**Project Report No. 427**

**Abstract and summary**

**January 2008**

# Detecting soil nitrogen supplies by canopy sensing – proof of concept

**by**

**R. Sylvester-Bradley[1], J.J.J. Wiltshire[1], D.R. Kindred[1], D.L.J. Hatley[2] and J. Wilson[3]**

[1]ADAS Boxworth, Boxworth, Cambridge, CB23 4NN

[2]ADAS Terrington, Bentinck Farm, Rhoon Road, Terrington St Clement, King's Lynn, Norfolk. PE34 4HZ

[3]Soil Essentials Ltd, Hilton of Fern, By Brechin, Angus, Scotland. DD9 6SB

This is the final report of a twelve month project, which started in October 2006. The project was funded by a contract of £15,000 from HGCA (Project No. 3285), with £5,000 each from Soil Essentials Ltd and Yara UK Ltd, making a total of £25,000.

The Home-Grown Cereals Authority (HGCA) has provided funding for this project but has not conducted the research or written this report. While the authors have worked on the best information available to them, neither HGCA nor the authors shall in any event be liable for any loss, damage or injury howsoever suffered directly or indirectly in relation to the report or the research on which it is based.

Reference herein to trade names and proprietary products without stating that they are protected does not imply that they may be regarded as unprotected and thus free for general use. No endorsement of named products is intended nor is it any criticism implied of other alternative, but unnamed, products.

**ABSTRACT** ..... **1**

**SUMMARY** ..... **2**

**TECHNICAL DETAIL** ..... ERROR! BOOKMARK NOT DEFINED.

**INTRODUCTION** ..... ERROR! BOOKMARK NOT DEFINED.

**MATERIALS & METHODS** ..... ERROR! BOOKMARK NOT DEFINED.

- **SITES** ..... **ERROR! BOOKMARK NOT DEFINED.**
- **SENSORS** ..... **ERROR! BOOKMARK NOT DEFINED.**
- **DATA COLLECTION AND ANALYSIS** ..... **ERROR! BOOKMARK NOT DEFINED.**

**RESULTS** ..... ERROR! BOOKMARK NOT DEFINED.

- **SOIL MINERAL N** ..... **ERROR! BOOKMARK NOT DEFINED.**
- **OVER-WINTER CROP GROWTH** ..... **ERROR! BOOKMARK NOT DEFINED.**
- **CANOPY REFLECTANCE** ..... **ERROR! BOOKMARK NOT DEFINED.**
- **CHANGE IN CANOPY REFLECTANCE** ..... **ERROR! BOOKMARK NOT DEFINED.**
- **OTHER FACTORS INFLUENCING REFLECTANCE** ..... **ERROR! BOOKMARK NOT DEFINED.**

**DISCUSSION** ..... ERROR! BOOKMARK NOT DEFINED.

**ACKNOWLEDGEMENTS** ..... ERROR! BOOKMARK NOT DEFINED.

**REFERENCES** ..... ERROR! BOOKMARK NOT DEFINED.

# Abstract

This research tested whether sensing the crop can indicate soil nitrogen supplies.

Nitrogen fertiliser experiments on cereals were established at four sites in 2005-6. In the following year, commercial cereal crops were grown. In 2006-7 at each site, the plot positions as used in the previous year were marked out once again for crop testing using a sensor.

Reflectance was measured monthly, December to March, during tillering using a Crop Circle instrument (provided by Soil Essentials Ltd) in the 2006-7 plots relating to the 2005-6 experiments. This comprised two sensors to measure reflectance at 880 nm (near-infrared, NIR) and 590 nm (orange). A Normalised Difference Vegetation Index (NDVI) was calculated to give a measure of vegetation cover. Soil mineral N data were obtained from another study at the same sites. Yields of grain and straw and their N concentrations were measured to give total N uptake. Data were interpreted for relationships between canopy reflectance and soil N.

Establishment and tillering were early and rapid at Boxworth and Rosemaund, but later and slower at Terrington and High Mowthorpe. The highest level of N applied in 2006 had a small effect on soil mineral N at Terrington and Rosemaund, but a large effect at Boxworth. Using total N uptake at harvest as an estimate of soil N supply, the largest response to N supply was also at Boxworth.

Over-fertilisation only led to high SMN residues at Boxworth, which had the lowest optimum N requirement in 2005-6 : 117 kg/ha, compared to, 220 to 237 kg/ha at other sites). Use of the sensor successfully detected the high SMN residue at Boxworth using the relationship between NDVI and soil N supply, especially at soil mineral N values below 150 kg/ha. This relationship was less variable and more useful (shallower slope) when N uptake (rather than soil mineral N) was used to estimate soil N supply. The relationships improved with later assessment of NDVI. Change in NDVI between assessment dates showed that canopies sometimes declined and sometimes grew during winter. However, change in NDVI was less useful for predicting soil N supply than absolute values of NDVI.

In conclusion at Boxworth, but not at three other sites, NDVI differentiated plots in need of fertiliser (soil mineral N up to around 150 kg/ha N) from those with ample soil N supplies.

# Summary


## Introduction

Judging soil N supplies is the most crucial, yet the most uncertain, element of judging fertiliser requirements on the farm. The best current method of judging soil N supplies involves field by field analysis of soil, to determine soil mineral N, to at least 60 cm depth. However, previous work has shown that, across a number of experiments, the crop recovers slightly more soil N than is measured as soil mineral N in February to 90cm depth. Furthermore, sampling and analysis are laborious and expensive, and the results are not regarded with high confidence by the industry. Most farmers therefore use look-up tables (e.g. in Defra booklet RB209), which may give even more imprecise results.

The research described here was undertaken to assess whether the new technology of canopy sensing might revitalise an old idea – that the crop could be used as a barometer of the soil. If proven, this approach could be applied to most cereal fields with relatively little investment because tractor- or sprayer-mounted canopy sensors are now available at affordable prices (~£3,000 each).

## Methods

In winter 2006-7, four cereal sites (Boxworth, Terrington, Rosemaund and High Mowthorpe) were identified where there had been N fertiliser experiments in 2006 with six N levels under HGCA Project 3084, and where Defra was funding analyses of soil mineral N and crop N content (through Defra Project IS0223).

As part of Defra Project IS0223, after sowing a cereal crop in autumn, all plots were re-marked out in the positions of the N fertiliser experiment plots in the previous season (2005-2006). The 2005-2006 treatments are summarised in Table 1. There were three replicates. Crops grown in 2006-2007 are listed in Table 2. Plots received no N applications in the 2006/2007 season.

Table 1 Sites, wheat varieties for N response plots and N treatments (total N applied) in 2005-2006.

| Site | Varieties | Total N applied (kg/ha N) |
|---|---|---|
| Boxworth | XI19 | 0, 70, 150, 210, 220, 290, 360, 370 |
| | Longbow, Norman, Alchemy, Gladiator | 0, 70, 150, 220, 290, 370 |
| Terrington | XI19 | 0, 70, 140, 210, 280, 350 |
| | Longbow, Virtue, Ambrosia, Gladiator | 0, 70, 150, 220, 290, 370 |
| Rosemaund | XI19, Longbow, Hustler, Ambrosia, Robigus | 0, 70, 150, 220, 290, 370 |
| High Mowthorpe | XI19, Longbow, Norman, Ambrosia, Istabraq | 0, 70, 140, 210, 280, 350 |

Table 2 Sites and details of crops grown in 2006-2007.

| Site | Crop | Variety | Sowing date | Emergence date |
|---|---|---|---|---|
| Boxworth | Winter wheat | Nijinsky | 26 Sep 2006 | 9 Oct 2006 |
| Terrington | Winter wheat | Nijinski | 27 Oct 2006 | 15 Nov 2006 |
| Rosemaund | Winter barley | Saffron | 20 Sep 2006 | 1 Oct 2006 |
| High Mowthorpe | Winter wheat | Gladiator | 30 Sep 2006 | 12 Oct 2006 |

At each site two additional plots (2 m wide by ~10 m long) were made in a discard area adjacent to the trial and reflectance data were collected as for the cereal plots from the previous N experiments. One plot was bare soil, and the other was the crop with additional N (200 kg/ha N in November and 200 kg/ha N in January) to give 'unlimited' growth. Also, to give an indication of varying light quality, a mat of green plastic was taken to each site at each measurement date, and reflectance data were collected as for the cereal plots.

The Crop Circle instrument, provided by Soil Essentials Ltd, comprised two sensors, each with its own light source (to minimise variation due to variation in ambient light

conditions). The sensors measured reflectance at 880 nm (near-infrared, NIR) and 590 nm (orange).

Reflectance was measured on a monthly basis throughout the period of tillering – December to March.

Normalised Difference Vegetation Index (NDVI) was calculated from the sensor data. NDVI gives a measure of vegetative cover. Dense canopies strongly absorb red wavelengths and reflect near-infrared wavelengths. NDVI is a measure of the difference in reflectance between these wavelength ranges, and high values (to a maximum of 1) indicate dense canopies. NDVI was calculated using reflectance intensity data for the two measured wavelengths, as follows.

NDVI = (NIR-visible/(NIR+visible)

In this work we used light of wavelength 590 nm as the visible light for this calculation.

Soil mineral N data were obtained from another study using the same site. For plots that had grown varieties other than Xi19 in the previous season, and that had the same previous N applications, plots were paired (paired varieties are on the same lines in Table 1) and one value was obtained for a pair of plots. Reflectance data were also paired in the same way, so that a pair of plots in 2005-2006 became one plot in 2006-2007.

Yields were recorded at crop maturity using a plot combine harvester. Samples of grain were submitted to a laboratory for grain N analysis, and grain uptake was calculated. Grab samples were also taken and straw and chaff were submitted to a laboratory for N analysis, from a sub-set of plots at each site. Nitrogen harvest indices were calculated for each of these plots, and were found to be similar for contrasting N treatments (applied in the previous season). The grand mean N harvest index value for each site was then used to correct grain N uptake, to provide total N uptake data for each plot. These values were used an indicator of soil N supply.

Analysis of variance (ANOVA) was used to compare effects of previous treatments on soil mineral N and soil N supply. Data were interpreted for relationships between canopy reflectance and soil N by fitting curves to relationships between NDVI and soil mineral N, and NDVI and soil N supply.

## Key results

*Soil mineral N*

Fig. 1 shows effects of N applied in 2006 on soil mineral N in November 2006 after establishment of the next crop. There was a small effect of the largest level of N at Terrington, and there were some significant but rather small differences at Rosemaund, but overall, the best site appearing to offer a good test-bed for detecting soil mineral N via canopy sensing was at Boxworth.

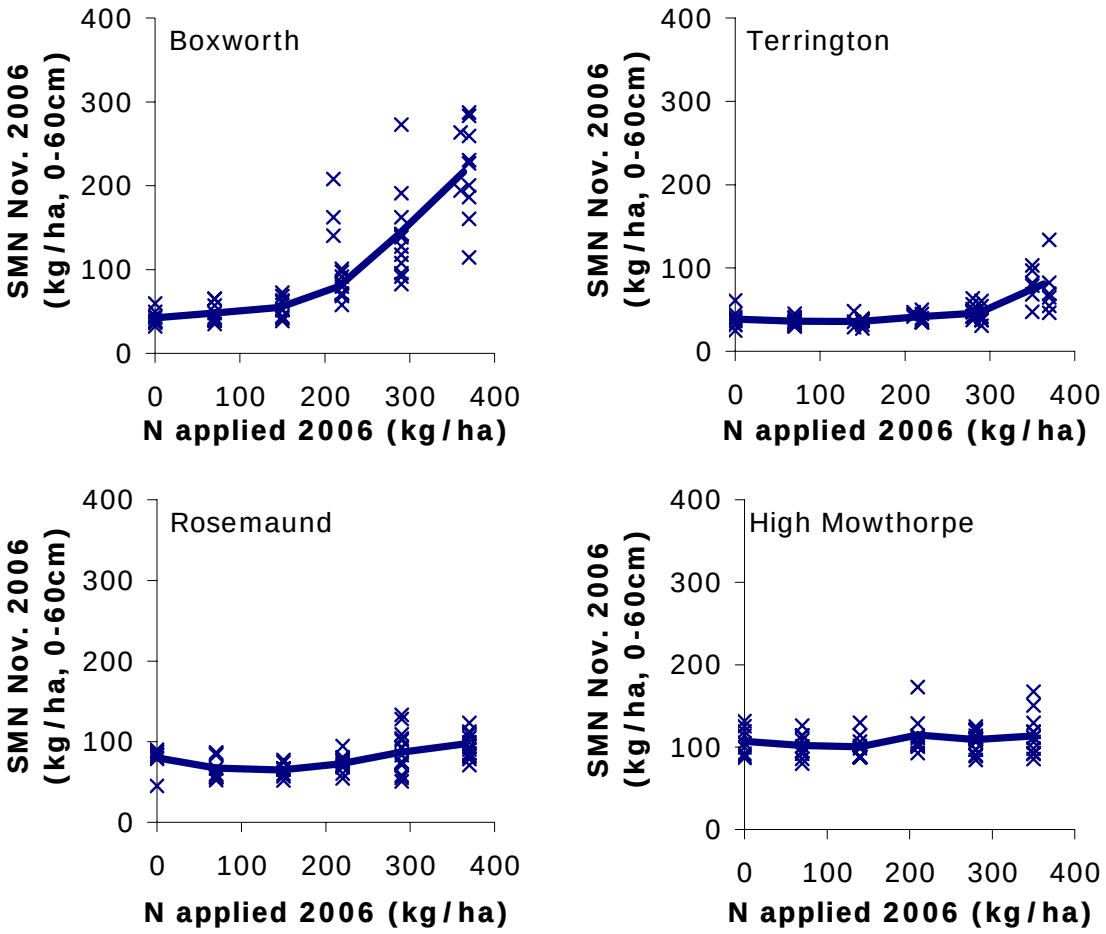


Fig. 1 Effect of N applied in spring 2006 on soil mineral N to 0.6 m depth in November 2006, for four sites. From ANOVA, Boxworth, P<0.001; Terrington, P<0.001; Rosemaund, P=0.05; High Mowthorpe, NS.

*Over-winter crop growth*

Digital images of the crops on each sensing date are shown in Fig. 2. Establishment and autumn tillering went well at Boxworth and Rosemaund. The crop at Terrington was sown later and there was little tillering before winter and, therefore, there was little ground cover. At High Mowthorpe, the coldest site, tillering was also slow.

*Canopy reflectance*

The relationship between NDVI and soil mineral N (0-60 cm, measured in November 2006) was poor at the three sites (Terrington, Rosemaund and High Mowthorpe) where there were poor responses of soil mineral N in November 2006 to N applied earlier in 2006. However, at Boxworth, where there was a clear response of soil mineral N to N applied, inspection of the relationships between NDVI and N applied suggests that the relationships could be useful, especially at soil mineral N values below 150 kg/ha (Fig. 3). The relationships shown for January, February and March dates were better than the relationship in December.

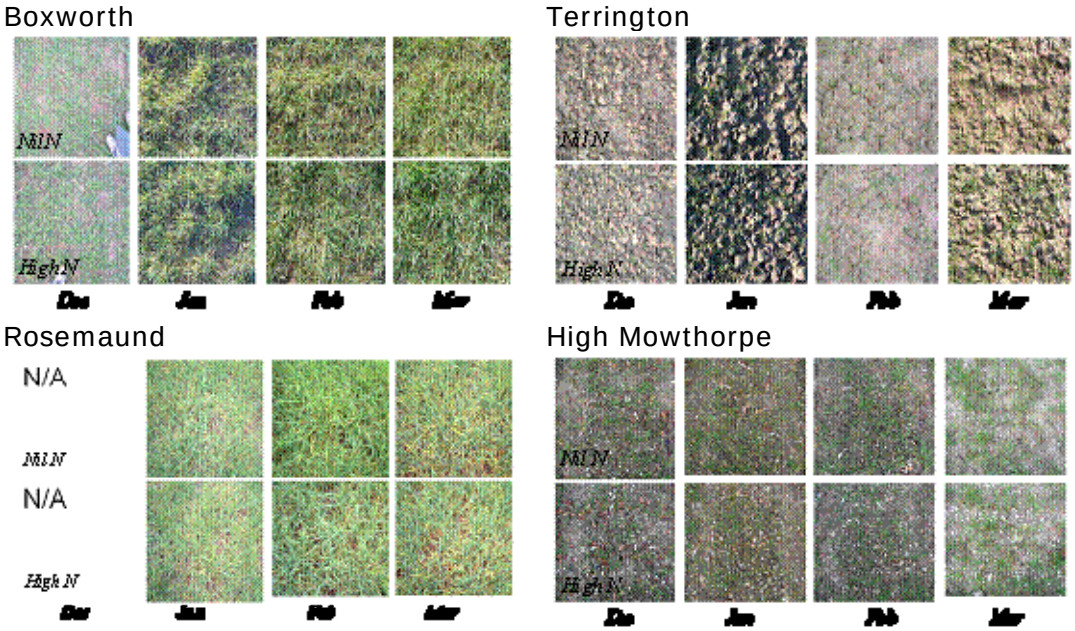


Fig. 2 Digital images of the crops at each site. The top row is with nil N applied in 2006 and the bottom is with the maximum N application.

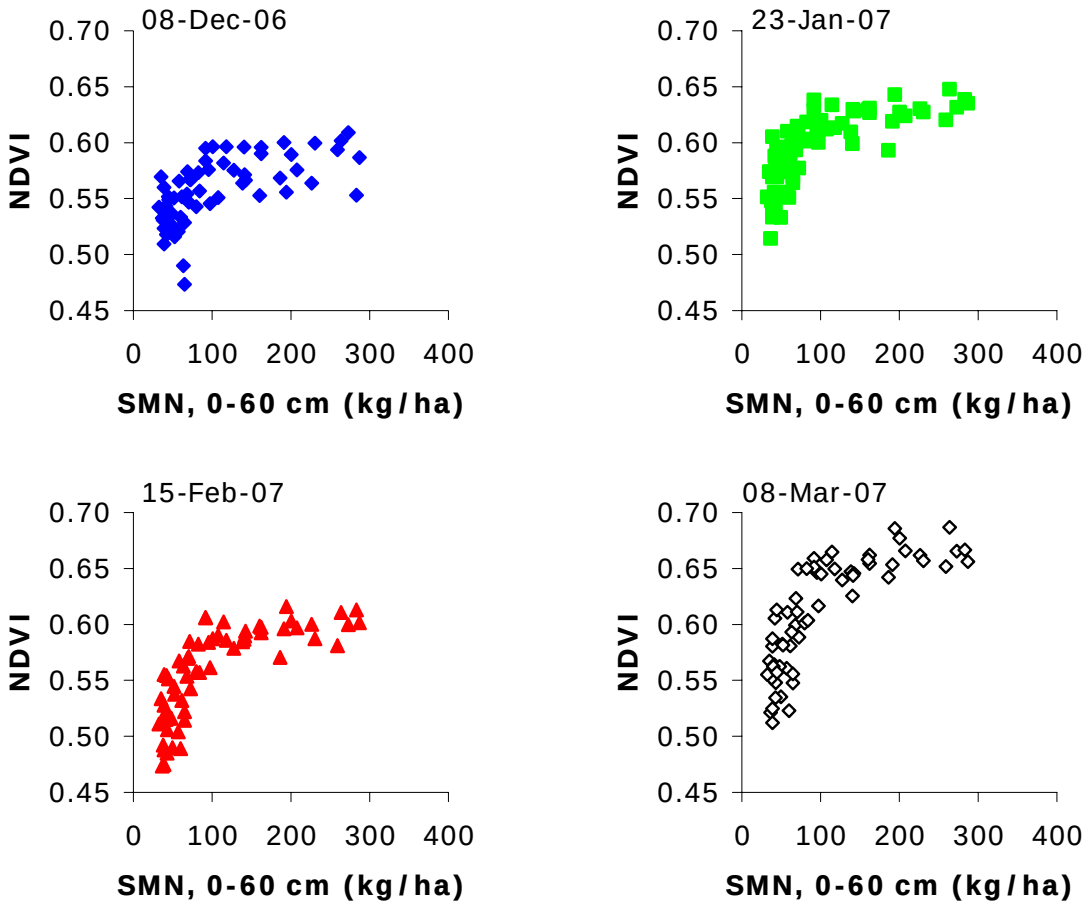


Fig. 3 Relationships between NDVI measured on four dates and soil mineral N (0-60 cm, measured in November 2006) at Boxworth. Values of percentage variance accounted for by an exponential curve were 46.4, 67.5, 72.4 and 76.5 for December, January, February and March dates respectively.

In Fig. 3, soil mineral N is used to estimate soil N supply. The most precise measure of soil N supply that can practically be taken by field measurement is N uptake by a crop with no N applied (i.e. N recovered from above-ground crop samples, including straw, chaff and grain). Using this approach (Fig. 4), the largest response was again at Boxworth.

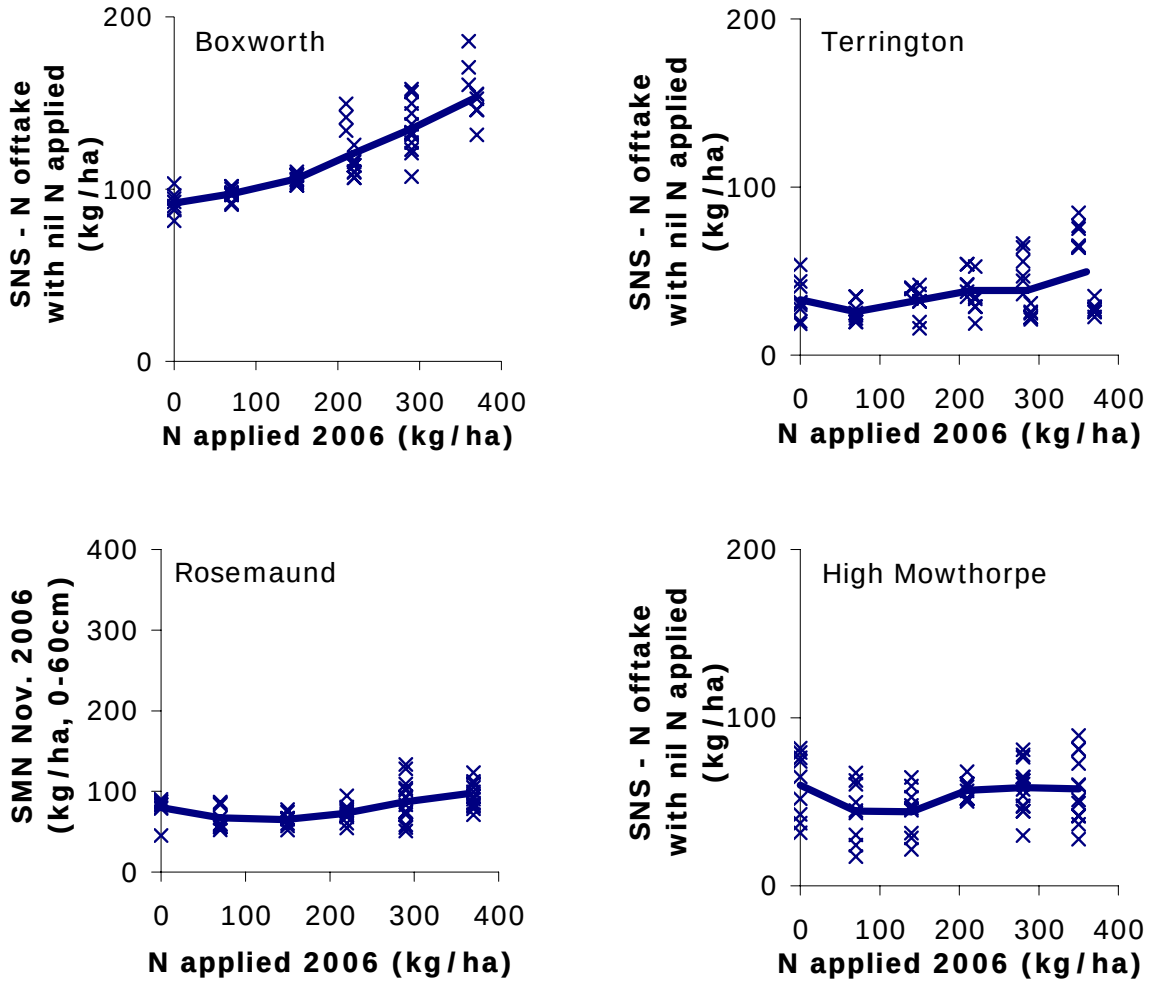


Fig. 4 Effect of N applied in spring 2006 on soil N supply (N uptake, kg/ha, with nil N applied), for four sites. From ANOVA, Boxworth, P<0.001; Terrington, P=0.008; Rosemaund, P=0.006; High Mowthorpe, not significant.

At Boxworth, where there was a clear response of soil N supply to N applied, the relationship between NDVI and soil N supply was better than at other sites. Comparison of the graphs in Fig. 5 with those in Fig. 3 shows that there appears to be better (less variation) and more useful (shallower slope) relationships when N uptake (rather than soil mineral N) is used to estimate soil N supply. This is confirmed by statistical analysis, as when N uptake (rather than soil mineral N) was used to estimate soil N supply, values were greater for percentage variance accounted for by the fitted lines. The relationships improved as assessment date (for NDVI) became later.

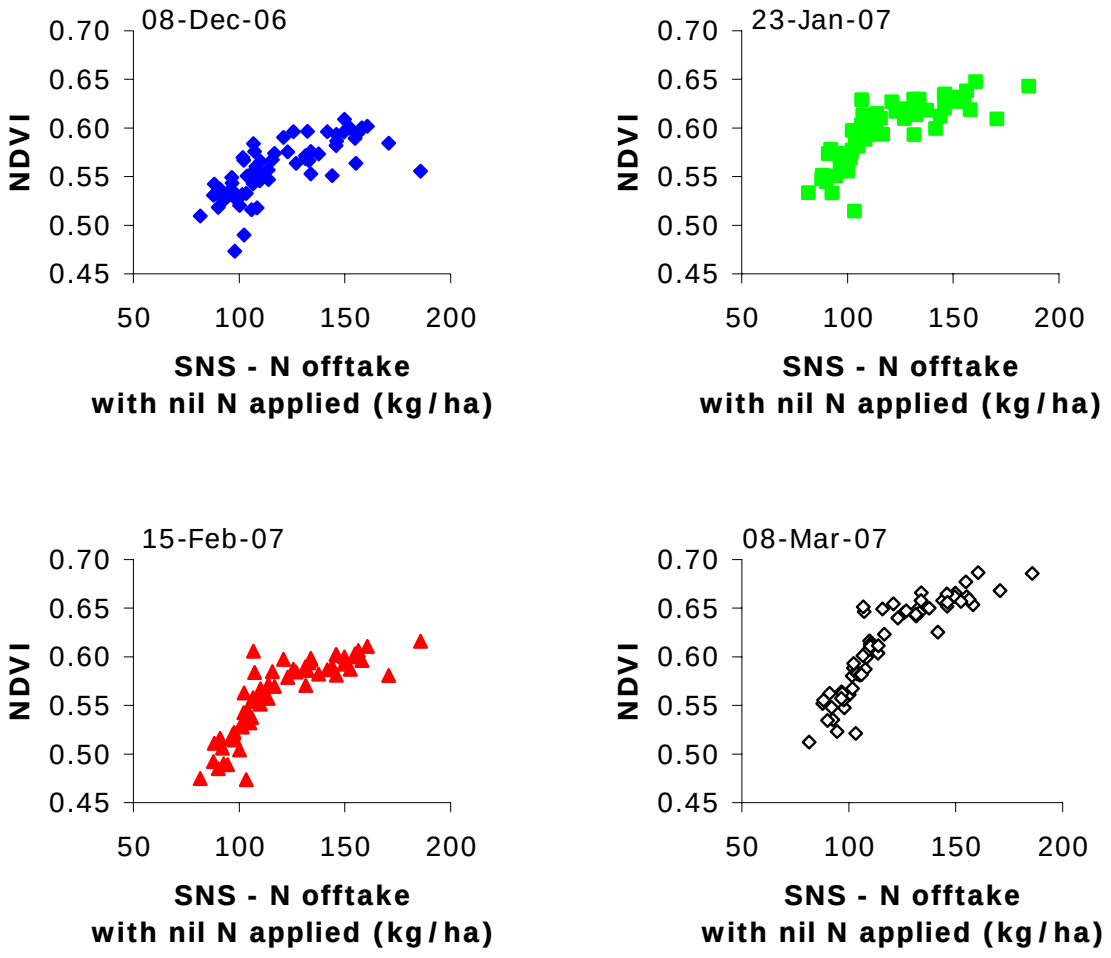


Fig. 5 Relationships between NDVI measured on four dates and soil N supply (N uptake, kg/ha, with nil N applied) at Boxworth. Values of percentage variance accounted for by an exponential curve were 55.3, 74.2, 81.9 and 85.6 for December, January, February and March dates respectively.

*Change in canopy reflectance*

The concept that canopy sensing for changes in canopy size might be used to indicate N supplies was tested by plotting change in NDVI since the previous assessment against soil N supply (N uptake with nil N applied). Positive values indicated an increase in canopy size (i.e. more canopy and less soil was 'visible' to the sensor), and negative values indicated a decrease. At Boxworth, for example, canopy size increased from December to January, then decreased by February, and increased again by the March assessment date. Inspection of photographs taken at Boxworth

(Fig. 4) supports this. The pattern of change differed between sites, and Terrington was the only site that did not show any period of canopy decline.

At Boxworth, the site of most interest because of the responses of soil mineral N and soil N supply to previous N application, values for percentage variance accounted for by fitted exponential curves showed a better relationship in February and March (52.9 and 51.7 respectively) than in January (3.5). Relationships at Terrington and High Mowthorpe were poor, but at Rosemaund relationships in January and March were better. However, even the best of these relationships had a lower percentage variance accounted for by a fitted exponential curve than did absolute values of NDVI at Boxworth, for January, February and March assessment dates.

Using change in NDVI per thermal time unit (°C d), rather than per time interval since the last assessment, appeared to improve some relationships, but the mathematical relationship (and so usefulness to predict soil N supply) was unchanged, as change in NDVI was divided by the same thermal time value for all treatments within a site. Changes in NDVI per unit thermal time were different between sites and between sampling dates, suggesting this would have limited value as a universal factor to use in predictions.

### Other factors influencing reflectance

At Terrington and Rosemaund NDVI values from bare soil were approximately constant from date to date, but at Boxworth and High Mowthorpe there were individual high values relative to other dates. The causes of these high values are not known. Values for NDVI from the green mat showed some variation: for example, values declined over time at Boxworth. This suggests ambient light conditions were having a small effect on NDVI. Values of NDVI from a crop with adequate N increased with time at all sites, suggesting increasing canopy sizes as would be expected. However, at Rosemaund this increase was small compared with other sites.

## Conclusions and implications

Over-fertilisation does not always lead to high SMN residues, but when it does (at Boxworth, which had the lowest optimum N requirement in 2005-2006: 117 kg/ha, compared to, 220 to 237 kg/ha at other sites), then we can detect it with sensors.

At Boxworth NDVI responded to soil mineral N up to around 150 kg/ha N (Fig. 6), but not above. At each of the other three sites NDVI was weekly related to soil mineral N, even though the ranges of soil mineral N values were within the range for which there was a response at Boxworth. This suggests that there were other factors, besides N supply, influencing canopy size.

The ranges in NDVI values for each measurement date were greater at Boxworth than at other sites. At Terrington and High Mowthorpe NDVI values were generally low and canopy ground cover was also low. In contrast, NDVI values at Rosemaund were high, even on plots with very low soil mineral N, indicating rapid canopy development in autumn before the first NDVI measurement. Previous work has shown that NDVI remains fairly constant at leaf area indices above 3 (e.g. Scotford and Miller, 2004), as NDVI values are poorly related to canopy size when there is full ground cover. The data indicate that canopy sensing over winter can indicate soil N supply in crops that have had a sufficient period of canopy growth to allow a measurable response to soil N supply, but are not approaching full canopy cover.

The improved relationships when using N uptake rather than soil mineral N support the view that the true estimate of soil N supply (crop N uptake at harvest with nil fertiliser N applied) was determined more precisely than soil mineral N. There is a danger that the errors in autumn soil sampling and soil mineral N analysis may cloud the potential of canopy sensor data to predict ‘true’ soil N supplies.

Changes in NDVI did not show advantages over absolute NDVI readings, because zero (soil only) and full-canopy readings varied from date to date. Also, change in NDVI per thermal time unit did not show any useful consistency between sites. This result suggests that thermal time is not the dominant cause of between-site variation in NDVI change.

At Boxworth, NDVI differentiated plots in need of fertiliser (soil mineral N up to around 150 kg/ha N) from those with ample soil N supplies. The future challenge is to refine the methodology and interpretation so that this can be achieved over a wide range of agronomic and environmental conditions, allowing useful comparison between sites.