

Interpretation

If crop sensors are to be successfully employed, it will be necessary to adopt N timings that allow the grower to wait until the crop visually reveals (in terms of crop reflectance) its nutrient needs. Over the last 3 years of the project, there has been no significant difference in applying N timed either all at GS30-31 or split between GS30 and GS33, indicating that there is a wider window of time for cost effective N application that gives opportunities to employ crop sensor technology for variable rate N.

Waiting until the stem elongation stage enables the crop to "display" (in crop canopy greenness and biomass) how much N is available to it at that time. It has been possible to show that the fertility status of the paddock and general growing season conditions can be reflected by crop sensor measurements such as NDVI. This is clearly apparent when comparing the GS30 NDVIs in 2008, 2009 and 2010 and the conditions for grain fill in the same three seasons (see Figure 3). Whilst this information gives us a useful guide to the health status of the crop canopy, it requires ground truthing for individual paddocks before one can conclude that an NDVI of x requires an N dose of y, particularly as different cultivars give slightly different NDVIs when grown on the same site. However, the project has been able to illustrate that NDVI comparisons between N Rich reference strips (50, 100kg N/ha applied at sowing) and the unfertilised crops can give a guide to likely response to N application.

Combined with a crop model such as Yield Prophet which provides an ability to track soil moisture and probable yield potential, the crop sensors do have a capacity to spatially vary N application in individual paddock situations.

However, until the crop sensors can fully discriminate between biomass and crop greenness - at present indices such as NDVI represent a "combination reflectance" of both biomass and N percentage - it is difficult to see how they can use an algorithm from one wheat crop and apply it to another without a reference point in that specific paddock.

Acknowledgments

This project was funded by GRDC project SFS 00017.