ON THE RELATIONSHIP BETWEEN HIGH SPECTRAL RESOLUTION CANOPY REFLECTANCE DATA AND PLANT BIOCHEMISTRY

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Abstract

Initial research with data from the Moniteq PMI airborne imaging spectrometer concentrated on the application of a curve fitting procedure to calculate the canopy 'red edge' position. The analysis revealed a small shift in red edge position to longer wavelengths with increased nitrogen fertilizer treatment. The traditional explanation for such a shift is increased chlorophyll concentration, however, this relationship has not been consistently observed from canopy reflectance data. Many alternative explanations have been suggested including changes in vegetation amount. In the research below the results obtained from the imaging spectrometer were tested using ground-based spectral measurements. It was contested that the observed shift in red edge position was primarily a function of increased vegetation amount since on average the biomass increased with fertilizer treatment. Standardising by both biomass group and individual biomass measurement still left some positive variation in red edge position with treatment. Nevertheless use of fertilizer treatment as a valid representation of canopy chemistry was questioned because of the large scatter of points within each treatment.

1. INTRODUCTION

Treatment average data from the Moniteq PMI airborne imaging spectrometer, operated in its spatial mode, were collected during the NERC 1988 Flight Campaign at the Somerset Levels, UK. These data were used to calculate the red edge position by application of the curve fitting procedure of Bonham-Carter (1988). The analysis revealed a red edge shift of 4 nm to longer wavelengths from a 0 kgN/ha treatment to one of 200 kgN/ha (Wyatt *et al.* 1989). The traditional explanation for this observation lies with increasing chlorophyll concentration (Horler *et al.* 1983), however, as Guyot and Baret (1988) summarised such a relationship has not been consistently observed from canopy reflectance data. Many alternative explanations have been suggested (Schutt *et al.* 1984; Horler *et al.* 1983; Baret *et al.* 1987) including changes in leaf cuticle condition, leaf overlap and biomass and, according to Curran *et al.* (1990), in canopy cover where underlying soil or vegetation also has a 'red edge'. In the case of the Somerset Levels, the underlying soil is peat which has been shown to have a 'red edge'.

Consequently before the conclusion that the red edge shift, observed for the Moniteq image data, is due to biochemical rather than biophysical processes, the possible effects of the large variation in biomass and canopy cover on the 'red edge' must be considered. This paper presents some initial research into the effect of biomass on the red edge of ground-based spectra collected near- simultaneously with the overflight.

2. METHODS

(i) *Data Collection*

In each of the 5 fertilizer treatments spectral measurements were made using an IRIS dual field-of-view spectroradiometer and a Milton Multiband radiometer. Two replicate IRIS spectra were collected for each of nine quadrats in treatments 0, 50 and 200kgN/ha. These were subsequently averaged to produce a per-quadrat spectrum. Owing to time limitations only 4 of the quadrats in each the 25 and 100kgN/ha treatments were sampled by the IRIS, so data from these treatments might be considered less representative of the the full field variation. The results presented here concentrate on Fourier- smoothed versions of the spectra covering the wavelength range of 450-800 nm.

At the same time as the IRIS spectra were being recorded NDVI and NIR/R reflectance ratio data were acquired using the Milton Multiband radiometer. Using a reflectance: LAI calibration curve, estimated leaf area index (ELAI) data were calculated for all the studied quadrats. These data were complemented by information on botanical composition, biomass and ground cover as well as a comprehensive suite of chemical analyses.

(ii) *Factor Analytic Decomposition*

To address the hypothesis that the shift in red edge position is entirely due to between quadrat alternations in biomass rather than a function of the fertilizer treatment, the IRIS spectra were grouped according to both treatment and classes of biomass and ELAI assigned on the basis of natural breaks in the collected data. Factor analytic decomposition (FAD) was subsequently performed on each of the treatment spectral groups and each of those for biomass and ELAI. The method is detailed by Huete (1986). In the treatment case it was assumed that the relationship between biochemical variations and the reflected response was masked by small changes in the vegetation between quadrats. These mainly comprised differences in biomass production and species diversity. As a first approximation the radiance data were assumed to vary only in response to these factors. Thus for a given group:

$L\lambda$ (group) + f(vegetation amount+species+k)

where k represents a constant biochemistry which varies between groups and not between quadrats. For the biomass and ELAI groups the same situation existed with the vegetation amount the constant factor. The FAD procedure was only partially completed to extract the first factor by regenerating the data matrix with one factor retained. This was undertaken since it was assumed that the underlying spectral feature was common to all spectra in each group and would provide for per treatment or per biomass group discrimination of the data.

(iii) *Calculation of Red Edge Position*

The method used to extract the red edge position from individual spectra and from the FAD reconstructed spectra is that used by Curran *et al.* (1990). In that paper the position is extracted using the maximum of the first derivative rather other more subjective assessments on the basis of the reflectance spectrum. In this case the first derivative was computed by fitting a quadratic curve using a 5 point wide running convolution of the dataset. The calculation of the first derivative value relied on the coefficients and method of Savitsky and Golay (1964).

3. RESULTS

(i) *Fertilizer Treatments, IRIS spectra and the Red Edge Position*

The IRIS spectra collected within each treatment although showing considerable variation were assumed first to represent distinct nitrogen groups (Fig. 1). Table 1 compares the groups of IRIS spectra for treatment, biomass and ELAI classes. Comparison of the first factor in the decomposition of each group (Fig. 2) reveals that the distribution in reflectance via this process is very similar to that observed for the data from field-averaged spectra of the Moniteq PMI imagery. Two separate groups comprising the 25 and 100kgN and the 0, 50 and 200kgN treatments can be observed. One proffered explanation for the discrepancy involved the drier nature of the 25 and 100kgN treatments both in terms of field drainage and the later sampling time of the spectra in these treatments. When the red edge position was considered, a progression corresponding to the order of the fertilizer treatments was revealed although with a marked asymptotic curvature to the data (Fig. 3).

(ii) *Biomass, IRIS spectra and Red Edge Position*

In the second phase of the experimental analysis of the IRIS spectra it was contested that the observed movement of the red edge position was solely an artifact of variations in biomass between sample quadrats (Table 1). First factors, however, from the biomass grouping did not show the clear division of spectra into a group of two and one of three as with the treatments. Instead a gradual progression in reflectance was observed but the order of the spectra did not follow the expected shift from group 1 to 6 (Fig. 4).

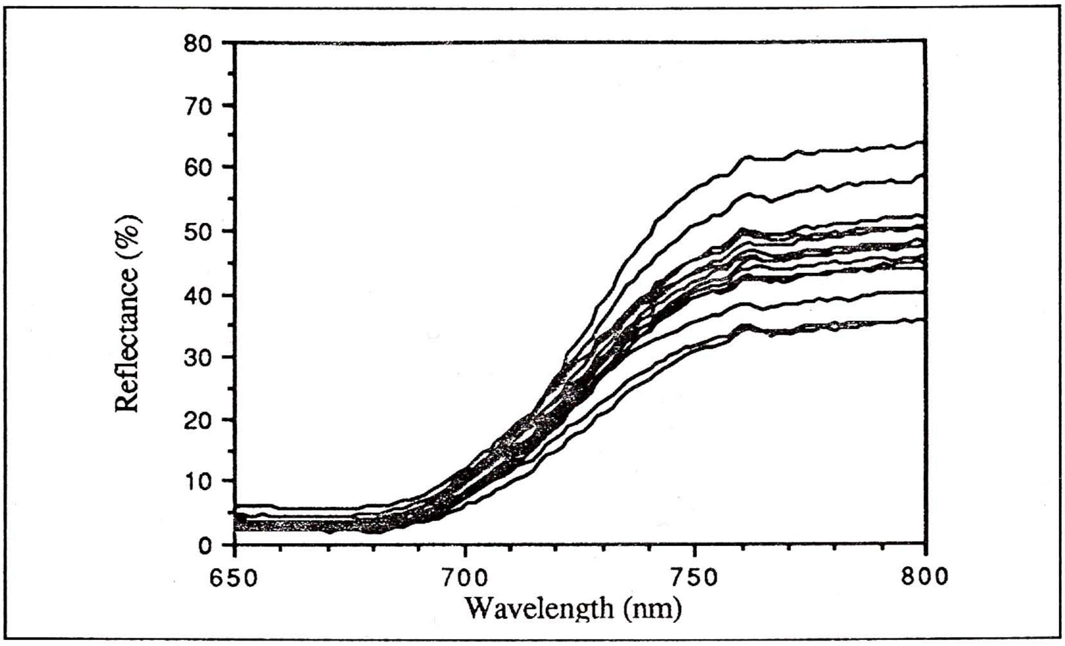

Fig. 1. Within-Treatment Variation in Spectral Response For the 200kgN/ha Treatment.

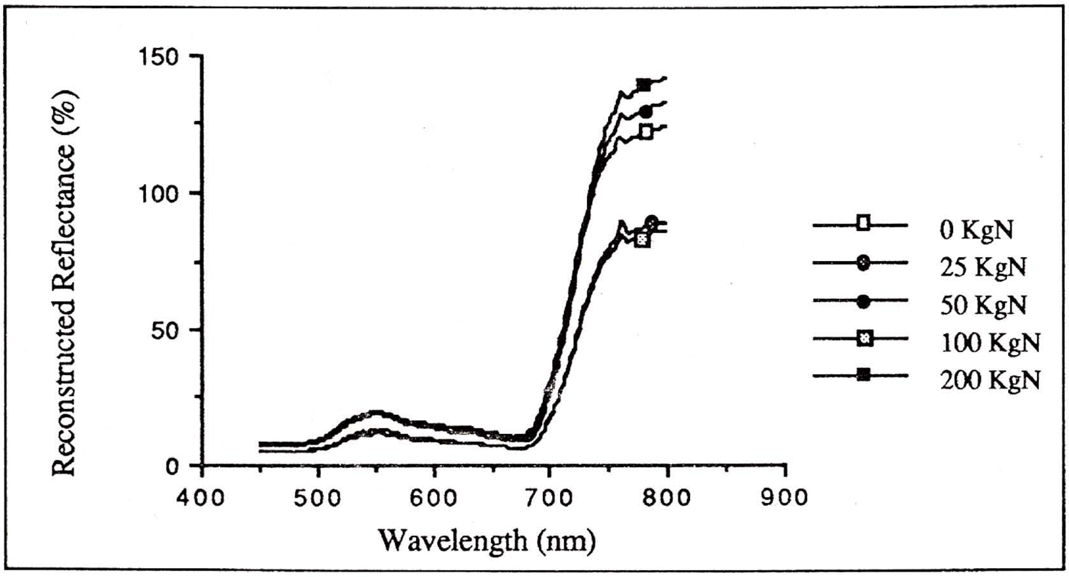

Fig. 2 First Component of Factor Analytic Decomposition of Spectra from Each Nitrogen Fertiliser Treatment.

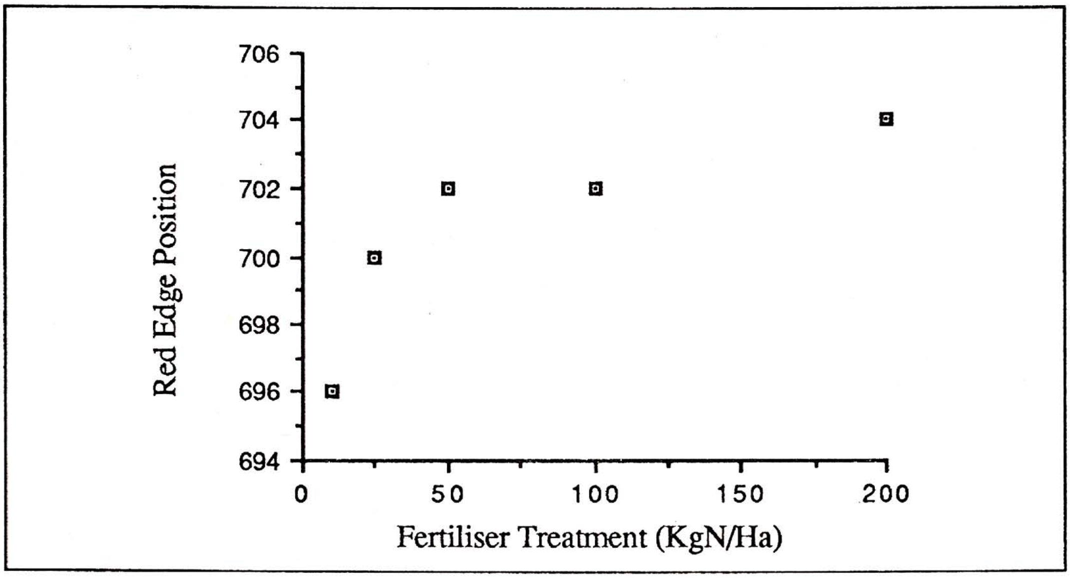

Fig. 3. Red Edge Position of the First Factor Spectra of Each Treatment.

TABLE 1
ASSIGNMENT OF INDIVIDUAL SPECTRA TO TREATMENT, BIOMASS AND ELAI GROUPS
(bold figures are fertilizer amount, bracketted figures are quadrat numbers)

Treatments

Group	1	2	3	4	5
	0(2,4,6,7, 9,11,12, 13,14)	**25**(2,6, 8,12)	**50**(1,2,4,6,7, 8,11,13,14)	**100**(1,7, 10,13)	**200**(1,2,3, 6,7,8,11,12, 13)

Biomass

Group	1	2	3	4	5	6
	0(6,9,13), **100**(10)	**0**(12,14), **25**(2,6), **50**(1,13, 14), **100**(1,7)	**50**(4,7), **100**(13), **200**(2,13)	**0**(2), **25**(8, 12), **200**(7,8)	**0**(7,11), **50**(6,8,11), **200**(3,12,13)	**0**(4), **50**(2), **200**(1,6)

Estimated LAI

Group	1	2	3	4	5	6
	100(13), **200**(2)	**0**(6,7,9,13, 14),**50**(8), **100**(10), **200**(11,12)	**25**(8), **50**(1,13), **100**(1), **200**(8)	**0**(2,4,11,12), **25**(2,12), **50**(7,14), **200**(7)	**25**(6), **50**(2,6), **100**(7), **200**(1)	**50**(4,11), **200**(3,6, 13)

When the red edge position was extracted a linear shift of 2 nm per group was observed except for the high biomass groups, five and six (Fig. 5). These mirrored the positions of the previous two groups thus producing an asymptotic variation of red edge and biomass. The maximum red edge position observed was also lower than that of the treatment groupings.

(iii) *Classification on the Basis of Estimated LAI*

Several recent environmental process models have attempted to include two forms of remotely sensed information; leaf area index (LAI), estimated from measurement of NDVI or the Near Infrared/Red Ratio, and information on cancopy chemistry. Employing estimated LAI (ELAI) data also collected at the time of overflight the IRIS spectra were again classified into 6 ELAI groups. These did not entirely correspond to the biomass groups but whether the poor correlation between biomass and ELAI (Fig. 6) is due to error in biomass collection, differences in the area sampled between the quadrat and the FOV of the broad-band radiometer or errors due to depression or inflation of the NDVI, is unknown. The first factor extracted for the ELAI classes again showed a pattern in red edge position similar to that observed for both the biomass and treatment groups. Only at the lowest ELAI was a higher than expected red edge position observed which it was

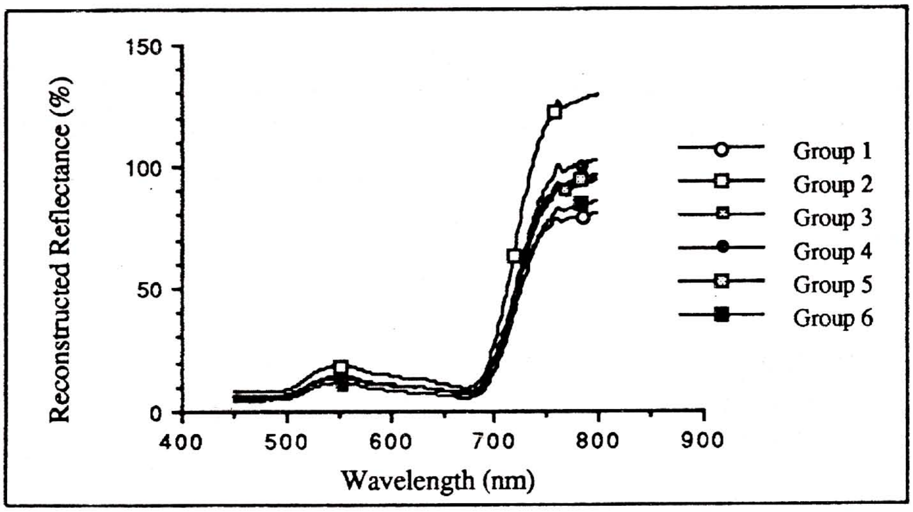

Fig. 4. First Component Spectral Curves for Each Biomass Group.

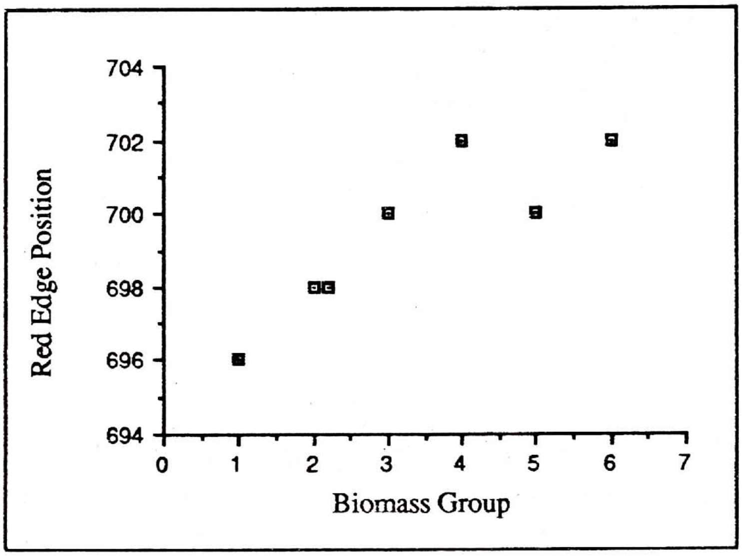

Fig. 5. Variation in Red Edge Position with Change in Biomass.

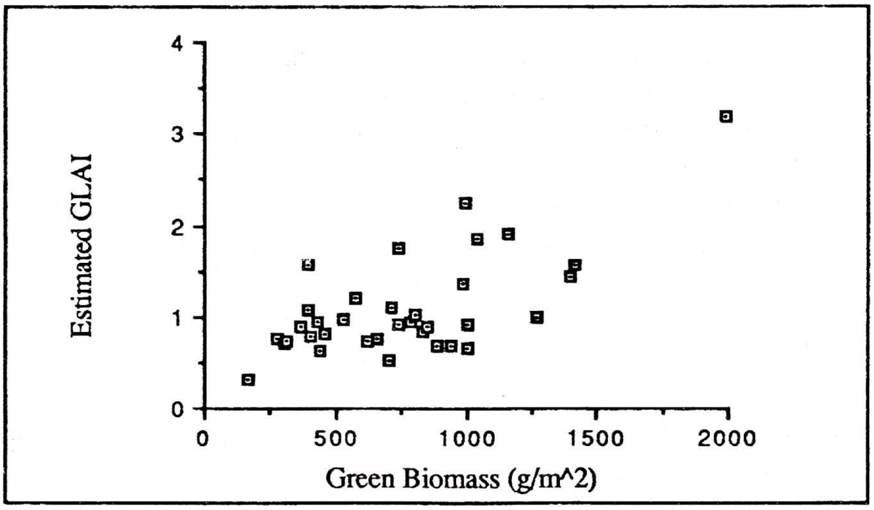

Fig. 6. Variation of the Estimated Leaf Area Index with Measured Green Biomass.

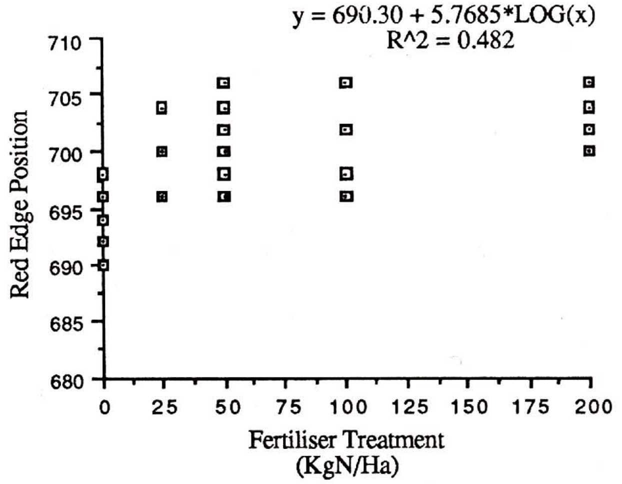

Fig. 7. Variation in Red Edge Position with Fertilizer Treatment - Individual Spectra.

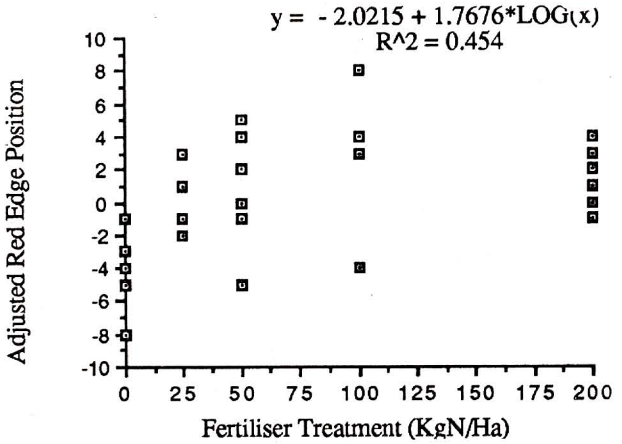

Fig. 9. Variation in Red Edge Position (Adjusted for Biomass) with Fertilizer Treatment.

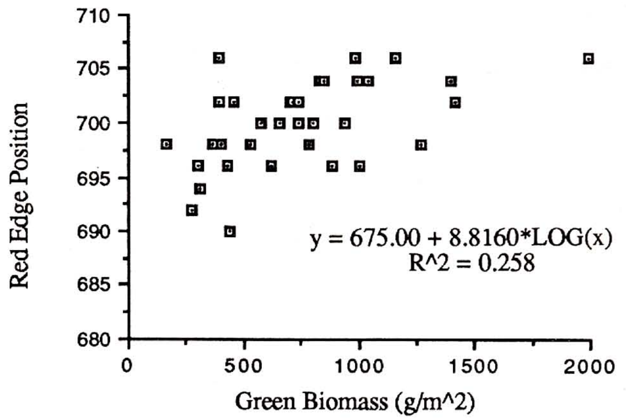

Fig. 8. Variation of Biomass with Red Edge Position - Individual Spectra.

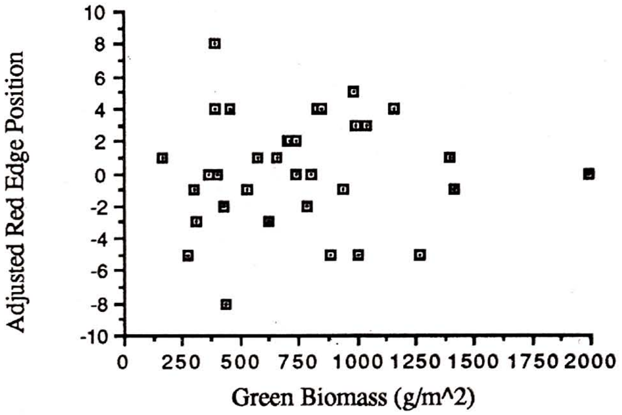

Fig. 10. Variation in Red Edge Position (Adjusted for Biomass) with Biomass.

considered may be a function of the effect of the soil on ELAI.

(iv) *Individual IRIS Spectra and Red Edge Position*

In all the above cases the classifications of spectra into biomass, ELAI or treatment groups showed considerable within-group variance (Fig. 7). It was therefore decided to examine the spectra uniquely in terms of their biomass or ELAI. These two parameters were considered alternative characterisations of vegetation amount, hypothesised to be the overall driver of the red edge shift. The red edge position for each spectrum was plotted both as a function of biomass and ELAI and simple and logarithmic curves fitted. In each case the distribution of data showed a similar pattern with an asymptotic shift in red edge with increased vegetation amount although with considerable vertical scatter (Fig. 8). To try to examine whether a treatment effect might exist independent of the biomass/ELAI the curves fitted to the data were assumed to represent the movement of red edge position with increasing vegetation amount. The curve functions were then used to regenerate the red edge position for each biomass and ELAI measurement. These data were compared to the observed red edge positions and the differences derived for comparison by treatment. Despite there being considerable scatter, a progression in red edge position can still be observed with treatment although perhaps less pronounced than for the pre-adjusted data (Fig. 9). Furthermore the scattergrams for both biomass and ELAI do not show any remaining progression of red edge position with increasing vegetation amount (Fig. 10). Clearly though, the representation of the data in terms of treatment is less than satisfactory. The next stage will, therefore, involve examination of unique spectra with vegetation amount, chemical characteristics and species diversity between spectra taken into account.

4. CONCLUSIONS

(i) The IRIS spectra showed a similar variation as that observed for the field-averaged imaging spectrometer spectra when the spectra were analysed in terms of treatment.

(ii) A red edge shift larger than that for the imaging spectrometer was also observed from the 0KgN to the 200KgN treatment. This was 8nm as opposed to 4nm observed from the Moniteq PMI data.

(iii) The hypothesis that red edge position will also show a shift to longer wavelengths with increasing biomass was also confirmed although deviation was noted for the higher biomass groupings.

(iv) The hypothesis that biomass was entirely responsible for the observed shift in red edge position rather than change in canopy chemistry was rejected because a progression of a red edge with fertilizer treatment was still observed once the deviation with biomass was removed.

(v) The scatter around treatment, biomass or ELAI groups was considerable and no satisfactory explanation for this variety has yet been produced. The use of treatments as a varaiable was, however, questioned and further work will concentrate on quadrat- specific chemical analyses.

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