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

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Aim

To determine whether crop reflectance at particular wavelengths of light can be used during stem elongation to determine the need for applied nitrogen. Part of GRDC Project SFS 00017.

Take home messages

- *Applied nitrogen (N) significantly reduced the yield of Derrimut wheat following lentils, yield being reduced from 3.2t/ha to 2.6t/ha as applied nitrogen was increased from 0 to 100kg N/ha in 25kg N/ha increments (linear relationship)*
- *Against a background of a very high soil N reserves (253kg N/ha 0-100cm), there was no effect of N timing; applications at sowing and in-crop (GS30) were equally detrimental to yield*
- *Where N rates were split equally between GS30 and GS38, yield was slightly higher than the single doses applied at sowing and at GS30, but this appeared to be related to lack of uptake for the second dose rather than a beneficial effect of the timing itself*
- *Yield decreases were associated with increased grain protein, such that the zero N treatment achieved an H2 grade (protein below 13 percent) compared to an H1 grade for the N applied treatments. However, the gain in premium ($4/t) was small in comparison to the cost of urea applied and the associated yield depression*
- *NDVI (normalised difference vegetative index) readings from the Greenseeker gave a good correlation (r^2= 0.88) to the N uptake of the crop when assessed between tillering (GS22) and flag leaf emergence (GS38)*
- *Using the Greenseeker as the basis for determining when N should be applied, illustrated that there was no difference in crop NDVI between the zero N plots and the those treated with pre-sowing N (benchmark N-rich strips) until GS38 (50 percent flag leaf emergence on the main stem)*
- *From GS38 onwards though NDVI differences were small (between the zero N and N applied plots) but statistically significant*
- *If the higher NDVI of the pre-sow N treatments were used as the signal to apply N at GS38, then in this trial it failed to improve yield and margin, since there was little or no rainfall for uptake and severe water stress during grain fill. Commercially, an N dose would not have been applied at this timing, due to the low level of stored soil water and dry seasonal conditions*
- *The work illustrates that crop reflectance technology, whilst extremely useful for predicting N uptake, should not be used in isolation from knowledge of soil water content or models that predict soil water content (such as Yield Prophet).*

Method

Location: Mayo Park Farms, Lubeck (courtesy of Peter & Ian Taylor)

Replicates: 4

Sowing date: 14 May

Seeding density: 214 plants/m^2

Crop type: Wheat cv. Derrimut

Seeding equipment: 12m Simplicity + Janke (narrow tyne) with 9in (22.5 cm) row spacing

Derrimut wheat was established in large plot trial (individual plot 6m x 30m) using farm scale equipment following lentils in 2007. The crop was fertilised with five different nitrogen (N) rates (0, 25, 50, 75 and 100kg N/ha) applied at three different timings (Table 1). Fertiliser used was granular urea (46 percent N).

Table 1. Nitrogen timing and rainfall subsequent to application.

Nitrogen timing	Description	Date of application	Rainfall following
1. 100% pre-drill	Single dose – pre-drill	14 May	23mm - 18 May
2. 100% GS30	Single dose – at start of stem elongation	30 July	3.5mm - 31 July 6mm - 2 August
3. 50% GS30 + 50% GS38	Split dose applied at start of stem elongation and flag leaf (50% emerged)	30 July 12 September	1.5mm - 16 September 5mm - 25 September

The trial was subject to a comprehensive assessment program which included crop structure assessments, dry matter and N content analysis, green area index, assessment with a hand-held Greenseeker, Yield Prophet monitoring, and yield and quality analysis. To determine whether there was a relationship between plant N uptake and crop reflectance (measured with the Greenseeker), above ground dry matter was assessed at key growth stages in the spring to determine dry matter and percent N content.

How do crop sensors work and what is NDVI and GAI?

- Crop reflectance sensors, such as the Crop Circle and GreenSeeker, measure light reflectance from the crop canopy at different wavelengths of light
- Reflectance, in the red and infrared wavelengths is strongly influenced by the biomass and chloropyhll content. The greater the chlorophyll content of the crop, the less red light is reflected
- With greater biomass content there is an increase in near infrared (NIR) reflectance
- These wavelengths are used to calculate NDVI (normalised difference vegetative index) for the crop, which is a simple index of canopy greenness.

$$\text{NDVI} = \frac{\text{reflectance at the red} - \text{near infrared wavelength}}{\text{reflectance at red} + \text{near infrared wavelength}}$$

- For most agricultural crop canopies, readings are between 0 and 1. The higher the reading the greater canopy greenness.

GAI is the Green Area Index. It is a measure of the green surface area of the crop canopy and in this trial was measured manually. It is expressed in m^2 of green canopy occupying m^2 of soil. Thus a GAI of 6 means there is 6m^2 of green surface on 1m^2 of soil. Only one side of the leaves are taken into account when calculating GAI.

Results

Soil nitrogen

This site was assessed to have 253kg N/ha in the 0-100cm profile when assessed on 28 April, with over 60 percent of the available N in the top 40cm.

Crop structure

Crop structure assessments and visual appearance were strongly linked to the fertile nature of the paddock. Tiller numbers averaged over 700 tillers/m^2 with head counts averaging 560 heads/m^2 (mean of all treatments). There was no difference in tiller number recorded at the start of stem elongation between 0 and 100kgN/ha applied at seeding. The same was true with head counts recorded just prior to harvest. The differences in tiller loss due to N rate and timing were small. With lower soil N reserves in previous seasons, N at sowing has lead to both higher tiller numbers and higher tiller loss between stem elongation and maturity.

Yield Prophet® – prediction of N response

Indications from Yield Prophet® showed that, despite the high yield potential of the site recorded in July and August (at the start of stem elongation Yield Prophet gave 80 percent probability of achieving 5t/ha, Figure 1), applied N would not be needed to reach maximum yield. The situation had not changed significantly at the end of August GS32-33 (Figure 2). Whilst the yield estimates were on the high side, the predictions surrounding the use of applied N were accurate.

One possible explanation for yields being on the high side was that since the phenology for Derrimut was not available, the report was based on Annuello. Yield Prophet predictions were approximately 8-10 days later at GS30 and GS31 than the growth stages recorded with Derrimut in the field (GS30 was predicted around 8 August whereas Derrimut in the field was at GS30 on 31 July). However, the probability curve does include the grain yield outcome achieved in the field.

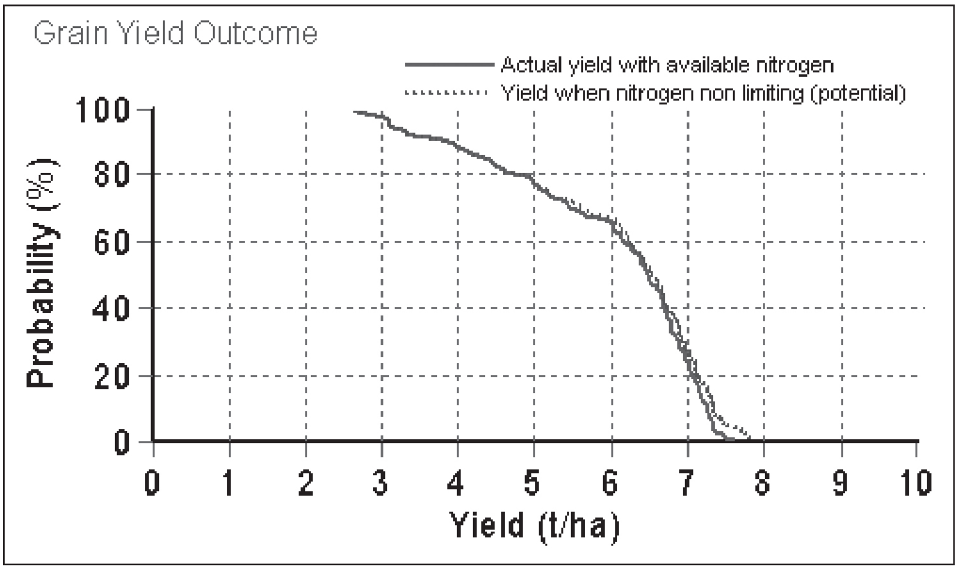

Figure 1. Yield Prophet grain yield probabilities taken from 31 July Report (GS30) on Lubeck wheat cv. Annuello sown 14 May.

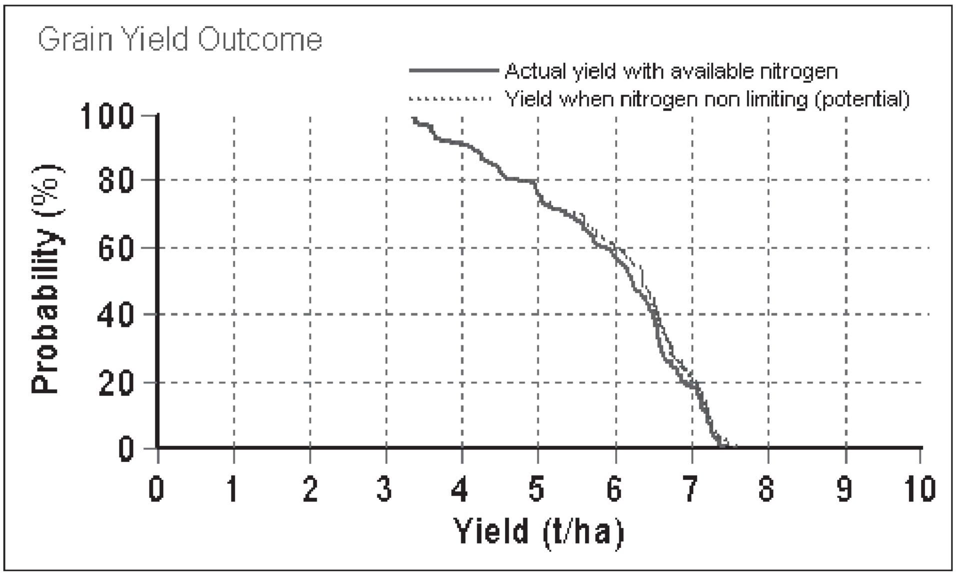

Figure 2. Yield Prophet grain yield probabilities taken from 29 August Report (GS32-33) on Lubeck wheat cv. Annuello sown 14 May.

Crop reflectance measurements (NDVI) and plant nitrogen uptake

Too determine whether there was a relationship between plant N uptake and crop reflectance (measured with the Greenseeker), above ground dry matter was assessed at key growth stages in the spring to determine dry matter and percent N content. From these two assessments, the relationship between N uptake by the plant and NDVI (normalised difference vegetative index – measurement units of the Greenseeker) was determined. Plant N uptake (kg N/ha) increased from 30-50 kg N/ha at GS22 to between 100-170kg N/ha at GS38 (Figure 3).

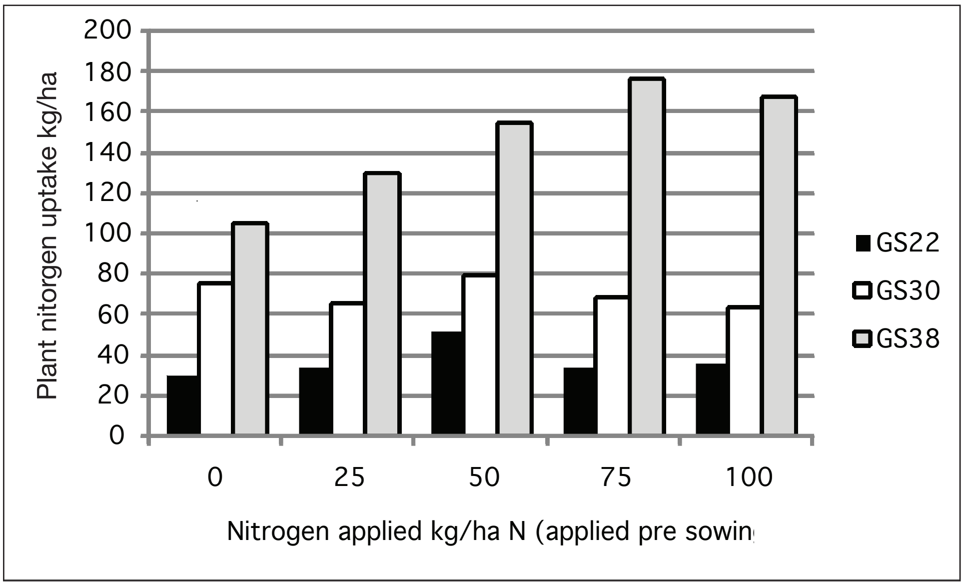

Figure 3. Nitrogen uptake in above ground biomass at GS22 (main stem and two tiller) - GS30, (pseudo stem erect) and GS38 (50 percent flag leaves emerged on the main stem) for different rates of pre-sown N (0, 25, 50, 75 and 100kg N/ha) in wheat cv. Derrimut.

At the same time as plant N uptake was assessed in above ground biomass, the trial was also assessed with the Greenseeker in order to quantify differences in 'greenness' between treatments (Figure 4). This assessment showed no significant difference in NDVI until GS38 when higher rates of N gave significantly higher NDVI compared to the control. Therefore it was not until flag leaf that the Greenseeker was able to detect differences in NDVI which also corresponded to differences in plant uptake of N.

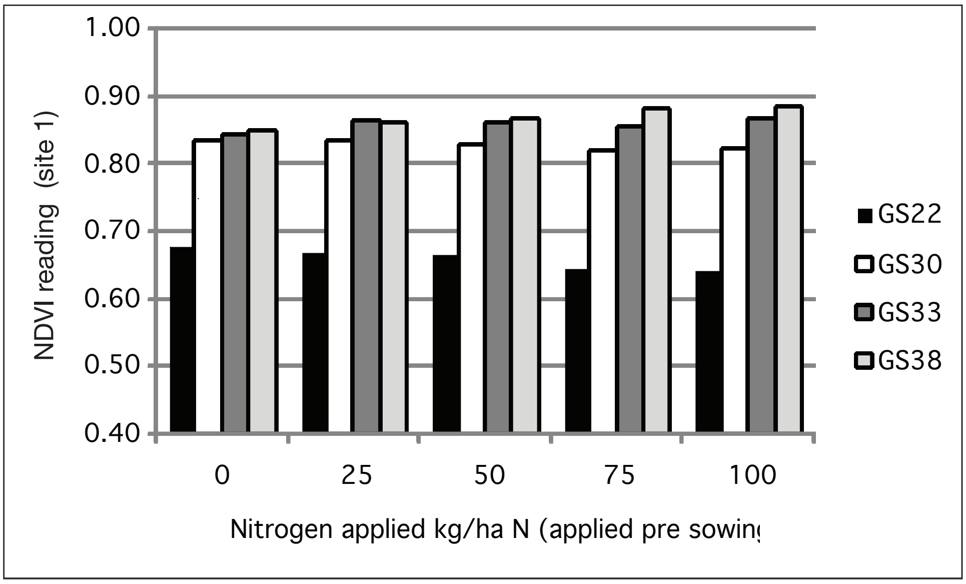

Figure 4. NDVI readings taken with the Greenseeker at GS22 (main stem and two tiller) - GS30, (pseudo stem erect) and GS38 (50 percent flag leaves emerged on the main stem) for different rates of pre sown N (0, 25, 50, 75 and 100kg N/ha) in wheat cv. Derrimut.

When NDVI readings from the different growth stages were plotted against plant N uptake (kg N/ha) there was a good correlation (r^2=0.88), indicating that crop reflectance up to flag leaf could be linked to N uptake (Figure 5). However differences in N uptake due to different growth stages were greater than differences generated by different N rates in this fertile paddock situation.

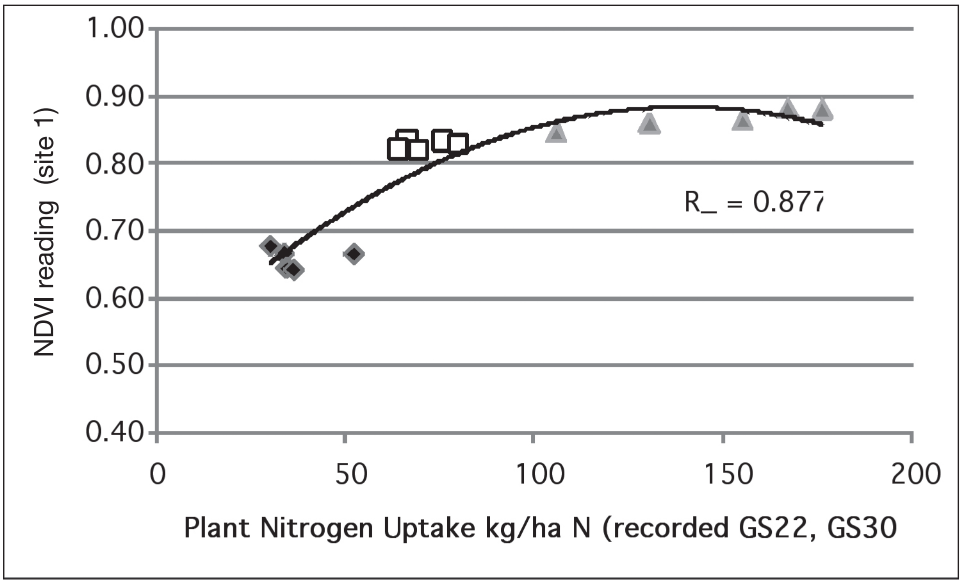

Figure 5. NDVI readings taken with the Greenseeker at GS22 (main stem and two tiller) - ◆, GS30 (pseudo stem erect) - ☐, and GS38 (50 percent flag leaves emerged on the main stem) - ▲, and the relationship with plant N uptake (in above ground biomass) in wheat cv. Derrimut.

Though the absolute differences in crop reflectance were small (Figure 6), there was significantly higher crop canopy greenness (NDVI) associated with N application when assessed from GS38-87 (compared to the zero N control) which was not apparent at GS30 and 33. At GS65, the difference in NDVI between the different levels of upfront N was ground truthed by examining the Green Area Index (GAI) of the crops fertilised at sowing with 0, 50 and 100kg N/ha level. This revealed that GAI in these treatments increased from 5.7 to 5.92 to 6.65 (m^2 of green canopy on $1m^2$ of soil) as applied N at sowing increased from 0, 50 to 100kg N/ha.

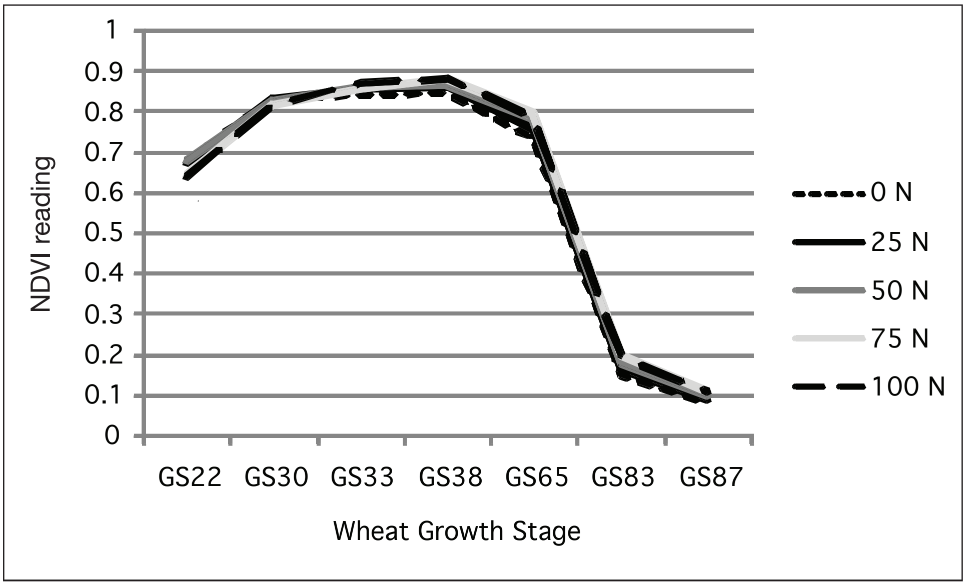

Figure 6. NDVI readings taken from GS22 (tillering) through to GS87 (late grain fill) based on crops treated with five rates of N at sowing, cv. Derrimut.

Water stress

At GS65 mid-flower (10 October), the crop was clearly stressed based on Yield Prophet predictions (22mm below the stress threshold) having crossed the stress threshold at ear emergence GS55-59 on 29 September (Figure 7). The predicted water stress during grain fill mirrors the sharp drop in NDVI (canopy greenness) observed in the 18 days between GS65 and GS83 (Figure 6).

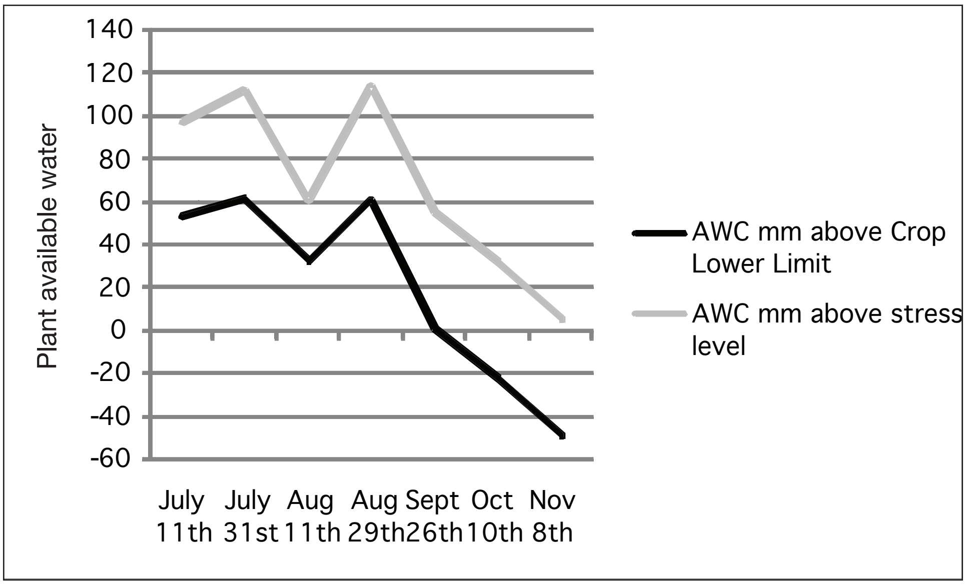

Figure 7. Yield Prophet predictions of soil water content (mm) in relation to stress threshold (for wheat) and crop lower limit based on Yield Prophet reports from 11 July to 8 November – Lubeck, Wimmera grey clay.

Yield and protein

There was a significant (p=0.001) linear trend for increasing amounts of applied N to reduce yield in this trial, irrespective of N timing. In association with the decreasing yield, there was a significant linear increase in grain protein (p=0.001) (Figures 8 and 9).

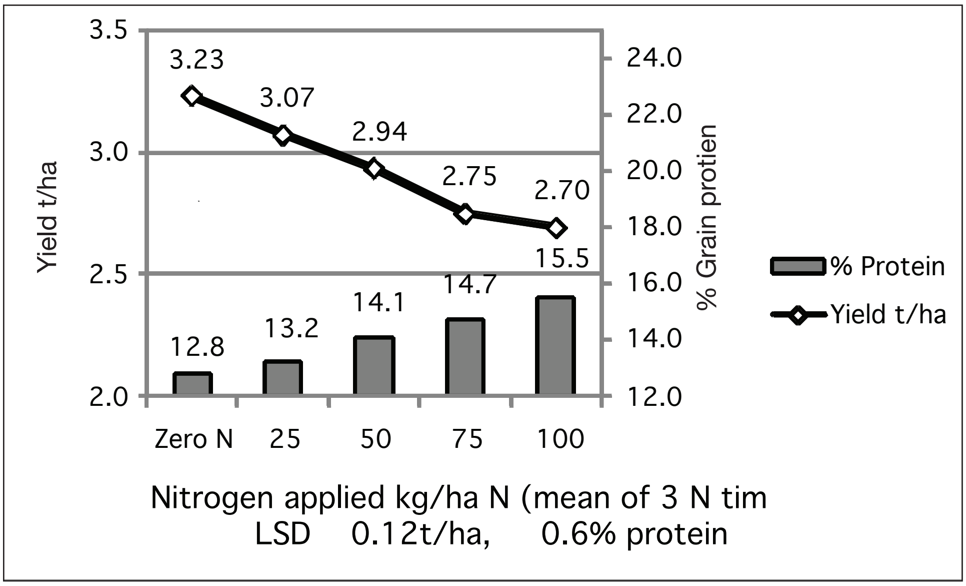

Figure 8. Influence of nitrogen rate on yield (t/ha) and percent protein of Derrimut wheat grown at Lubeck (mean of three nitrogen timings).

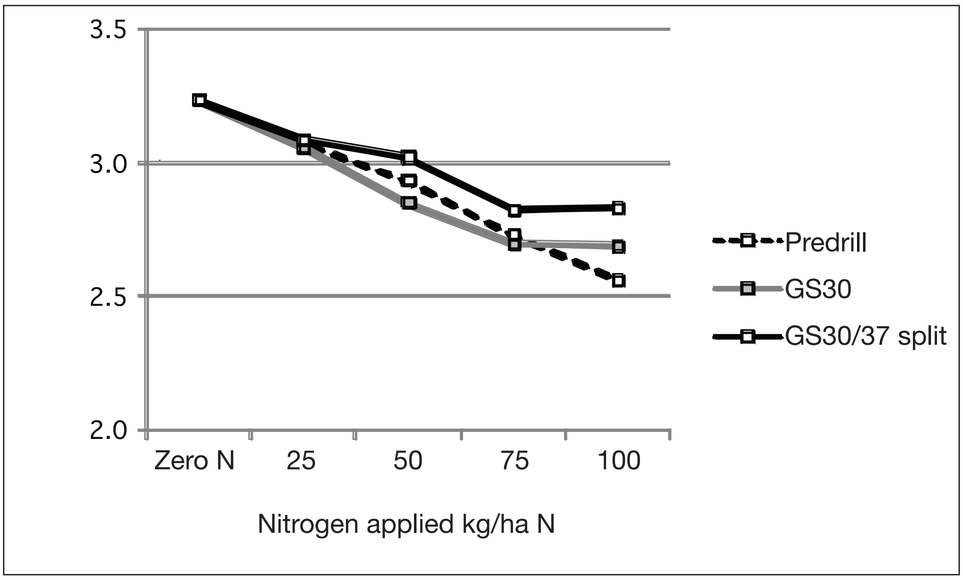

Figure 9. Influence of nitrogen timing and rate on yield (t/ha) of Derrimut wheat grown at Lubeck.

There was evidence that the later N split (p=0.054) was higher yielding than earlier applications, but evidence from weather records and grain protein (Figure 10) would suggest that the later application of the split (GS30/38) was not taken up, hence did not have such a detrimental effect on yield.

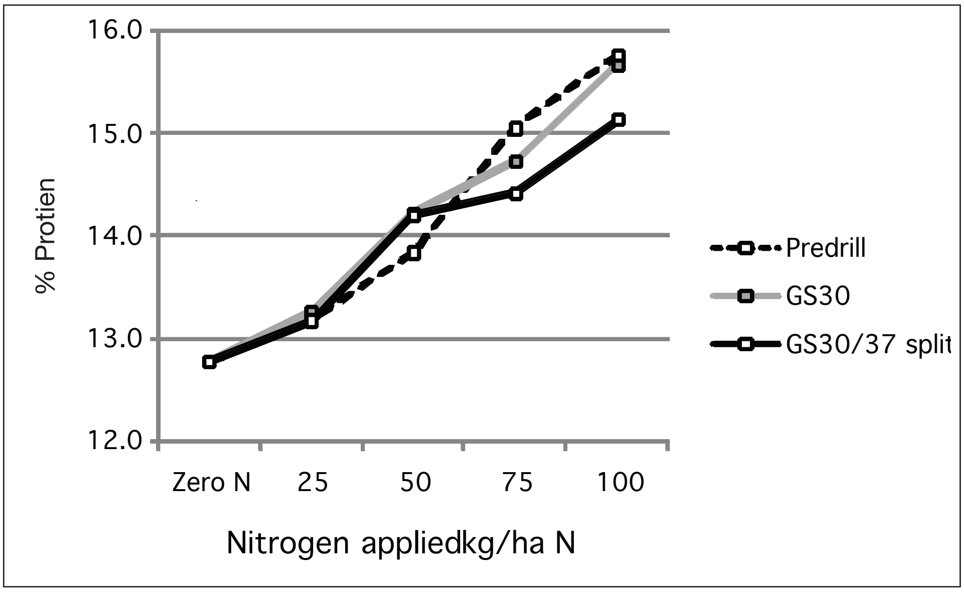

Figure 10. Influence of nitrogen timing and rate on grain protein of Derrimut wheat grown at Lubeck.

Margins

Since the application of N reduced yield, there was a large reduction in gross income after urea cost was taken into account (Table 2). This effect was more pronounced in 2008 due to the high prices of N fertiliser. Though the influence of N application increased grain protein content from H2 grade to H1, this $4/t advantage was small relative to the overall cost of the fertiliser and its negative impact on yield.

The mean margin of the split N timings was higher than the pre-drill and GS30 applications, principally due to lack of uptake of the second N dose (illustrated by lower protein and rainfall records).

Table 2. Gross income for Derrimut wheat based on yield and protein after nitrogen costs (not including application cost) – based on AWB cash price for H1 of $245/t ($273/t - $28/t freight) and H2 at $241/t ($269/t - $28) delivered 7 January 2009. All treatments except zero N were H1 quality.

Nitrogen timing	N rate kg N/ ha	Yield t/ha	Protein %	Gross income$/ha	Gross income – urea cost $/ha*
1. Single dose – pre-drill	0N	3.23	12.8	779	779
	25N	3.08	13.2	753	702
	50N	2.94	13.8	720	617
	75N	2.73	15.1	669	514
	100N	2.57	15.8	628	422
2. 100% GS30 - single dose at start of stem elongation	25N	3.06	13.3	750	698
	50N	2.85	14.2	699	596
	75N	2.70	14.7	661	506
	100N	2.69	15.7	659	453
3. 50% GS30 + 50% GS37 - split dose applied at start of stem elongation and flag leaf just visible	25N	3.09	13.2	756	705
	50N	3.02	14.2	741	638
	75N	2.83	14.4	692	538
	100N	2.83	15.1	694	488

Cost of N as urea (46% N) - $950/t or $2.07/kg N

**Note: Application cost has not been included in these costings and growers should apply their own costs to these results. Clearly, N timings based on a split application have higher costs than single applications, but have the advantage of spreading risk.*

The following figures are put forward as a guide: pre-drilling application costs $31/ha, top-dressing $8/ha and at sowing using a triple bin less than $5/ha.

Interpretation

N content of the plant (kg N/ha) was correlated to NDVI readings from the Greenseeker when assessed from tillering (GS22) to flag leaf emergence (GS38). The different rates of N at seeding (0, 25, 50, 75 and 100kg N/ha) created N-rich strips for comparison of canopy greenness and NDVI later in the spring. Based on the comparison of these different N levels with the zero N plots, it was possible to conclude that the crop canopy was not deficient in N at tillering and early stem elongation (based on no difference in canopy greenness as detected by Greenseeker readings in NDVI). Therefore up to GS30, the Greenseeker was very useful for confirming that N uptake in above ground biomass was the same irrespective of the amount of N applied at sowing, ie. that applied N was not required.

At flag leaf emergence GS38, there was clear evidence from NDVI readings and plant N uptake that the zero N treatment was giving lower readings than where N had been applied at sowing. The differences in NDVI were small (0.02-0.04 NDVI units) but statistically significant ($p=0.001$). Therefore, if it was assumed that N-rich crops (greener plots with N at sowing) possessed the desirable level of greenness and plant N content it might be argued that N should have been applied at this later timing (GS38). In last season's Lubeck trial, N applied at (GS33) created the highest yields.

In fact, the higher NDVI, plant N content and resultant GAI of these N-rich crops served to reduce yield compared to the untreated control. Application of N at GS38 as part of a split resulted in no advantage over the untreated crops, principally due to lack of rainfall for uptake at this later growth stage.

In a commercial situation if a change in NDVI was being used as the trigger to apply N, it is unlikely that any urea would have been applied due to the low stored soil water content and lack of rainfall for N uptake. This scenario was played out on the host farm whereby required nitrogen rates were split, with half applied at GS30-31 and the second dose planned to be applied at GS33-39. With low stored water and no rainfall during the critical period, the second dose of N was never applied. This illustrates that crop reflectance on its own cannot be used as trigger for N application, unless it is able to also measure moisture stress.

Greener crops (crops with N at sowing) set up as benchmarks to indicate when soil N was exhausted were successful at demonstrating the high soil N reserve up to flag leaf emergence GS38, at which time a lower NDVI of the zero N plots correlated to lower levels of N in the plant. Using N at these later stem elongation timings was not successful in 2008 since there was little rainfall subsequent to application. In 2007, when GS33 represented the optimum application timing, there was both early November rainfall and 7.5mm following application at GS33. In addition, with a soil N reserve of 113kg N/ha, Yield Prophet predicted a 70 percent probability of obtaining a response to N in that season (BCG 2007 Season Research Results, page 62).

Application

The work serves to illustrate the value of knowing your soil N reserve with regard to N application, particularly where applications are being made at sowing. To take advantage of crop reflectance technology such as the Greenseeker, it will still be necessary to link outputs with soil water levels to secure the greatest value from this technology. However, the trial has served to illustrate that NDVI reading can be linked to N already present in the plant at key timings for N application in the spring.

The work taking place at two other sites in Australia will be repeated in a less fertile scenario next season.