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Defining and evaluating methods of using crop canopy data collected by boom-mounted sensors to adjust plant growth regulator inputs and the timings of nitrogen applications

by

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1. ABSTRACT

The aim of the project was to interpret and evaluate crop canopy information for winter wheat crops collected using boom-mounted sensors that could then be used in the planning of nitrogen fertiliser timing and plant growth regulator application strategies. These strategies would aim to minimise the risk of lodging whilst also maintaining crop yield and minimising plant growth regulator (PGR) use.

Experimental plots were established over three seasons on two sites with different soil types using seed rates in the range 70 to 400 seeds/m^2 to give different crop canopy characteristics. Measurements of the crop canopy characteristics (crop height and a Normalised Vegetation Difference Index – NDVI) made at each site and on three occasions in each season using a boom-mounted sensor system showed that there was a consistent relationship between NDVI and Leaf Area Index (LAI)/Green Area Index (GAI) measured with a manually operated light attenuation instrument. There was also a relationship between the variability of the NDVI signal and the tiller/shoot number which, for a given field calibration, could provide information about plant populations on a spatially selective basis. It was therefore concluded that crop canopy sensing systems could provide input data for managing root and stem lodging risk based on existing decision rules. The sensor systems gave the steepest responses for both the NDVI/LAI (GAI) and the variability of NDVI/tiller (shoot) counts relationships at the early measurement timings and this corresponds to the times at which decisions relating to nitrogen timings and PGR inputs are most relevant.

In the first year of the project, plots were managed using variable treatments determined from a set of decision rules defined for each of three separate strategies: standard, variable nitrogen timings and variable PGR inputs. Results were found to be dominated by weather effects during the 2006/07 season and therefore for the final two years of the work a more conventional randomised plot design was used. Crop yields from plots treated with no early nitrogen and a low PGR input consistently gave lower yields than those treated with a standard nitrogen split and either a low PGR input or a robust PGR input. Crop lodging was only recorded on the heavy land site with some lodging for all strategies and seed rates in the first year of the work, for the highest seed rate plots only in the second year and no lodging in the third year. Lodging risk analyses were therefore based on previously established relationships.

2. SUMMARY

2.1. Introduction and background

Concern over crop lodging has increased as combine harvester capacity (tonnes/machine per season) has needed to increase in response to economic pressures such that a standing crop is now a critical requirement in any UK cereal production strategy. Crop lodging also incurs potential additional costs related to crop drying and increases the risk of mycotoxins in the grain. However, there are also increasing concerns about the chemical residues of plant growth regulators in the food chain. The most commonly occurring pesticide residues in grain are glyphosate and plant growth regulators. There is concern over the levels of use of some plant growth regulator formulations but current alternatives are less effective when used alone and are more expensive. Therefore, approaches that minimise the risk of lodging using well managed inputs of growth regulators based on information about the crop canopy have potentially important advantages. If plant growth regulator use is restricted then an important way of reducing lodging risk relates to the adjustment of the timings of nitrogen inputs.

This project aimed at testing the hypothesis that the risk of crop lodging can be effectively managed by applying growth regulators and adjusting the timings and splits of nitrogen inputs based on measurements of the crop canopy structure. A review of approaches to crop canopy sensing identified spectral reflectance as the principle most commonly used as a basis for determining cereal crop canopy characteristics both in research studies and commercial developments. The work described in this report builds on previous studies conducted as part of an HGCA Fellowship (HGCA Project Ref. 2265 that commenced on 01/05/2000) in which it was shown that there was the potential to obtain information about crop canopy structure from boom-mounted sensors in terms of both Green Area Index and shoot/tiller numbers and hence a basis for the management of lodging risk using established relationships.

2.2. Methods

The project was conducted over three cropping seasons and involved the establishment of winter wheat plots on two sites: a heavy land site near Biggleswade in Bedfordshire, and a light land site near Andover in Hampshire. Different crop canopies were achieved at each site by using seed rates in the range 70 to 400 seeds/m^2. A boom-mounted sensor system, developed as part of previous project work (Scotford and Miller, 2004) and including radiometers to measure spectral reflectance and ultrasonic transducers to monitor boom height, was mounted on a self-propelled lawn mower chassis that enabled the transducers to be moved across the plots at a speed of approximately 4.0 km/h with data recorded directly to a computer at a rate of 10 Hz. Measurements were made on three occasions at each site: in early March, April and May. On each measurement occasion, the Leaf Area Index/Green Area Index was measured in each plot with a manually operated light attenuation instrument ("Sun Scan" – Delta-T Devices Ltd).

In the first year of the work plots received treatments based on three strategies:

- Standard nitrogen split and standard PGR programme according to best practice for the site.
- Standard nitrogen split with a variable PGR programme based on crop canopy measurements.
- Variable nitrogen split based on crop canopy measurements and a standard PGR programme.

Decision rules were developed based on the results of the crop canopy measurements and applications of both nitrogen and plant growth regulators were made according to these rules. In the early spring of 2007, crop canopies, particularly at the heavy land site, had much greater Leaf Area Indices than expected following a relatively mild winter. There then followed a dry spring period during which crops at the heavy land site lost leaf such that the application strategies based on the developing canopy could not be implemented as initially envisaged. It was therefore decided that in the second and third years of the work a more conventional randomised plot experimental design would be used with defined treatments applied representing the three strategies. For each of the plots in each year, assessments were made of:

- Shoot counts in February/March prior to the first scan timing – counted manually;
- Final ear population (ears/m^2) at GS 80- counted manually.
- Crop height – measured manually at GS 80 and with the sensor system at the earlier timings.
- Lodging (>45^o) and leaning (<45^o) - % of crop area and date of occurrence – assessed manually.
- Grain yield at 15% moisture content – using a plot combine.
- Specific grain weight and thousand grain weight – from analysis of collected grain samples.

In addition to the measurements made with the boom-mounted sensors in the first year of the project, assessment were made of the lodging risk for each plot at the heavy land site at the March timing by an experienced agronomist enabling a direct comparison with these manual estimates and results from the sensor measurements.

2.3. Key results

Results from measurements of a vegetative index (Normalised Vegetation Difference Index – NDVI) and Leaf Area Index/Green Area Index showed a consistent form over all seasons at both sites. Because measurements with the sensors and the manually operated light attenuating instrument were made relatively early in the season, it was assumed that there would be a close relationship between the parameters of Leaf Area Index and Green Area Index such that existing rules relating to the evaluation of lodging risk that use Green Area Index as a parameter could be used in the study. Examples of the measured relationships are given in Figures I and II. It can be seen that the largest changes in the measured NDVI for a given change in the Leaf Area Index (LAI) occurred at the early sampling times when the crop was at the earlier growth stages. This is consistent with the measurement of NDVI tending to saturate as the crop canopy gets larger such that for values of LAI above 3.0, sensor resolution is relatively poor. Information relating to the management of lodging risk will therefore be generated when the reflectance sensing instrument is relatively sensitive to changes in crop canopy structure.

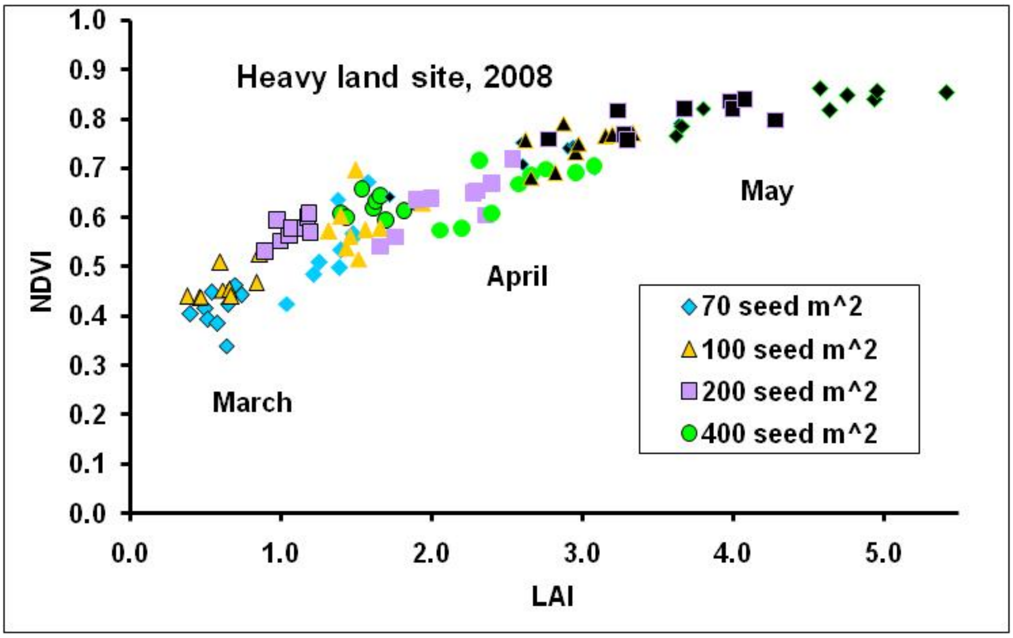

Figure I. The relationship between Leaf Area Index (LAI) and a Vegetation Index (NDVI) measured at the heavy land site on three occasions in 2008.

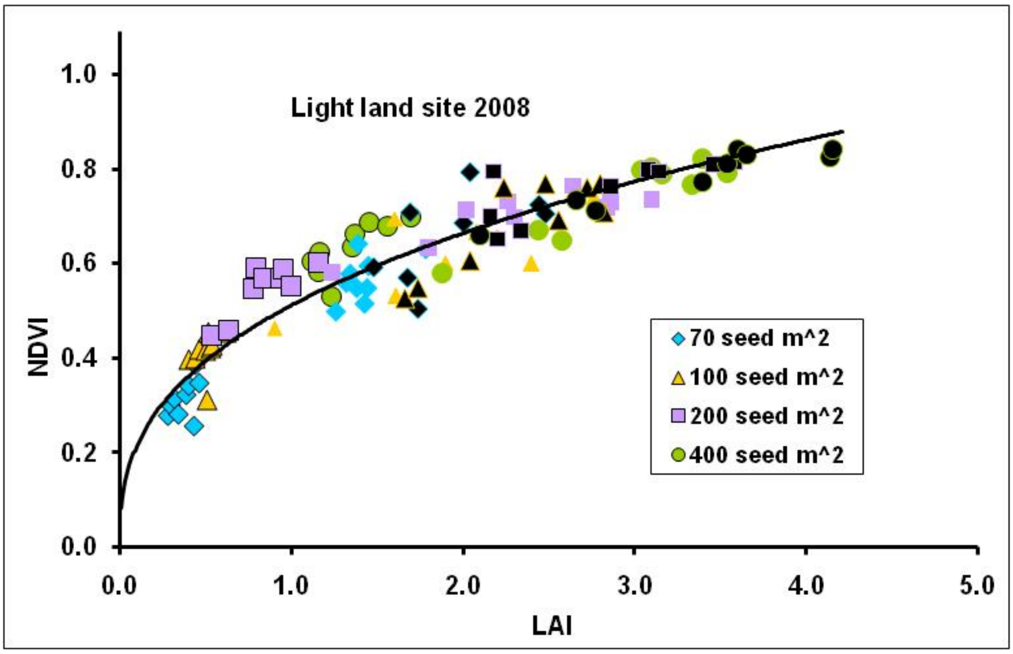

Figure II. The relationship between Leaf Area Index (LAI) and a Vegetation Index (NDVI) measured at the light land site in March (lined symbols) and April (unlined symbols) during 2008.

In the second and third years of the study the variability of the NDVI value from the sensor cluster was shown to correlate well with manual counts of tiller numbers made early in the season at both sites (see Figures III and IV) whereas no correlation was established in the first year of the project. This probably relates to the size of the “footprint” of the sensor. In the first year the boom was positioned approximately 1.0 m above the crop at the earliest sampling time giving a footprint in the order of 0.1 m^2. For years two and three, the height of the boom was reduced such that the sensors were approximately 0.5 m above the crop canopy at all sampling times giving a “footprint” area of the order of $0.02m^2$.

Although the variability in sensor output decreased with increasing seed rate and growth stage as expected, there were still relationships between the coefficient of variation of the NDVI signal and manually recorded tiller counts for sensor measurements made at the May timing at both sites.

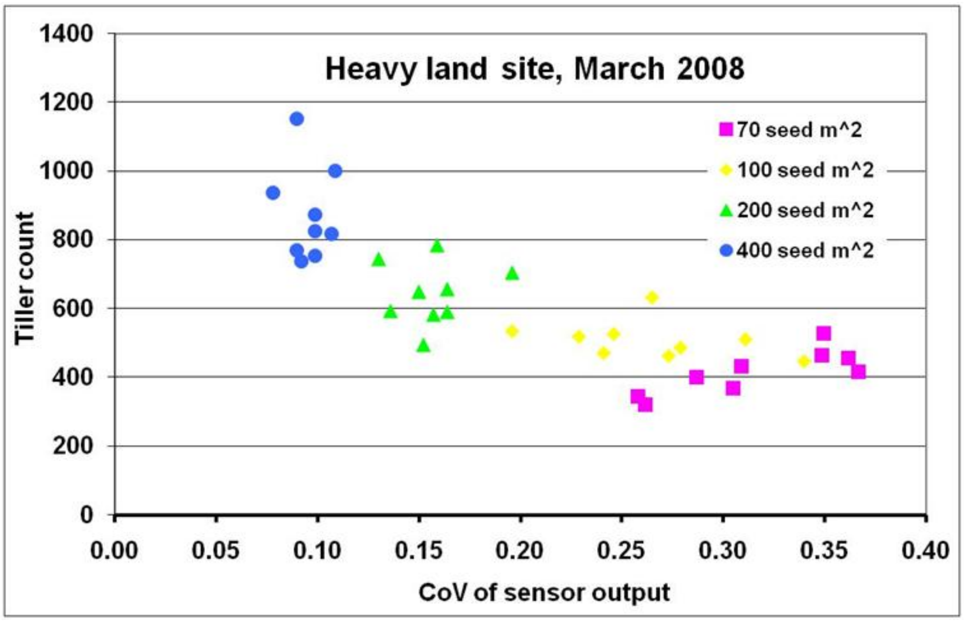

Figure III. Coefficient of Variation (CoV) of NDVI measured with the sensors plotted against manually counted tiller numbers in March 2008 at the heavy land site

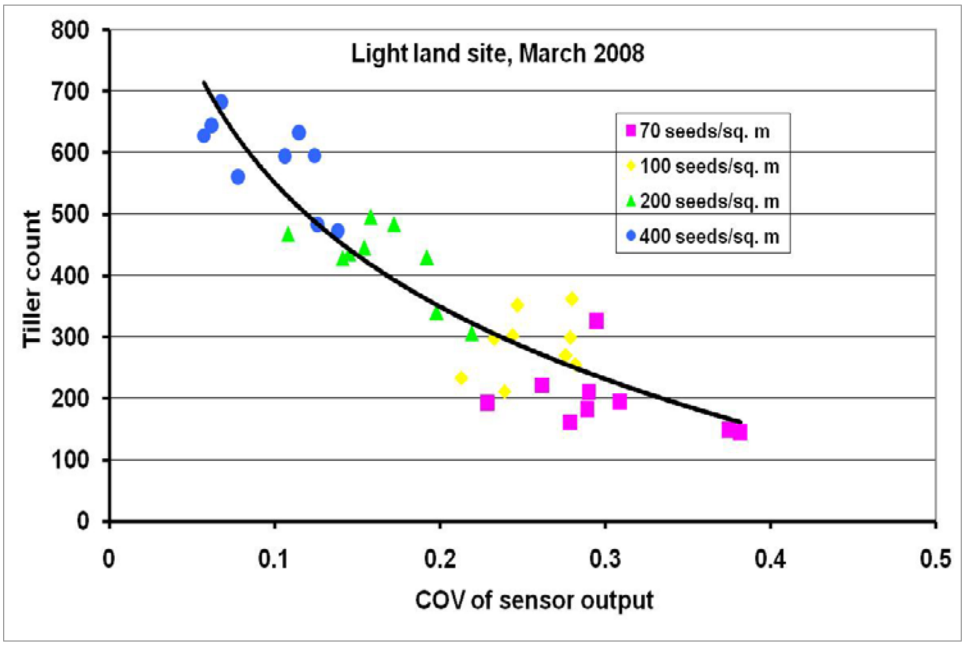

Figure IV. Coefficient of Variation (CoV) of NDVI measured with the sensors plotted against manually counted tiller numbers in March 2008 at the light land site

Assessments of the lodging risk made manually by an experienced agronomist on the heavy land site in the first year of the project showed a consistent relationship with the Leaf Area Index (LAI) measured with the light attenuation instrument. Measurements of the crop canopy on the light and heavy land sites in the spring of 2007 showed very different Leaf Area Indices for comparable tiller counts (Figure V) indicating that the tillers on the heavy land site were much larger than those on the light land.

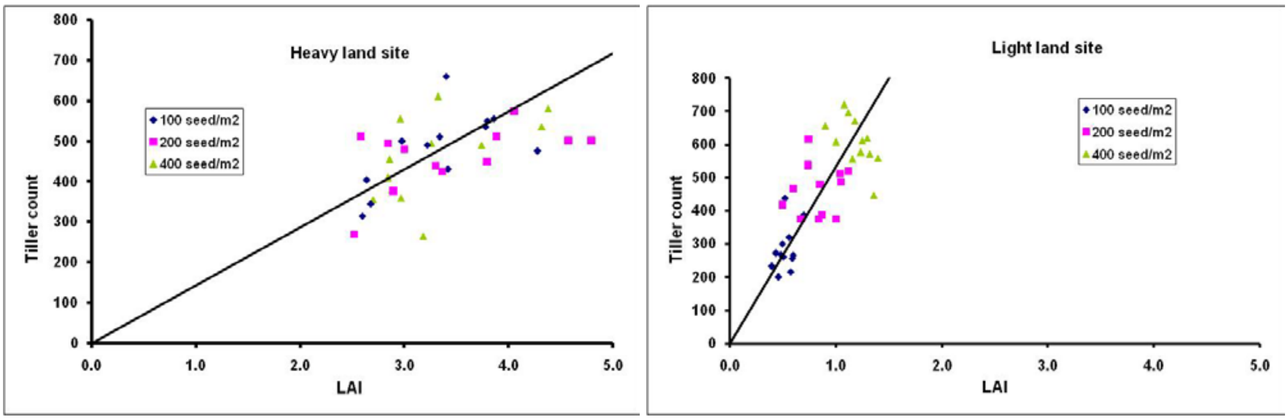

Figure V. The relationship between Leaf Area Index (LAI) and tiller counts at the two site in March 2007.

Examples of the relationships between plot yields and the applied treatments for the 2009 harvest season are shown in Figures VI and VII.

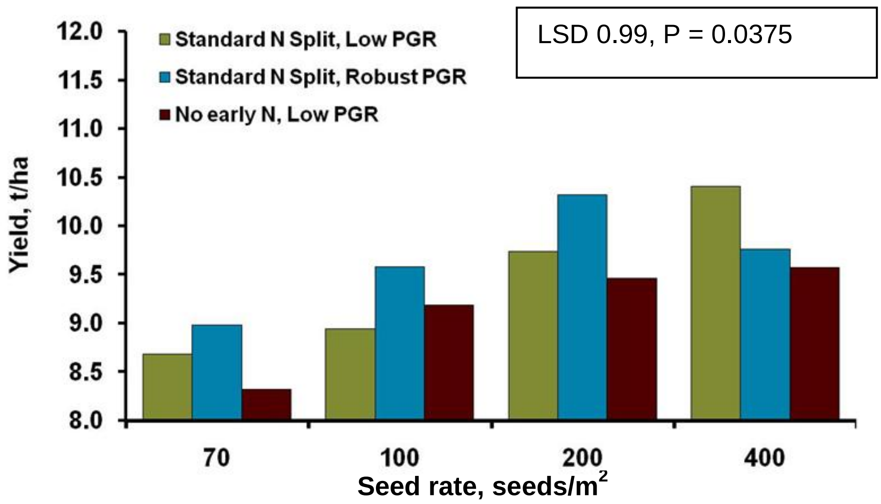

Figure VI. Plot yields recorded on the heavy land site in the 2009 harvest season

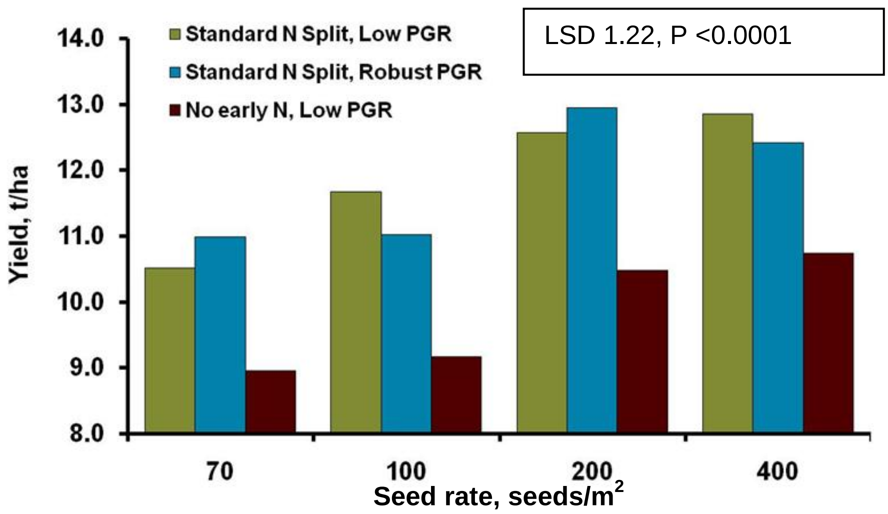

Figure VII. Plot yields recorded on the light land site in the 2009 harvest season

The agronomic assessment showed some consistent trends, namely:

- Not applying early nitrogen consistently gave lower yields although this loss of yield compared with a standard application strategy was not always statistically significant: this result emphasises the need for lodging predictions to be as accurate as possible since delays in nitrogen application for reasons other than lodging control are likely to result in a yield loss.
- Only low levels of lodging were recorded over the period during which the study was conducted: no lodging in any season was recorded on the light land site; and on the heavy land site lodging occurred mainly in the first year of the study, with only plots established at the highest seed rate showing lodging in year 2 of the study, and no lodging recorded in the last year of the work. The low levels of lodging in years 2 and 3 were mainly due to seasonal effects.
- The effect of the applied treatments on crop height was variable between both sites and seasons but where significant differences were recorded these followed the expected trends with plots having a low PGR input giving taller crops (e.g. at the light land site in the 2009 season) and those receiving a robust PGR input giving shorter crops (e.g. the heavy land site in the 2008 season).
- There were some differences in the number of ears/m^2 and the specific grain weight but these were mainly related to seed rate rather than the application strategy.
- The expected form of yield against seed rate relationship was found for both sites and soil types (Figures VI and VII) with yields generally increasing with seed rates up to 200 seeds/m^2 and then declining at the higher seed rate. This relationship was particularly pronounced on the light land site for all seasons and on the heavy land site in the 2009 season only – in the earlier seasons at the heavy land site the relationship between seed rate and yield showed less variation.

2.4. Main implications from the work

The study showed that the output from crop sensing systems has the potential to provide data relating to the canopy that would aid the assessment and management of the risk of crop lodging. The main advantage of using a sensor-based system is that information could be collected in a spatially variable manner and any treatments could then be applied on a spatially variable basis. Such an approach would minimise potential crop losses from delayed nitrogen applications where these were not needed to give control of lodging and would also enable the minimum quantity of plant growth regulator to be used.

Because of the low levels of lodging recorded in the experiments, particularly in the last two years of the work, the results obtained have been interpreted using established guidelines for managing crop lodging (HGCA, 2005). These relate to a number of factors but those relevant to the management of a wheat crop in the spring concern:

- Root lodging where the risk increases when the plant population exceeds 200 plants/m^2;
- Stem lodging where the risk increases when the canopy at GS31 is large – having a Green Area Index of 2 or more.

Results of the work described in this report indicate that measures of plant population can be obtained by monitoring the variability of the vegetation index signal from the boom-mounted sensors. It is recognised that the relationships are likely to vary with field and crop condition and therefore some form of in-field calibration would be needed to implement this approach. However, when calibrated it would then be possible to map a field and identify areas where the root lodging risk was high and implement an appropriate management strategy on a spatially variable basis. A robust relationship was found between measures of a vegetation index (NDVI) and Leaf Area/Green Area Index such that sensors could again be used to identify areas within a field where a spatially variable approach to the management of stem lodging could be implemented.

The study was conducted in close collaboration with commercial organisations concerned with crop sensing technologies. While the principles behind the measurements made are likely to relate to results obtained with commercial designs of sensing system, important differences may arise due to:

- The detailed wavelengths used and the calculation of a measure of canopy structure – not all commercial approaches use a Normalised Vegetation Difference Index as calculated in this work and the wavelengths used may influence factors such as the readings from different soil surfaces.
- The size of the sensor “footprint” and the frequency at which data is collected – this being particularly relevant to the determination of plant populations based on signal variability although other sensing systems may use other principles of operation.

The measurements of crop canopy structure in this study were made at defined dates rather than at fixed crop growth stages. Other project work is aiming to improve the prediction of crop nitrogen demand using canopy sensors as one component of a management system and this work will include considerations relating to crop development.

The good agreement between estimates of lodging risk based on visual assessment by an experienced agronomist and those derived from sensor measurements is encouraging and adds to the confidence relating to the development of lodging risk management strategies based on sensor measurements. However, the large differences in tiller size between crops established in the same season on two different sites with different soil types and the absence in any of the crop years of lodging on the light land site suggests that there continues to be scope for refining the prediction of lodging risk using sensor data.