PROJECT REPORT No. 277

OPTIMISING FUNGICIDE APPLICATION ACCORDING TO CROP CANOPY CHARACTERISTICS IN WHEAT

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by

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This is the final report of a thirty-month project which started in October 1998. The work was funded by a grant of £125,176 from HGCA (project no. 2074).

CONTENTS

Page No.

ABSTRACT

A two-year study was conducted to determine the interactions between spray application variables and crop canopy structure so as to explore the potential for improving the performance of fungicides applied to cereal crops. The work involved a review of methods of sensing crop canopy characteristics that concluded that reflectance radiometry to determine a vegetative index, particularly at early stages of growth, was an appropriate method that could be developed commercially.

Field experiments then used radiometry to define areas of high and low crop canopy density and treatment plots based on spray application variables were defined in each area. In the first seasons work, only deposits were measured at two growth stages using a tracer dye technique. In year 2, sites in different parts of East Anglia used a T2 fungicide applied at the later growth stage and with a different dye to measure both deposit distribution and fungicide efficacy.

Results from experiments conducted in the first year's trials showed large differences in mean deposit levels at the two growth stages with deposits per unit of leaf weight at growth stage 39 43% less than those at growth stage 32. At a given growth stage, there was some variation in deposit levels and distribution between the areas of high and low crop canopy density but these were not statistically significant. Total deposit levels at both growth stages were increased by an average of 13% by angling nozzles at 45^{o} to the vertical and by 38% by using a volume rate of 100 l/ha compared with 200 l/ha applications. The largest differences were measured at the earlier growth stage. Higher deposits were consistently measured when applying a fine spray.

Results from the second year's experiments also showed no difference in mean deposit levels per unit of leaf weight in the areas of high and low canopy density. Deposits were again higher from the low volume (100 l/ha) applications compared with applications at 200 l/ha but no differences were established from using angled nozzles or a fine spray quality. No differences in levels of disease control between treatments in high and low crop canopy areas were measured.

Results from the project indicated:

(i) that there may be the potential to improve the use of fungicides by matching applications to crop growth stage although some further experiments are required to confirm that efficacy can be maintained under such conditions;

(ii) there is currently little to be gained from spatially variable applications of T2 fungicides in cereal crops based on measurements of crop canopy characteristics;

(iii) that savings in pesticide use can be achieved by changes to spray application parameters including adjustments to account for canopy characteristics: in wheat, increased crop deposits could be obtained particularly at early stages of growth by using volume rates of 100 l/ha applied with conventional nozzles systems and by angling the nozzles;

(iv) reflectance radiometry is an effective and relatively low cost way of characterising crop canopy characteristics particularly at early growth stages (before GS 32).

SUMMARY

A two-year study was conducted to determine the interactions between spray application variables and crop canopy structure so as to explore the potential for improving the performance of fungicides applied to cereal crops. The work involved a review of methods of sensing crop canopy characterisation that concluded that reflectance radiometry to determine a vegetative index particularly at early stages of growth was an appropriate method that could be developed commercially.

A series of field experiments then used radiometry to define areas of high and low crop canopy density and treatment plots based on spray application variables were defined in each area. Applications to plots were made with a conventional tractor-mounted 24 m boom sprayer travelling at a nominal speed of 8 km/h. Nozzle conditions for treatments were selected such that comparisons could be made relating to:

- applications at 100 against 200 l/ha;
- the use of fine as well as medium spray qualities;
- angling the nozzles rearwards at 45^{o} to the vertical as an alternative to the conventional vertical nozzle configuration.

A total of eight treatment plots were used with two replications such that the interactions between application variables could be considered. In the first seasons work, only deposits were measured at two growth stages (GS32 and GS39) using a tracer dye technique. In year 2, three sites in different parts of East Anglia used a T2 fungicide applied at the later growth stage and with a different dye to measure both deposit distribution and efficacy. When considering fungicide efficacy it was recognised that there may be an interaction between the establishment and transmission of fungal disease and plant canopy density. For this reason, control treatments with no T2 fungicide applied were incorporated into the trial design for the second year experiments.

Results from experiments conducted in the first years trials showed large differences in mean deposit levels at the two growth stages with deposits per unit of leaf weight at growth stage 39 43% less than those at growth stage 32. At a given growth stage, there was some variation in deposit levels and distribution between the areas of high and low crop canopy density but these were not statistically significant. Total deposit levels in the crop at both growth stages were increased by an average of 13% by angling nozzles at 45^{o} to the vertical and by 38% by using a volume rate of 100 l/ha compared with 200 l/ha applications with the largest differences measured at the earlier growth stage. Higher deposits were consistently measured when applying a fine spray.

Results from experiments conducted in the second year of the project also showed no difference in mean deposit levels per unit of leaf weight in the areas of high and low canopy density. Deposits were again higher from the low volume (100 l/ha) applications compared with applications at 200 l/ha but no differences were established due to the use of angled nozzles or a fine spray quality at the later growth stage used for this second set of experiments. No differences in levels of disease control between treatments in high and low crop canopy areas were measured. There were also no statistically significant differences in the levels of control achieved by the different application techniques or between treated and control plots. This result suggested that for the year in which this trial was conducted (harvest year 2000), the control provided by the T1 fungicide application provided a high level of protection well into the season even though attempts were made to increase the sensitivity to the experimental variables by using a reduced dose of active ingredients at the T1 timing.

Results from the project therefore indicated:

(i) that there may be the potential to improve the use of fungicides by matching applications to crop growth stage although some further experiments are required to confirm that efficacy can be maintained under such conditions;

(ii) there is currently little to be gained from spatially variable applications of T2 fungicides in cereal crops based on measurements of crop canopy characteristics;

(iii) that savings in pesticide use can be achieved by making changes to spray application parameters including adjustments to account for canopy characteristics: in cereal crops, increased crop deposits could be obtained particularly at early stages of growth by using volume rates of 100 l/ha applied with conventional nozzles systems and by angling the nozzles to the vertical;

(iv) reflectance radiometry is an effective and relatively low cost way of characterising crop canopy characteristics in cereals particularly at early growth stages (before GS 32);

(v) some of the lack of sensitivity in the experiment may have arisen because the measurements of crop canopy characteristics were made well ahead of the timing of the spray applications: this was done so as to make measurements with the canopy sensing system operating to give high resolution between different parts of the same field: there may be increased potential to optimise fungicide use if sensing systems were able to give a more direct estimate of canopy structure particularly at later stages of growth;

(vi) the advantages of matching fungicide and growth regulator sprays to crop canopy characteristics within a given field are likely to be more substantial in fields with a large spatial variation in crop canopy conditions: more information is needed on the typical ranges of crop canopy conditions and the extent to which canopy conditions and seasonal effects influence the spread and damage due to fungal diseases.

1. INTRODUCTION

Relatively cheap and physically robust sensing systems that can be used for monitoring aspects of crop canopy structure have been developed. As a result, there is now the possibility to match the delivery of plant protection products to measurements of crop structure, if appropriate relationships linking descriptors of the canopy and the application method can be defined. One such potential application relates to the use of fungicides in cereal crops where the basic mode of action, whether protectant or eradicant, is related to activity at the leaf surface of the crop. A simple hypothesis in such circumstances might therefore be that the volume rate of a fixed concentration of tank mixed formulations should be directly related to the leaf area index (LAI) of the crop canopy.

Experimental work by Secher (1997) has indicated that there may be the potential to improve the use of fungicides when dose rates applied to a winter wheat crop were varied in accordance with crop characteristics assessed using boom-mounted radiometers. Yield results from areas treated with the spatially variable fungicide input were statistically higher than the uniformly treated crop. This was not supported by results reported by Bjerre (1999) where no increases in yield were recorded from spatially variable treatments applied on the basis of a vegetation index assessed using radiometers. Bjerre's work used the simple hypothesis outlined above and aimed at delivering a given amount of fungicide per unit area of crop leaf surface. In support of the approach, some preliminary results from experiments by Secher were quoted in which spray deposits at different levels in a wheat crop canopy treated conventionally were found to vary depending on the density of the canopy with less penetration into the canopy being recorded in areas of higher canopy density as expected.

The establishment and spread of a fungal disease within a crop canopy is also likely to be influenced by crop canopy density. Paveley *et al* (1996) considered the scope for the spatially variable application of fungicide and noted that variations in the structure of the crop canopy may have the opposite effect on the distribution of disease to that relating to fungicide application. They also concluded that the spatially variable application of fungicides in response to directly sensed disease parameters would require very sensitive, complex and automated field monitoring techniques.

In this project we have sought to establish how spray application parameters can be adjusted to change deposition patterns in areas of different cereal crop canopy density and the extent to which these adjustments can be used to optimise fungicide use. The work was conducted by a project consortium that included Silsoe Research Institute, Morley Research Centre, Novartis Crop Protection Ltd (now Syngenta Crop Protection (UK)), and Micron Sprayers. Advice was given to the consortium by an independent agronomist (Mr John Clark) and this input is gratefully acknowledged – see Section 7 of this report.

There is a substantial body of literature that relates spray application techniques to levels of deposit on both the crop and weeds within the crop together with the associated efficacy in Northern European cereal crops. This data has been reviewed by a number of authors (e.g. Hislop, 1987; Knocke, 1994) and a detailed consideration of the effect of application parameters is beyond the scope of this report. Many studies of spray application performance in cereal crops have been conducted at defined growth stages (e.g. Rutherford *et al*., 1989; Rutherford and Miller, 1993) and while others have used a range of crop growth stages (e.g. Bryant and Courshee, 1985). However, little work has aimed at linking spray deposits and efficacy to crop canopy structure either at a single growth stage or over a range of crop canopy development. This has been partly due to the technical difficulties of measuring crop canopy structure particularly using non-destructive techniques. The recent development of instrumentation systems for characterising elements of crop canopy structure non-destructively has made it possible to consider correlating spray deposition characteristics with aspects of crop canopy structure and considering the implications that such correlations may have for the improved use of crop protection chemicals such as fungicides and growth regulators.

Some studies have examined the relationships between crop canopy structure and spray deposit distributions. Bonciarelli and Covarelli (1995) showed that there is a robust relationship between the proportion of spray intercepted by a crop and the leaf area index, and that the nature of this relationship is influenced by the volume application rate. Results reported by Bryant and Courshee (1985) showed that deposits at different levels in a cereal crop were almost constant over a range of volume rates between 50 and 200 l/ha at a given crop growth stage but with higher levels of deposit being recorded in a smaller canopy as expected. It is also likely that the relationships between application parameters such as droplet size distribution (spray quality), delivery angle and volume rate, and the magnitude and distribution of deposits within a cereal canopy is influenced by crop canopy structure. Laboratory studies by Combellack and Richardson (1985) using a static boom and plants on a moving track showed increases in deposit in the order of 60% by angling the spray at 45º to the direction of travel and similar results have been obtained in field trials (Robinson - personal communication with data). An important feature of the nozzle angling experiments conducted under field conditions was the ability to manipulate the site of deposition within the crop canopy by adjusting the delivery angle. The work of Combellack and Richardson suggested that while total capture may be increased by changing nozzle angles on the boom, there were likely to be changes in the distribution of deposits that could have important implications for product efficacy.

When using conventional nozzle designs, the variables of spray quality, application volume rate and forward speed are inter-related. It is, for example, only possible to apply coarse sprays at low volume rates by travelling at relatively high speeds. The review by Knocke (1994) indicated a strong trend towards increased deposit levels from a given application when finer quality sprays with smaller droplet sizes were used. The trend in terms of volume application rate was also towards higher efficacy at the lower rates although the trend in this case was less pronounced. Field trials such as those reported by Rutherford and Miller (1993) and Cawood *et al*., (1995) in which applications were made with different nozzle systems giving different delivery conditions at different volume rates confirm the trend towards higher deposit levels when using finer sprays and lower volume rates. In the case of the grass weed herbicide trial reported by Cawood *et al*., lower volume rates and finer spray quality gave higher levels of efficacy.

The work described in this report therefore had the objectives of:-

(i) reviewing methods of sensing crop canopy structure with the aim of selecting an appropriate system that could be used in a series of field experiments examining the possible interactions between application variables, crop canopy structure, spray deposit distribution and the efficacy of fungicides;

(ii) making measurements of deposit magnitude and distribution from sprays applied with different qualities (droplet size distribution), volume rates and delivery angles to areas of a field identified as having relatively high and low crop canopy density;

(iii) assessing the interaction between fungicide efficacy, spray delivery parameters and crop canopy density for a winter or spring wheat crop at a given stage of crop development;

(iv) reviewing the results from the study so as to make recommendations relating to the application of fungicides in a precision farming system and the need for further work to develop these approaches.

Some aspects of the project work have been published (Miller *et al*., 2000; Miller *et al*., 2001) with due acknowledgement to the Home Grown Cereals Authority and others involved in the work.

2. REVIEW OF METHODS FOR SENSING CROP CANOPY STRUCTURE

Possible sensing approaches reviewed are summarised in Table 2.1. Two possible systems were identified and considered in more detail, namely:-

- the use of a laser-based range-finding instrument that would measure the distance from a position equivalent to a nozzle mounted on a spray boom to the first point of interception with the crop canopy for a range of trajectory angles corresponding to different spray fan angles (Miller and Walklate, 2000);

- a system for measuring the integrated reflectance characteristics from the complete crop canopy in a configuration for determining a normalised vegetation index (Paice *et al*., 1999) derived from reflectance measurements in the wavebands 640-660 nm (red) and 790-810 nm (near infra-red). Previous work (e.g. Curran 1983) has shown a good correlation between vegetation indices determined from spectral reflectance measurements and leaf area index in cereal crops for leaf area indices up to approximately 3.

It was recognised that both of the possible crop canopy sensing methods would not give good resolution of differences in canopy structure when leaf area indices were greater than approximately 3. However, it was considered that if information relating to crop canopy structure was to be used as a basis for making decisions, then measurements would need to be made at relatively early stages of growth when the potential systems would give some discrimination of differences in canopy structure. The spectral reflectance method of monitoring the crop canopy was selected since this had been developed to a practical stage where it could be used in field conditions in a reasonably reliable and practical manner. It was also recognised that the principles of measuring a vegetation index was being used in other HGCA funded research work and had been developed commercially as a means of matching nitrogen applications to local need via the Hydro-Agri "N sensor" – Wollring *et al*., 1998.

Table 2.1 Summary of potential systems for determining crop canopy characteristics

Basis of system	Advantages	Disadvantages
Spectral reflectance to determine a vegetation index	• Subject of much research – e.g. Curran, (1983); Paice *et al*., (1999); Jones (2000). • Developed for commercial applications particularly relating to nitrogen application, e.g. Wollring *et al*., 1998. Large number of data sets relating to cereal crop canopies. • Subject of continuing development particularly with regard to the use of hyperspectral information.	• Likely to give poor resolution at later stages of growth in cereal crop canopies.
Optical "LIDAR" system, or range measuring device	• Good simulation of spray droplet trajectories, Miller and Walklate, 2000. • Developed experimentally from equipment that is commercially available. • Experimental use heavily based on larger (orchard) canopies, Walklate *et al*., 1997.	• Not well developed for cereal crop applications (yet?). • Relatively high cost.
Ultra-sonic detectors	• Relatively low cost and widely available – used on automatic cameras. • Has been used for agricultural machinery applications, e.g. spray boom height sensors. – O'Sullivan (1986).	• Not well developed for applications relating to the characteristics of cereal crop canopies. • Potentially fragile – requires protection.
RADAR systems	• Good for sampling large areas particularly from aerial or satellite platforms. Not highly dependant on atmospheric conditions – Dampney *et al*., (1998).	• Not well developed for practical use on ground-based equipment.
Mechanical deflector – pendulum	• Simple and robust. • Developed experimentally for forage crop systems – Hammen and Ehlert, 1999.	• Not well developed for cereal crop conditions. • May lack sensitivity. • Crop damage at later growth stages.
Capacitance measurement	Developed experimentally – e.g. Greathead *et al*., 1987. Uses well established principles.	• Not well suited to continuous measurement.

3. MEASUREMENTS OF SPRAY DEPOSITION IN CEREAL CROP CANOPIES

3.1 Measurements of crop characteristics and field plot layouts

Radiometers (Skye Instruments type SKR 1800) were mounted vertically downwards on the boom of a 24 m wide mounted sprayer at a spacing of approximately 4 m. A single radiometer was mounted vertically upwards on the sprayer boom to provide a correction for incident radiation levels. The sprayer was then driven along tramlines in the crop at a speed of approximately 10 km/h and with a boom height of 1.5 above the crop such that radiometer measurements were obtained for circular sampling areas approximately 0.6 m in diameter at a sampling interval of about 0.3 m. Radiometer measurements were recorded simultaneously with field location determined from a Global Positioning System (Racal Ltd.) operating in differential mode. This enabled field maps to be plotted showing the distribution of a calculated normalised vegetation index based on a Kriging interpolation model (Paice *et al.*, 1999). Each field area was divided into two approximately equal areas by determining a threshold vegetation index that then defined areas of relatively high and relatively low crop canopy density. Sixteen treatment plots, two replicates of eight application treatments, each 10 x 20 m, were then allocated to the areas of high and low crop canopy density.

3.2 Spray application and determination of deposit distribution

The spray application variables investigated were volume application rates of 100 and 200 l/ha applied as fine or medium spray qualities with conventional flat fan nozzles operating either vertically downwards or at an angle of 45E forwards. All treatments were sprayed from a 24 m mounted sprayer treating plots positioned to one side of the tramlines. Treatments were achieved using the nozzle conditions specified in Table 3.2.1.

Extended range flat fan nozzles were used that were rated at operating pressures of between 1.0 and 4.0 bar. It was recognised that the selection of a pressure of 1.0 bar to achieve a medium quality spray at a volume rate of 100 l/ha was on the edge of the operating envelope for the nozzles chosen but was selected to keep the range of forward speeds for the different treatments as small as possible.

Table 3.2.1. Nozzle conditions used in the application treatments

Spray quality	Volume application rate, l/ha	Nozzle orientation	Nozzle descriptor	Pressure, bar	Forward speed, km/h
Fine	100	Vertical	FF110/0.6/3.0	3.0	7.0
Fine	100	45E angle	FF110/0.6/3.0	3.0	7.0
Medium	100	Vertical	FF110/1.2/3.0	1.0	8.3
Medium	100	45E angle	FF110/1.2/3.0	1.0	8.3
Fine	200	Vertical	FF110/1.2/3.0	4.0	8.2
Fine	200	45E angle	FF110/1.2/3.0	4.0	8.2
Medium	200	Vertical	FF110/1.6/3.0	2.0	7.8
Medium	200	45E angle	FF110/1.6/3.0	2.0	7.8

In the first year of the work (1999), applications of a tracer dye with a non-ionic surfactant at 0.1% ("Agral" – Zeneca Agrochemicals – now Syngenta) were made to winter and spring wheat crops grown at Silsoe Research Institute at growth stages 32 and 39. From each treated plot, two sets of ten crop tillers were sampled at random from the centre of the plot and were sectioned into three components by cutting stems between the main leaves at growth stage 32 and at comparable positions for growth stage 39. Cut plant sections were placed in a pre-tared plastic bag, weighed and the dye on the plant sections recovered by adding a measured volume (50 mls) of de-ionised water and agitating vigorously for approximately 15 seconds. The wash solution was then transferred to tubes and taken to a laboratory for spectrophotometric analysis calibrated against samples of the original sprayed liquid taken from the nozzles. Different tracer dyes were used at the two crop growth stages to minimise the risk of cross-contamination.

In the second year's experiments (2000), a crop of winter wheat on a commercial farm at Otley (Suffolk) and spring wheat crops at Silsoe in Bedfordshire and near Cambridge were sprayed with a T2 fungicide of Twist (F279-trifloxystrobin) at 1.0 l/ha and Alto (cyproconazole) at 0.16 l/ha. A fluorescent tracer dye was added to the tank mix (Helios at 50 g/ha) in order to allow deposits to be quantified as in the first year's experiment. Recovery of dye from sectioned plants was by washing in a 90% hexane, 10% acetone liquid mix and the resulting dye solutions were sent to the laboratories at Novartis Crop Protection Ltd at Whittlesford (now Syngenta) for spectroflourimetric analysis again using reference standards collected from the nozzles at the time of spraying. Care was taken to ensure that containers used for the plant washing and transport of the dye solutions were not influenced by the solvent mixture used.

In all experiments two glass slides were mounted horizontally in the centre of each plot prior to the spray application and dye deposits recovered and quantified to provide a first check of the application rate applied to the plot.

3.3 Radiometry results and plot layouts for experiments in the first year of the project (1999)

Figures 3.3.1 and 3.3.2 show the field maps of the normalised vegetation index measured in the two fields of winter and spring wheat respectively, the distribution of high and low area of crop canopy density after applying the thresholding technique and the positions of the plots in both the areas of high and low crop canopy density. In the field of winter wheat (Figure 3.3.1), the area of highest canopy density occurred in the central area with lower densities around the edge. In the spring wheat crop, lower canopy densities were also found towards the edge of the field together with an area in the southern part of the field.

Plots were distributed at random in each of the high and low crop canopy density areas in the each field. The positions of plots was determined on the thresholded maps of normalised vegetation index and then marked out in the field using GPS and distance measurements down tramlines. Plot positions in the field were marked with labelled and colour-coded canes to facilitate both the spray application and subsequent sampling.

Spray applications were made by:-

(i) Setting the sprayer for required treatment in terms of nozzle size, angle and operating pressure;

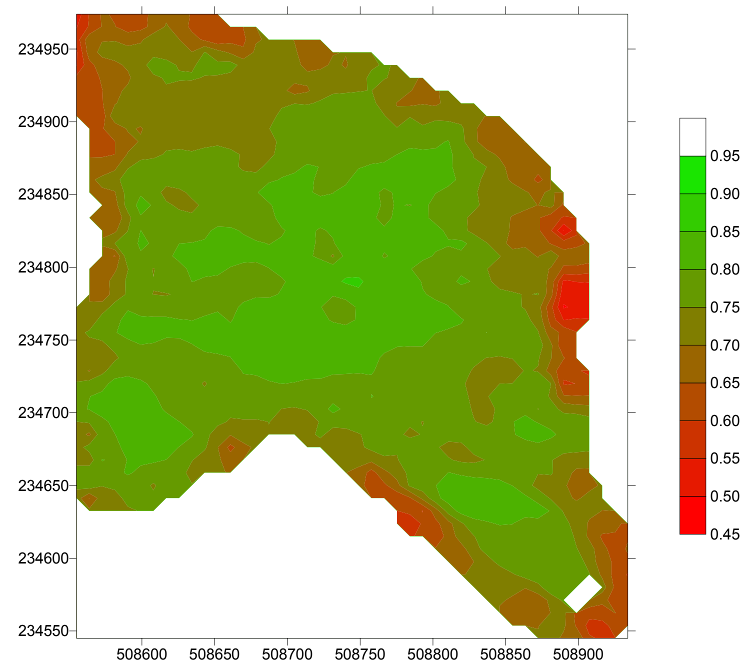

Figure 3.3.1 (a) **Radiometry data for winter wheat crop in year 1 (1999).**

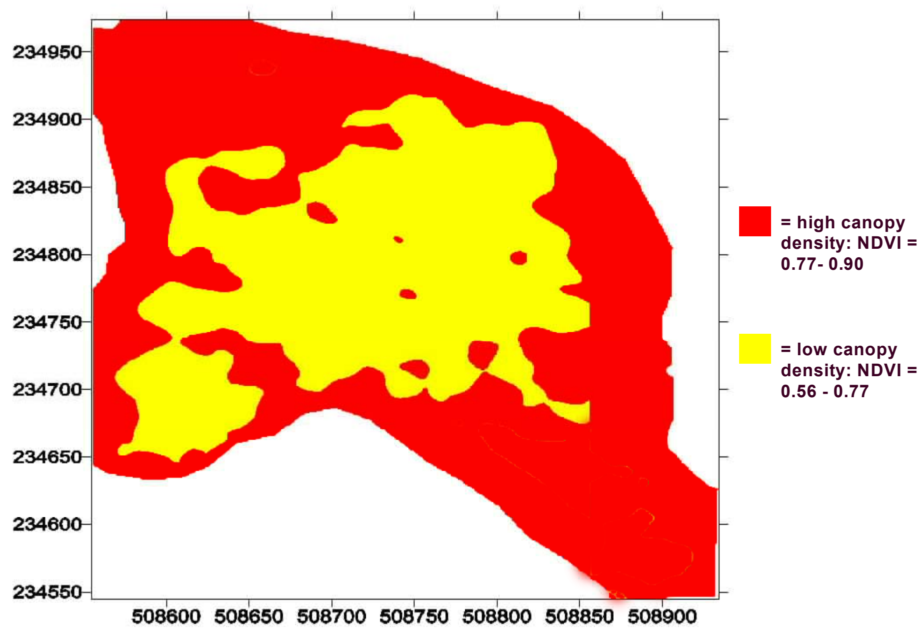

Figure 3.3.1 (b) **Radiometry data for winter wheat crop in year 1 (1999) thresholded to show high and low crop canopy density areas**

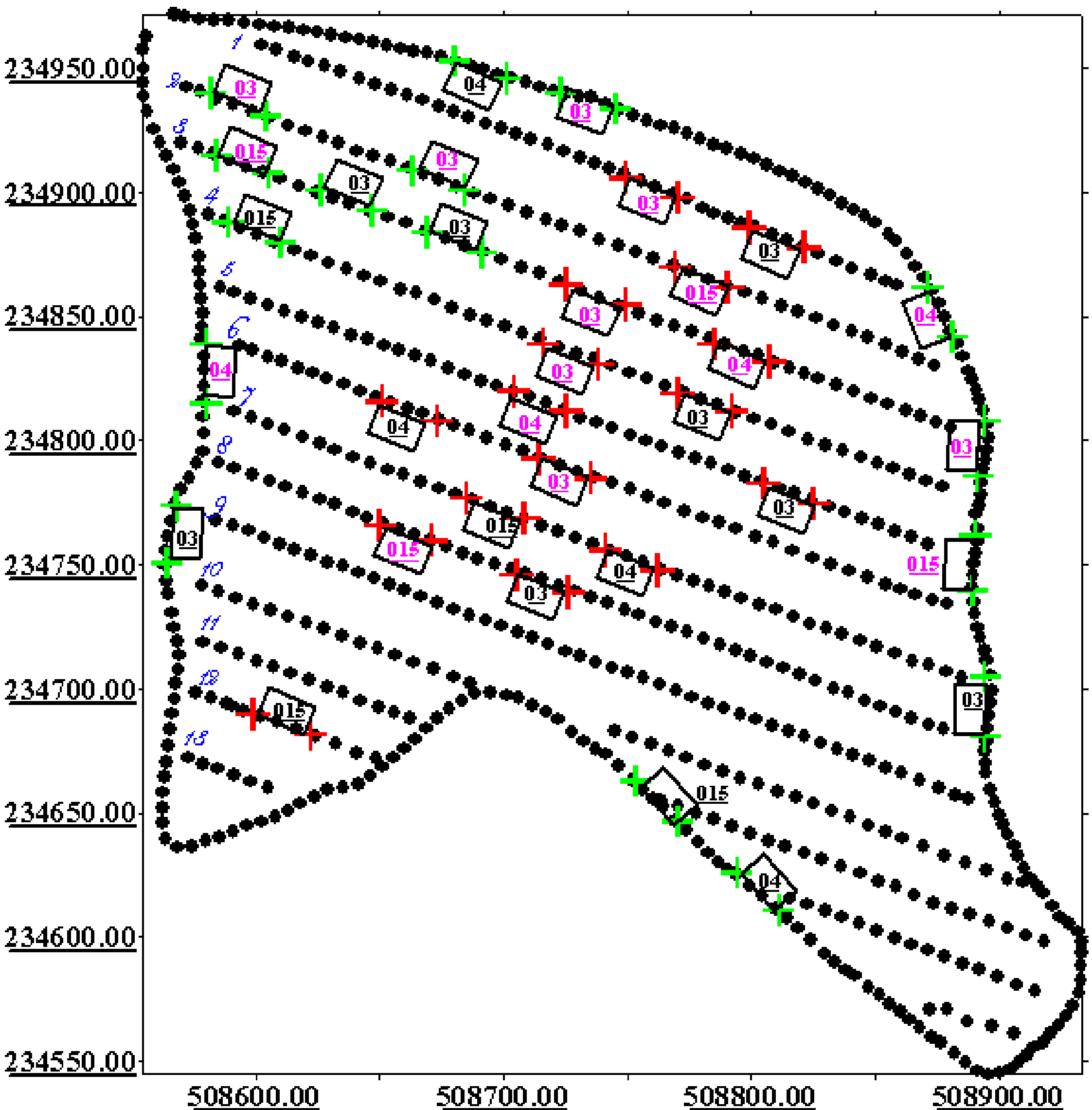

Figure 3.3.1 (c) **Winter wheat field showing position of plots in high and low crop canopy areas.**

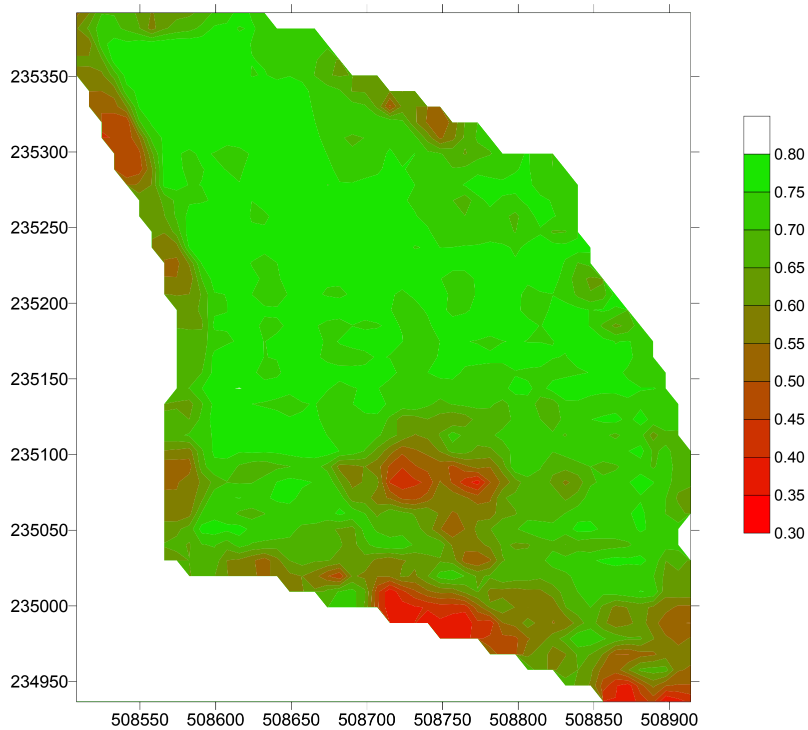

Figure 3.3.2 (a) Radiometry data for spring wheat crop in year 1 (1999).

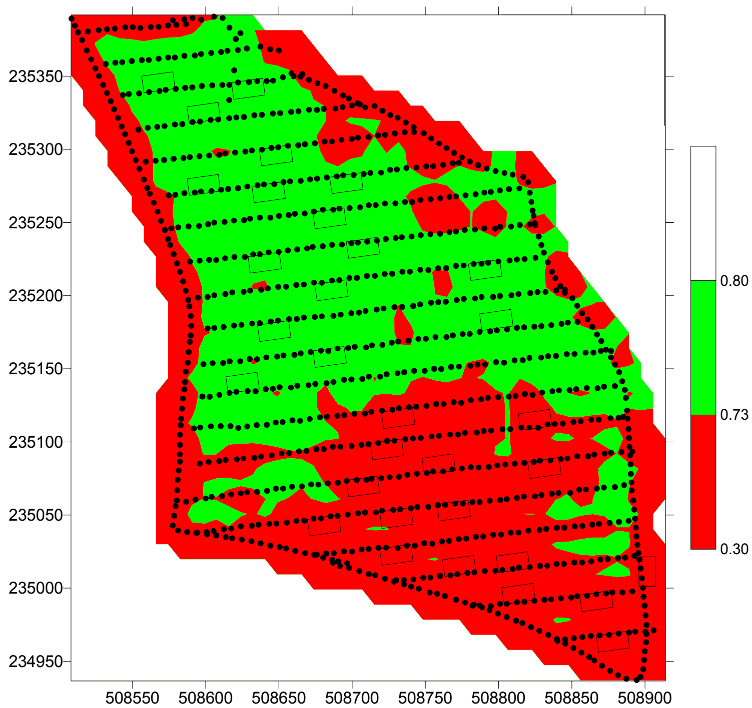

Figure 3.3.2 (b) Radiometry data for spring wheat crop in year 1 (1999) thresholded to show high and low crop canopy density areas and the position of treatment plots.

(ii) checking the calibration of the machine;

(iii) driving down the appropriate tramline to apply the treatment.

The order of treatments applied was such as to minimise the effects of cross-plot contamination due to any drifting spray.

3.4 Radiometry results and plot layouts for experiments in the second year of the project (2000)

A field site growing winter wheat on a heavy clay soil was identified in the Ipswich area and measurements of the normalised vegetation index were made on 28th March 2000, - see Figure 3.4.1 (a), using the same techniques as for the 1999 experiments. Results from this series of measurements showed areas of higher canopy density in the centre of the field with an area of lower density towards the northern end (top of page) that was identifiably due to slug damage. As in the 1999 experiments, a threshold level of normalised vegetation index was then selected such that the field could be divided into two approximately equal areas of high and low crop canopy density and experimental plots distributed randomly on each of the identified areas – see Figure 3.4.1 (b). White areas on Figure 3.4.1 were due to loss of position signal – in some cases due to driving round power lines and in others due to poor GPS reception.

The same approach was taken with a field of spring wheat growing on a medium soil in Cambridgeshire – Figure 3.4.2. When initially surveyed it was thought that the crop cover was too small to give a reliable indication of canopy characteristics. However, the results indicated a real feature of the field cropping that could not be detected with the naked eye and hence this early growth stage measurement of the vegetative index was used to determine experimental plot positions – Figure 3.4.2. In this field the areas of higher crop canopy density tended to occur in the northern part of the field.

A third field of spring wheat established on a heavy soil type at Silsoe Research Institute was measured with the boom mounted radiometer system on 29th May 2000 to give the result shown in Figure 3.4.3. This field had a relatively high grass weed population that probably influenced the results of the vegetative index. Higher levels of vegetation index were measured again in the centre of this field and towards the southern end.

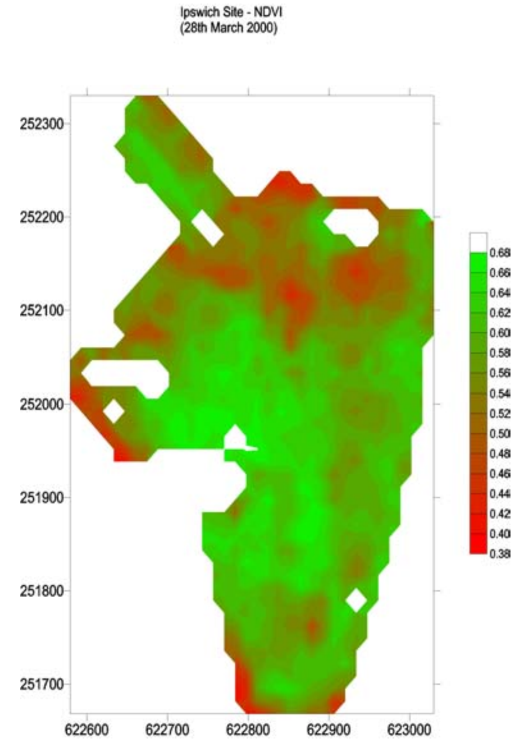

Figure 3.4.1 (a) **Radiometry data for winter wheat crop at the Suffolk site in year 2 (2000).**

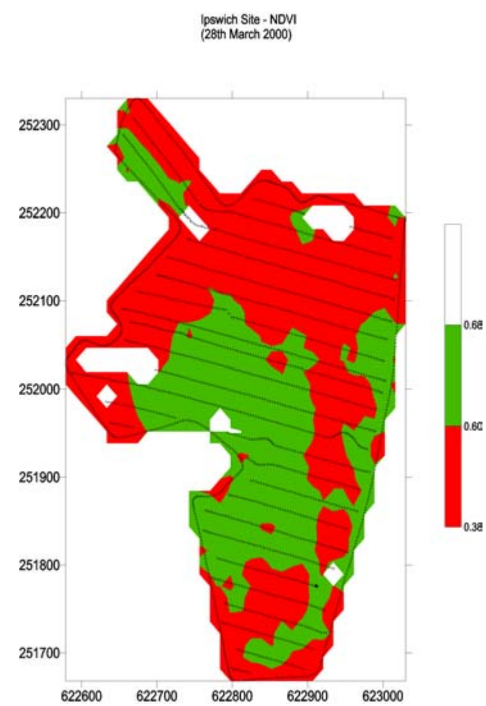

Figure 3.4.1 (b) Radiometry data for winter wheat crop at the Suffolk site in year 2 (2000) thresholded to show high and low crop canopy density areas

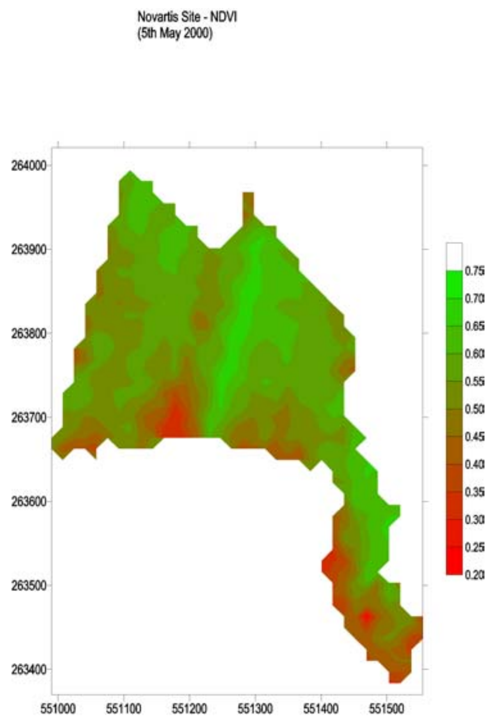

Figure 3.4.2 (a) **Radiometry data for spring wheat crop at the Cambridgeshire site in year 2 (2000).**

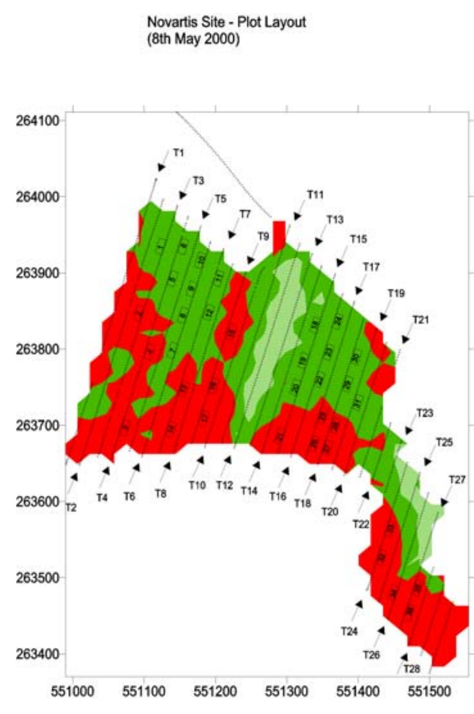

Figure 3.4.2 (b) **Radiometry data for spring wheat crop at the Cambridgeshire site in year 2 (2000) thresholded to show high and low crop canopy density areas**

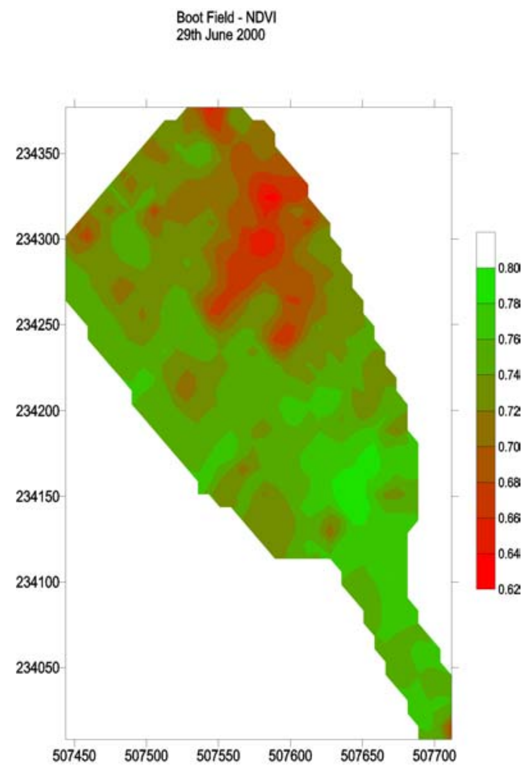

Figure 3.4.3 (a) **Radiometry data for spring wheat crop at the Silsoe site in year 2 (2000).**

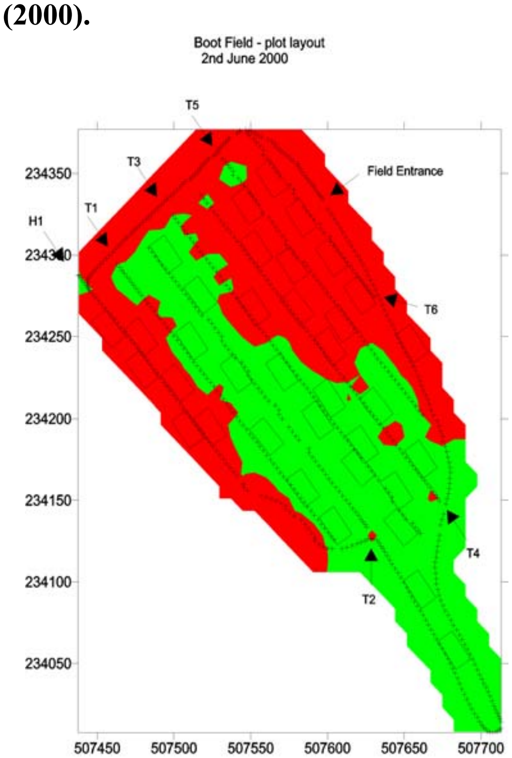

Figure 3.4.3 (b) **Radiometry data for spring wheat crop at the Silsoe site in year 2 (2000) thresholded to show high and low crop canopy density areas**

3.5 Spray deposit distribution measurements using a tracer dye in the first year of the project

Table 3.5.1 shows the mean spray deposits expressed as Φl/g of leaf weight measured at the three levels in the crop canopy for the winter wheat crop treated at growth stages 32 and 39. These results have been normalised to account for the different volumes applied and show some of the expected trends particularly in relation to the levels of deposit at the two stages of growth. Deposit levels per unit of leaf weight measured at growth stage 39 were 43% less than those at growth stage 32 and this directly reflects the increase in plant size and weight. At the early growth stage, mean deposit levels per unit of leaf weight were higher in the low crop canopy density areas but not significantly so. At the later stage, higher deposit levels were found in the higher canopy density areas and this was not consistent with the original simple hypothesis. It should be noted that higher levels of deposit per unit leaf weight do not necessarily indicate higher total deposits because of the increase in leaf weights with growth stage. For example, overall mean leaf weights at the early stage of growth (GS 32) for the winter wheat crop had a mean value of 23.3 grams and this figure had increased to 40.9 grams at growth stage 39.

While the statistical analysis of the data presented in Table 3.5.1 did not show any significant treatment differences, it did indicate substantial interactions between the variables. This is in line with expectation particularly considering spray application variables and crop canopy characteristics.

Table 3.5.1 Measured spray deposits, Φl/g leaf weight, at growth stages 32 and 39 in the winter wheat crop normalised to represent expected levels per 100 l/ha of applied spray at both volume rates.

TREATMENTS				SPRAY DEPOSIT, GS32			SPRAY DEPOSIT GS39		
				Section of Tiller			Section of Tiller		
Crop Density	Spray Quality	Volume l/ha	Nozzle Angle	Top	Middle	Base	Top	Middle	Base
High	Fine	100	Angled	23.3	16.6	7.0	16.8	2.5	0.5
			Straight	15.0	11.7	7.0	21.2	2.2	0.5
		200	Angled	12.2	10.0	3.6	16.8	2.3	0.3
			Straight	8.5	7.7	2.9	13.7	1.8	0.4
	Medium	100	Angled	14.4	12.8	6.7	17.8	3.5	0.9
			Straight	17.2	13.4	5.7	15.6	2.6	0.5
		200	Angled	10.0	8.5	3.0	13.1	1.9	0.3
			Straight	9.0	9.6	4.0	12.2	3.0	0.8
Low	Fine	100	Angled	26.2	13.6	7.0	18.0	2.0	0.5
			Straight	16.0	13.0	6.9	11.3	1.5	0.4
		200	Angled	13.2	12.0	5.0	11.9	2.2	0.4
			Straight	11.7	9.3	3.8	14.8	2.3	0.3
	Medium	100	Angled	18.1	17.3	7.8	11.5	2.6	0.6
			Straight	10.6	10.9	6.2	13.1	2.3	0.4
		200	Angled	8.5	9.2	3.4	13.0	2.3	0.5
			Straight	8.2	9.2	3.8	13.4	2.0	0.4
Standard Error of Mean					1.80			1.31	

The relationship between deposit levels and application variables, measured across treatments, see Figure 3.5.1, showed that:-

- applications with a fine quality spray tended to give higher levels of deposit per unit of leaf weight with the largest differences in mean deposit of 15.7% measured at the earlier growth stage compared with 7.6% at growth stage 39;

- angling the nozzles increased the total deposit per unit of leaf weight by 22% at growth stage 32 and 4% at 39 with some evidence that angling increased deposits at the higher levels in the canopy as expected;

- operation at 100 l/ha gave higher deposits per unit of leaf weight than at 200 l/ha by 63 and 14% at growth stages 32 and 39 respectively; while this trend is consistent with previously published data (e.g. Bryant and Courshee, 1985; Cawood *et al*., 1995), the magnitude of the difference at the earlier growth stage is much larger than expected.

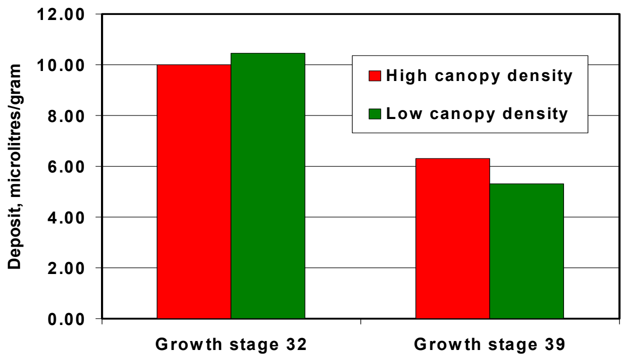

Figure 3.5.1 (a). The Effect of Canopy Density

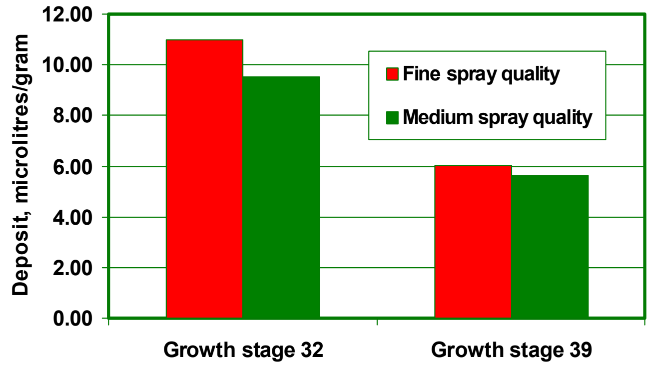

Figure 3.5.1 (b). The Effect of Spray Quality

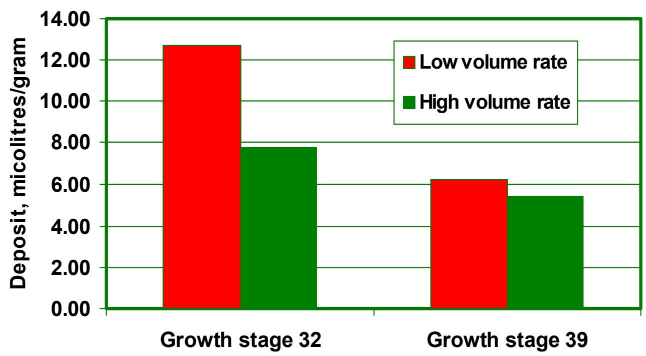

Figure 3.5.1 (c). The Effect of Volume Application Rate

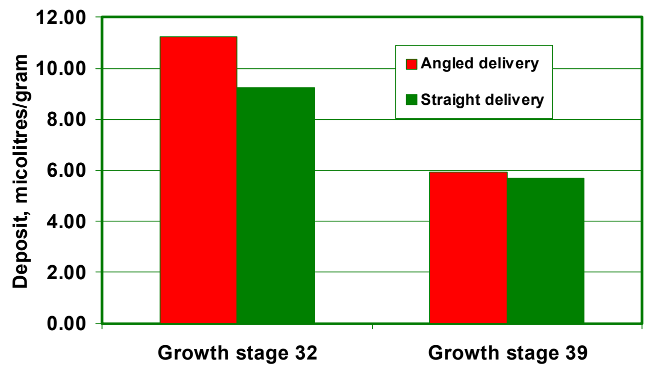

Figure 3.5.1 (d). The Effect of Angled Delivery

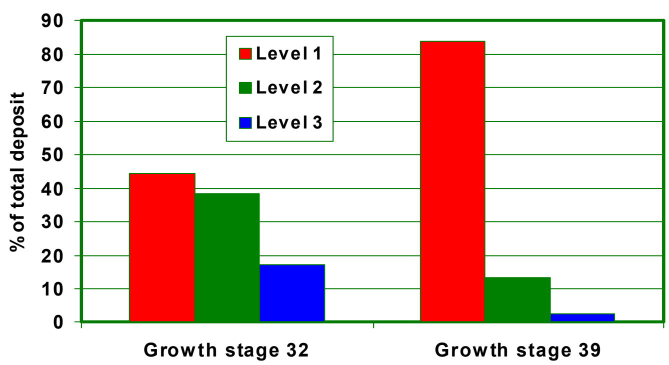

Figure 3.5.1 (e). The Penetration of Spray into the Canopy at the two Growth Stages.

Figure 3.5.1. Mean measured deposit levels for the main treatment variables in the experiments in the first year of the work.

The distribution of deposit was very different at the two growth stages examined. At growth stage 32, deposit levels at top and middle sections were generally comparable whereas at growth stage 39 more than 80% of the total deposit was in the top section of the canopy. This reflects changes in the canopy structure as well as the mean size of the overall crop canopy. There was some evidence of increased penetration into the canopy when using coarser sprays, higher volume rates and nozzles directed downwards but the effects were small and not statistically significant.

Similar results were obtained for the spring wheat crop (see Table 3.5.2). There was some indication of increased spray penetration into the canopy particularly at the later growth stage and this probably related to differences in the canopy structure. It is again noticeable that the main application variable influencing deposits was the volume application rate with higher deposits at the 100 l/ha application as previously.

Table 3.5.2 Measured spray deposits, Φl/g leaf weight, at growth stages 32 and 39 in the spring wheat crop normalised to represent expected levels per 100 l/ha of applied spray at both volume rates.

TREATMENTS				SPRAY DEPOSIT, GS32			SPRAY DEPOSIT GS39		
				Section of Tiller			Section of Tiller		
Crop Density	Spray Quality	Volume l/ha	Nozzle Angle	Top	Middle	Base	Top	Middle	Base
High	Fine	100	Angled	16.9	13.7	4.1	20.7	2.9	1.0
			Straight	13.2	11.4	3.5	18.2	4.6	1.5
		200	Angled	12.1	6.1	2.0	22.1	3.0	0.9
			Straight	17.5	5.5	2.5	15.1	3.5	1.0
	Medium	100	Angled	27.6	10.1	6.7	25.8	5.9	1.5
			Straight	27.4	14.0	6.4	22.4	4.1	1.3
		200	Angled	15.5	7.3	3.9	17.9	5.1	1.9
			Straight	13.2	5.8	2.3	16.7	4.4	1.3
Low	Fine	100	Angled	24.9	6.9	4.8	24.6	9.6	1.7
			Straight	20.2	10.6	4.0	23.9	4.0	1.4
		200	Angled	12.6	4.3	2.6	21.0	5.3	1.8
			Straight	15.9	4.0	2.7	32.5	6.5	1.8
	Medium	100	Angled	29.6	7.8	4.7	20.7	6.1	1.9
			Straight	21.2	5.7	4.2	22.8	6.7	2.4
		200	Angled	17.7	4.7	3.5	18.5	4.5	1.3
			Straight	18.2	6.0	2.8	17.7	6.1	2.0
Standard Error of Mean					2.15			1.28	

3.6 Measured spray deposit distributions for the T2 fungicide applications made at sites in Suffolk, Cambridgeshire and at Silsoe in the second year of the project

Measured deposit levels in the treated crops at the Suffolk and Cambridgeshire site are summarised in Table 3.6.1 with the main treatment effects plotted in Figure 3.6.1.

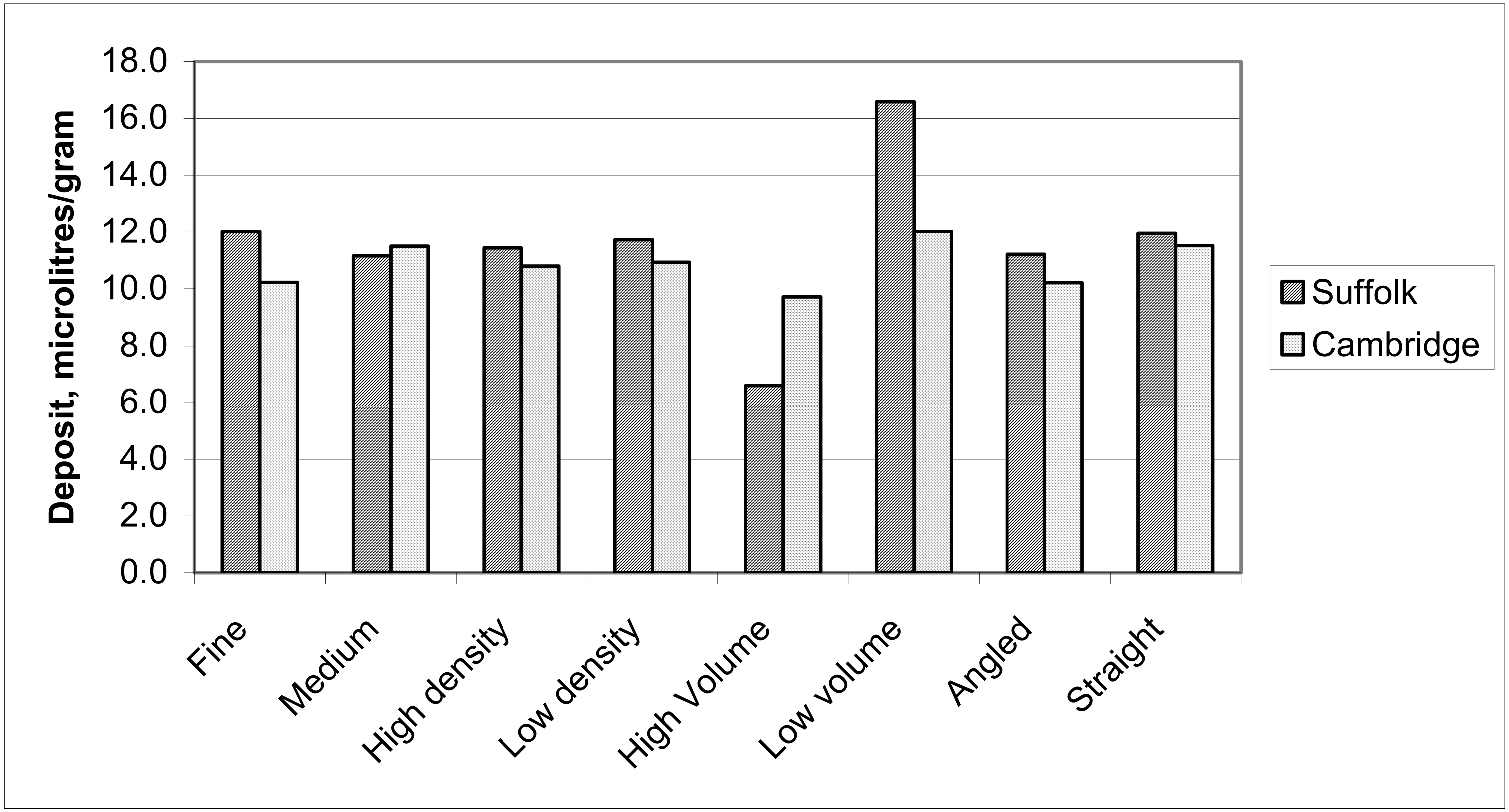

Figure 3.6.1 Mean deposits for the different application variables at the Cambridgeshire and Suffolk sites in year 2 of the work.

Table 3.6.1 Measured spray deposits, Φl/g leaf weight, at the Suffolk and Cambridgeshire field sites sprayed at growth stage 39; - data normalised to account for volume rate differences

TREATMENTS				Suffolk			Cambridge		
Crop	Spray	Volume	Nozzle	Section of Tiller			Section of Tiller		
Density	Quality	l/ha	Angle	Top	Middle	Base	Top	Middle	Base
High	Fine	100	Angled	27.7	22.5	4.9	12.7	5.5	2.1
			Straight	25.9	15.8	4.2	31.9	9.0	3.3
		200	Angled	10.8	7.1	0.9	17.7	8.5	3.8
			Straight	12.0	7.0	1.2	18.6	7.8	2.7
	Medium	100	Angled	18.8	13.2	3.3	20.7	10.0	2.4
			Straight	35.0	19.0	5.6	24.8	12.0	2.9
		200	Angled	10.4	8.4	1.2	24.6	8.6	2.3
			Straight	8.2	8.1	3.4	16.6	7.5	3.4
Low	Fine	100	Angled	20.0	22.6	5.4	19.7	8.4	3.2
			Straight	27.7	29.0	4.9	28.5	7.8	2.3
		200	Angled	8.6	8.2	2.8	14.0	6.2	1.6
			Straight	10.6	7.1	1.5	19.2	8.6	2.5
	Medium	100	Angled	22.4	24.3	6.2	27.7	9.0	3.8
			Straight	13.0	19.8	7.0	28.6	9.4	2.9
		200	Angled	8.0	9.2	2.5	20.8	8.6	3.4
			Straight	9.8	9.0	2.2	14.2	8.7	3.5

Deposits measured at the Silsoe site were below the level of reliable detection and the reason for this was identified as the use of stored batch of tracer dye that had degraded with time.

Results in Table 3.6.1 and Figure 3.6.1 give values that are in close agreement with those measured in the previous season – see Section 3.5 of this report. This gives an increased level of confidence in the results since the tracing techniques used were very different and the laboratory analysis was undertaken by a different team. The main differences in application variables was again due to volume rate (see main treatment effects plotted in Figure 3.6.1) with a large increase in mean total deposits at the lower volume rate particularly at the Suffolk site. Differences due to crop canopy structure were very small at both sites – again in agreement with the data obtained in the previous season.

4. ASSESSMENTS OF DISEASE CONTROL

Assessments of spray efficacy and disease control were made only in the second year of the project involving crops at sites in Suffolk, Cambridgeshire and at Silsoe Research Institute. These assessments related to the application of a T2 fungicide. In order to achieve some resolution between treatments, farmers were asked to use a relatively weak triazole spray at the first fungicide application and it was agreed that this would be an application of 0.5 l/ha of Tilt (propiconazole) applied with the conventional method on each farm. The dose rates of the Twist and Alto mixture used for the T2 application were also reduced from the full label recommendation to 1.0 and 0.16 l/ha respectively again with the objective of improving the resolution between application treatments.

Applications to plots were made using a 24 m boom sprayer as in the first year's experiments with the nozzle set up and calibration being made before treating the prescribed plots. The area between the plots was treated with the same products applied with a conventional application system. Disease assessments were made at crop anthesis and growth stage 75 although detail assessments on each plot were made at one growth stage only. Treatment and assessment dates are summarised in Table 4.1.

There was concern that the occurrence of disease and its spread within the crop canopy was likely to be a function of canopy density and that this could interact with any treatment effects in this experiment. Plots with no applied T2 fungicide were therefore included in both high and low crop canopy areas at each site.

T3 fungicide applications were made to each of the field sites following the conventional farm practice and were applied by the farmer.

Table 4.1 Summary of spray treatment and disease assessments at each site

Site	Treatment date	Date of detailed disease assessment
Suffolk	17th May 2000	22nd June 2000
Cambridgeshire	6th June 2000	17th July 2000
Silsoe Research Institute	14th June 2000	20th July 2000

Results from the disease assessments at each site are summarised in Tables 4.2 to 4.4. Levels of disease in all cases were low with no statistical differences between the application treatments. Disease levels in the untreated plots at the Suffolk and Cambridgeshire sites were also low and although there was evidence of a treatment effect on the lower leaves of the canopy there were no significant effects relating to disease control on leaf 1. At the Silsoe site (Table 4.4), again there were no differences between the different application treatments but there were higher disease levels in the untreated plots. Poor weed control at this site may have been a factor influencing the result obtained.

Plot yields were recorded by the farmer at the Cambridgeshire site using a yield mapping combine and the results are shown in Table 4.5. No significant differences in yield relate to the fungicide treatments and it is likely that other variable factors in the field have given the relatively small differences between yields from the plots. It is noticeable that the mean yield from the low volume rate application treatment at 9.30 tonnes/ha was greater than that for the 200 l/ha application (9.18 tonnes/ha) but the difference is not statistically significant.

Table 4.2 Assessments of disease levels in the plots at the Suffolk site – assessed on 22 June 2000

TREATMENTS				Leaf 1		Leaf 2			Leaf 3		
Crop Density	**Spray Quality**	**Volume l/ha**	**Nozzle Angle**	**Septoria tritici**	**Green leaf area**	**Septoria tritici**	**Brown rust**	**Green leaf area**	**Septoria tritici**	**Brown rust**	**Green leaf area**
High	Fine	100	Angled	1.00	92.5	8.5	0.01	81.5	20.0	0.01	55.0
			Straight	1.10	91.0	10.0	0.01	80.5	23.5	0.01	50.0
		200	Angled	0.80	93.5	7.0	0.01	82.5	17.5	0.01	53.5
			Straight	0.75	92.5	8.0	0.05	82.5	16.5	0.01	55.0
	Medium	100	Angled	0.65	94.0	8.0	0.10	81.5	21.0	0.05	52.5
			Straight	0.75	93.5	8.5	0.01	81.5	21.0	0.01	51.5
		200	Angled	0.65	95.5	6.8	0.00	82.5	17.5	0.00	56.0
			Straight	0.65	94.0	10.5	0.00	78.5	21.0	0.01	57.5
Low	Fine	100	Angled	0.55	96.0	5.5	0.01	83.5	12.5	0.20	62.5
			Straight	0.45	97.0	5.0	0.01	83.5	12.5	0.10	57.5
		200	Angled	0.75	94.5	7.5	0.01	80.0	18.0	0.01	52.5
			Straight	0.85	94.5	6.8	0.00	81.0	17.0	0.05	50.0
	Medium	100	Angled	0.75	94.5	7.0	0.15	80.5	17.0	0.05	50.0
			Straight	1.00	93.5	6.5	0.01	81.5	14.5	0.06	57.5
		200	Angled	0.50	96.0	7.0	0.01	80.0	13.5	0.05	53.5
			Straight	0.75	94.0	8.0	0.00	80.0	18.5	0.00	54.0
untreated, high density				0.90	93.0	10.0	0.10	80.0	22.0	0.20	47.0
untreated, low density				0.90	94.5	9.0	0.06	77.5	26.0	0.01	40.0

Table 4.3 Assessments of disease levels in the plots at the Cambridgeshire site – assessed on 17 July 2000

TREATMENTS				Leaf 1			Leaf 2			Leaf 3
Crop Density	**Spray Quality**	**Volume l/ha**	**Nozzle Angle**	**Septoria tritici**	**Mildew**	**Green leaf area**	**Septoria tritici**	**Mildew**	**Green leaf area**	**Green leaf area**
High	Fine	100	Angled	1.25	0.85	94.5	6.5	1.25	88.0	3.5
			Straight	0.6	0.01	94.5	10.0	0.20	85.5	2.0
		200	Angled	1.0	0.05	93.5	7.0	0.55	86.5	1.5
			Straight	0.5	0.05	95.0	5.3	0.05	90.5	14.5
	Medium	100	Angled	1.15	0.06	94.0	4.5	0.11	86.5	5.0
			Straight	0.5	0.10	95.0	5.7	0.10	88.5	4.5
		200	Angled	0.75	0.01	95.0	10.5	0.05	84.5	2.0
			Straight	0.5	0.06	95.0	9.0	0.06	87.0	6.5
Low	Fine	100	Angled	0.85	0.00	95.0	8.0	0.00	86.5	2.5
			Straight	0.65	0.15	94.5	6.5	0.25	86.0	7.0
		200	Angled	0.4	0.30	95.0	8.5	0.75	88.5	5.5
			Straight	0.35	0.05	95.5	8.5	0.40	85.5	5.5
	Medium	100	Angled	0.65	0.00	95.5	8.5	0.01	86.5	7.0
			Straight	0.55	0.06	95.5	9.0	0.30	87.5	5.5
		200	Angled	1.5	0.00	93.0	8.5	0.01	86.5	2.5
			Straight	1.0	0.30	95.0	2.9	0.40	92.0	3.0
untreated, high density				0.7	0.11	94.5	6.5	0.45	87.5	6.0
untreated, low density				0.45	0.50	95.0	8.0	0.76	87.5	2.5

Table 4.4 Assessments of disease levels in the plots at the Silsoe site – assessed on 20 July 2000

TREATMENTS				Leaf 1				Leaf 2				Leaf 3		
Crop Density	Spray Quality	Volume l/ha	Nozzle Angle	Septoria tritici	Brown rust	Mildew	Green leaf area	Septoria tritici	Brown rust	Mildew	Green leaf area	Septoria tritici	Mildew	Green leaf area
High	Fine	100	Angled	0.80	0.00	0.00	94.5	14.5	0.00	0.00	76.0	41.5	0.00	16.5
			Straight	0.60	0.00	0.00	92.5	13.5	0.00	0.10	79.5	34.0	0.10	22.5
		200	Angled	2.10	0.00	1.00	92.5	11.5	0.00	2.50	78.0	39.0	2.05	23.5
			Straight	0.50	0.00	0.00	95.0	19.0	0.00	0.10	76.5	38.0	0.00	12.5
	Medium	100	Angled	0.25	0.00	0.00	95.5	11.5	0.00	0.01	85.5	24.0	0.10	33.5
			Straight	0.20	0.01	0.00	95.5	8.25	0.05	0.25	80.5	31.5	0.50	25.0
		200	Angled	0.20	0.05	1.00	96.0	5.0	0.00	0.01	90.5	25.0	0.01	20.5
			Straight	0.25	0.00	0.00	96.0	2.0	0.00	0.01	90.0	20.5	0.05	51.0
Low	Fine	100	Angled	0.10	0.00	0.00	97.0	1.15	0.00	0.00	94.0	3.5	0.01	84.5
			Straight	0.20	0.10	0.00	95.5	0.55	0.05	0.15	93.0	6.0	0.30	83.0
		200	Angled	0.15	0.00	0.00	96.5	4.25	0.00	0.05	91.5	11.5	0.10	51.5
			Straight	0.15	0.00	0.00	96.5	0.4	0.00	0.00	95.5	1.0	0.00	90.0
	Medium	100	Angled	0.20	0.01	0.05	96.0	5.5	0.00	1.50	90.5	16.0	2.60	57.0
			Straight	0.15	0.00	0.05	95.5	6.0	0.00	2.00	88.0	17.0	2.50	47.5
		200	Angled	0.25	0.00	0.00	96.0	4.0	0.00	1.50	93.5	21.0	1.55	57.0
			Straight	0.20	0.00	0.00	96.0	5.25	0.00	1.50	90.5	10.5	0.75	50.0
untreated, high density				6.1	1.5	0.15	83.5	18.0	0.5	1.25	73.0	42.5	1.6	12.0
untreated, low density				1.75	2.5	1.15	93.5	11.0	3.0	2.00	79.5	19.5	3.0	20.5

Table 4.5 Crop yields at the Cambridgeshire site

TREATMENTS Crop Density	 Spray Quality	 Volume l/ha	 Nozzle Angle	Recorded yield, tonnes/ha
High	Fine	100	Angled	9.07
			Straight	9.74
		200	Angled	9.14
			Straight	9.34
	Medium	100	Angled	10.01
			Straight	9.12
		200	Angled	9.71
			Straight	9.19
Low	Fine	100	Angled	9.08
			Straight	9.09
		200	Angled	9.23
			Straight	8.80
	Medium	100	Angled	9.30
			Straight	9.02
		200	Angled	9.25
			Straight	8.80
unsprayed – high density				9.29
unsprayed – low density				9.32

5. DISCUSSION OF RESULTS

5.1 General discussion

The lack of significant differences in deposit distribution between the areas of high and low crop canopy structure may relate to the field conditions used for the work. Although there were differences in canopy structure in all of the fields used for the study, the indication is that these were not sufficiently large to influence the spray deposition patterns obtained. However, the differences between the applications at the two growth stages used in the first year's work suggest that there is scope to improve the match between spray application parameters and crop canopy structure even if this is not on spatially variable basis within a field as a first step. Such an approach requires an effective method of sensing crop canopy structure and it may be that existing approaches, while effective at early growth stages, give inadequate resolution in a well-established crop canopy.

The approach based on a single measurement of crop canopy structure at an early growth stage was explored as one that could be practically implemented with existing sensing systems and little disruption to existing farming practices. However, there is then the scope for the spatial variability in crop canopy structure to change substantially from the time when the sensing measurements are made to when the spray application treatments applied particularly at the later stages of growth. Making measurements of crop canopy structure immediately prior to application may improve the potential to match fungicide applications to canopy structure but this would then involve:

- sensor measurements of the crop canopy either shortly or immediately prior to an application – if a mapping approach is to be adopted then a separate operation in the field would be required;

- the use of a sensor system that is able to resolve differences in crop canopy structure when working with relatively well established crops having a leaf area index of more than 3.0.

The large difference in total deposit levels measured between applications at 100 and 200 l/ha in both years of the project may relate to the nozzle conditions selected particularly the use of a pressure of 1.0 bar. There was some evidence from the microscope slides in each plot that the 200 l/ha treatment was under-applied or had a higher than expected non-uniformity across the plot, and this may have related to the spray formation with this nozzle at a relatively low operating pressure.

The effects of spray application volume rate and the effect of angling nozzles has implications beyond the application of fungicides to all plant protection products. The increase in deposit levels when operating at low volume application rates and with angled nozzles could enable improved spraying performance to be achieved particularly when combined with the improved timeliness effects that can be associated with operation at reduced volume rates (Rutherford and Miller, 1993). The results from the first year's experiments suggested a greater sensitivity to spray application variables in terms of target deposit at the earlier stage of growth. The study was primarily concerned with evaluating the potential for improving fungicide applications and therefore experiments in the second year used a T2 fungicide application as the test condition. Results gave no resolution between the application treatments evaluated probably due to:-

(i) the relatively low disease pressure relating to the T2 application: this is likely to have components relating to seasonal effects, site selection and the effect of the T1 application – although attempts were made to increase the sensitivity to application variables by using reduced dose rates at the first and second fungicide applications, the overall resolution was still very low with only small differences between sprayed and unsprayed plots;

(ii) differences in spray deposit level being small and not significant at the later growth stages;

(iii) the influence of other factors on disease levels and grain yield some of which may have had a spatially variable component in the field area that was not fully taken out by the randomised distribution of plots in each of the high and low crop canopy density areas.

The scale of the reported work was limited with trials for efficacy only conducted in a single season. There was some constraint on the selection of fungicide treatments to be used. The trials occupied relatively large areas of fields (typically 10 + ha) and it was not feasible to sacrifice a large component of crop yield or quality particularly when operating on commercial farms.

5.2 Implications for Levy-payers

Results from this study suggest that there is a greater potential benefit from matching the way that sprays are delivered to a given cereal crop canopy rather than seeking to respond to spatial variability in the first instance. This is particularly likely to be the case at the early stages of growth and therefore be relevant to autumn herbicides and the first fungicide application. Before this finding can be fully exploited by cereal growers there is a need to conduct a series of field trials to confirm that reduced dose rates and applied volumes of fungicide used at T1 will give adequate levels of control as suggested from the approach and results obtained from this study, see also 5.3 below. Much of the current sensor development aimed at monitoring the cereal crop canopy and particularly that associated with the development of precision farming approaches has aimed at quantifying differences in canopy characteristics in different parts of a field (e.g. the "Hydro Precise N-sensor" – Wollring *et al*., 1998). While this approach will be needed when fully automating the application of inputs such as fungicide and nitrogen fertiliser, the results obtained from this study indicate that there may be the potential to reduce the use of leaf surface acting chemicals by using a simplified descriptor of the crop canopy condition. Such descriptors may then, for example, be determined by visual inspection to give a single value for the whole of a field at a given time or growth stage.

Results from this study also indicate that better targeting of inputs applied directly to the crop are likely to be achieved by:

- using volume application rates of nearer 100 l/ha rather than 200 l/ha - not only does this give higher target retention of the input as demonstrated in this study but also increases work rates due to reduced filling times and therefore increases the opportunities for improved timeliness;

- using angled sprays particularly to increase total retention at early stages of growth - up to growth stage 32 in wheat.

The potential to further reduce volume rates is being explored in a LINK project that started late in 2001 with HGCA as a partner.

5.3 Opportunities for further research

Future research aimed at exploring the potential for improving agrochemical use with a mode of action based on leaf area therefore needs to examine methods of sensing crop canopy characteristics, to relate such measurements to conventional descriptions of the canopy such as growth stage and then to relate the canopy to application parameters particularly volume application rate. An initial step, as indicated above, would be to use crops at different stages of development prior to examining variations at a given growth stage and the potential for spatially variable treatments. Further research, building on the results from the study reported here, is needed to:

(a) verify that adequate levels of disease control are obtained when T1 fungicides are applied in accordance with rules based on the extent of crop canopy development;

(b) examine methods of sensing crop canopy condition that can be used to aid decisions relating to inputs: it is recognised that the measure of vegetative index used in this study is influenced by both leaf colour and crop structure and work as part of an HGCA Fellowship project is now investigating methods of using multiple low cost sensors mounted on a boom to automatically collect information potentially over a wider range of growing conditions; and

(c) to link spray application variables to the characteristics of the target crop so that control systems such as those that have been developed for spatially variable applications (Miller and Paice, 1998) can be used more widely to improve pesticide use.

This study used a relatively small number of field sites and was conducted over a limited time period with assessments of disease control being made in one season only. There is a need to extend the approach so as to:

(i) assess the likely range of in-field variability of crop canopy characteristics at different stages of growth and then apply the approaches taken in the work reported here to conditions where there is high within field variability of crop canopy conditions;

(ii) include assessments of disease control based on the application of fungicide matched to crop canopy density over at least two further growing seasons

6. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:-

(i) there are differences in crop canopy density in cereal crops that can be measured with boom mounted radiometers to give maps of a vegetative index that can be used as an aid to crop management;

(ii) application to cereal crops at growth stage 39 gave deposit levels and distributions that were relatively insensitive to application variables although the use of low volume rates (100 l/ha) did give higher deposits than application rates of 200 l/ha: no differences in the level of disease control were established between plots in the high and low crop canopy density areas of the fields or associated with the different application treatments;

(iii) results from experiments in the first year of the project showed large differences in deposit levels between the two crop growth stages examined with higher deposits at the early growth stage as expected. The sensitivity to the application variables, particularly volume application rate, was also greater at the earlier stage of growth.

It is therefore recommended that the results be used to match spray application to crop canopy characteristics on a whole field scale initially rather than aiming for spatial variability within a field. Further work is then needed:-

(a) to examine the relation between spray application variables and deposits on both cereals and weeds at early stages of growth representing autumn and early spring applications since the work in this report suggests that the main advantages will be gained at these timings;

(b) to verify that radiometry is appropriate for characterising crop canopies at these early growth stages;

(c) to conduct a series of field experiments to quantify the potential for improved pesticide use by matching delivery more closely to crop canopy conditions.

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