HGCA

PROJECT REPORT No. 81

EVALUATION OF SPRAYER SYSTEMS FOR APPLYING AGRO-CHEMICALS TO CEREAL CROPS

I. HGCA-FUNDED WORK IN ENGLAND

II. HGCA-FUNDED WORK IN SCOTLAND

OCTOBER 1993

PRICE £15.00

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PART I: HGCA-FUNDED WORK IN ENGLAND

by

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Final report of a collaborative project involving ADAS, Silsoe Research Institute and IACR-Long Ashton Research Station. The work commenced in May 1987 and lasted for five years. A grant of £275,719 was provided by the Home-Grown Cereals Authority (Project No. 0012/5/87).

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EVALUATION OF SPRAYER SYSTEMS FOR APPLYING AGRO-CHEMICALS TO CEREAL CROPS

PART II: HGCA-FUNDED WORK IN SCOTLAND

by

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Final report of a project at SAC-Edinburgh. The work commenced in July 1987 and lasted for five years. It was funded by a grant of £61,808 from the Home-Grown Cereals Authority (Project No. 0018/3/87).

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PART II: HGCA - FUNDED WORK IN SCOTLAND

Abstract

In the first three years of the project, the performance of the Crop Tilter at 200 l/ha, a twin-fluid nozzle (Airtec) system at two pressure settings, a swirl nozzle (Country Workshops Superjet 100) and a flat fan nozzle all operating at 100 l/ha were compared with a reference flat fan sprayer operating at 200 l/ha. Laboratory measurements were made of droplet size and velocity distributions for each of the systems. Field studies examined spray deposit distributions, biological response and crop yield in randomised plot experiments. Spray droplets from the twin-fluid nozzle greater than some 120 um were found to contain air inclusions such that the spray quality from this nozzle could not be classified using established techniques. The spray from the swirl nozzle had a smaller percentage of volume in droplets less than 100 um in diameter compared with the flat fan nozzle operating at the same volume rate but vertical droplet velocities from this nozzle were substantially lower.

Spray drift from all of the application systems was less than 3.5% of sprayer output when measured 8 m downwards of a single pass of the sprayer and in wind speeds of up to 25 km/h measured at a height of 2 m. Drift from the flat fan and drift from the cone nozzles operating at 100 l/ha were approximately equal but were double that from the reference flat fan system operating at 200 l/ha. The twin-fluid nozzle at 70-100 l/ha gave drift volumes equal to or less than the reference 200 l/ha system depending upon pressure settings. The Crop Tilter also gave substantial drift reductions when compared with the reference system, mainly due to the reduced boom height with this system.

Results from the herbicide trials showed no significant differences between application methods in terms of weed control and crop yield, both at full and reduced dose rates.

Fungicide treatments of propiconazole or prochloraz plus fenpropidin or fenpropimorph were applied through each system at full and half dose rate at, or shortly after, full flag leaf emergence. Disease was assessed at the milky ripe growth stage and yield measurements taken. The standard 200 l/ha medium quality spray proved a reliable method of disease control but control was often equally good when sprays were applied through twin fluid nozzles, swirl nozzles or hydraulic nozzles at 100 1/ha, though it was sometimes impaired, particularly when fungicide doses were reduced.

The final two years of the project examined the performance of two air assisted "sleeve boom" sprayers. These were compared with the same conventional hydraulic nozzle system. Air flow characteristics both above and within the crop canopy were measured and differences found that were likely to modify deposition patterns within the crop canopy. In field trials to study the efficacy of herbicides and fungicides, the air- assisted and standard hydraulic nozzle systems were found to be equally effective and grain yields were not statistically different. Spray drift was significantly reduced with air-assisted sleeve-boom sprayers compared with

fine hydraulic nozzles at 100 l/ha such that drift volumes were less than with the conventional 200 l/ha system. The velocity and direction of air-assistance was found to be a significant factor influencing spray behaviour.

The spray deposit measurements in the field trials indicated that there was some scope for manipulating deposit distribution patterns in the crop by adjusting the physical characteristics of the sprays and the conditions at delivery to the spray target. However, the differences between applications systems when averaged over a number of sites and growing seasons were not statistically significant. Differences in the physical characteristics and delivery of the spray from the application systems did give significant differences in the drift measured in both field and laboratory conditions. Measured spray deposits, however, were more variable reflecting the influence of crop structure and environmental conditions in the region of the crop canopy at the time of spray delivery. Where increases in deposit or changes in deposit distribution were achieved, differences between application systems were relatively small and did not result in statistically significant improvements in biological response or crop yield. Such changes could, however, improve the robustness of a chemical application.

The application systems studied (except the Crop Tilter) achieved the deposit levels and distribution patterns at a volume rate of 100 l/ha that were comparable with the standard flat fan hydraulic nozzle operating at 200 l/ha. Results from a computer model showed that this reduction in volume rate would improve the work rate of the sprayer by between 20 and 30% and would increase the opportunity for making a timely application. Improvements in timeliness may then provide scope for dose rate reductions providing that the level and distribution of spray deposits on the target surface is maintained at the lower volume rate. Further work is required to quantify the effects of timeliness and to determine the factors influencing crop canopy/spray interactions. Results from the work reported here also show the importance of drift control when using low volume rate application methods.

The need to control spray drift and minimise environmental and bystander contamination is now a part of the requirements of the Code of Practice for the use of agricultural and horticultural pesticides. The air- assisted, twin-fluid and Crop Tilter systems which gave good drift control in this study could give further improvements in timeliness if used in higher wind speed conditions than would be acceptable for comparable conventional spraying systems. This would require recognition within the Code of Practice that there is an acceptable level of drift and that the maximum allowable wind speed for safe sprayer operation is a function of the detailed design of the spraying system.

Introduction

Developments in pesticide application equipment during the last ten years have attracted farmers with claims for increased efficiency, lower application rates, reduced doses and costs. Innovative designs will continue to appear, and raise demands for detailed performance data. In evaluating application systems there is a need to understand how factors in the fundamental design of the nozzles or the sprayers influence the performance of the complete system. The advent of sophisticated instrument systems, the ability to measure not only droplet size but also velocity, presents a new opportunity to understand the spray production and deposition processes more fully and hence relate the physical characteristics of spray production and delivery to deposits within the crop canopy and the biological performance of sprays under field conditions.

In this series of experiments, commercially available application systems were selected to provide contrasting values for droplet size and velocity. A system based on a "standard" hydraulic flat fan nozzle was included as a reference. The experiments provide comparative data on the physical characteristics of the sprays, their efficacy, and their safety for bystanders and the environment.

The field performance of an agricultural pesticide will depend on a number of factors other than those related to the method of application, including:

- the mode of action of the chemical formulation;
- the stage of development of both the crop and pest;
- the weather conditions at the time of application and in the period following the application;
- presence of pesticide resistance in target population.

Changes in spray deposition pattern arising from a particular method of application may not therefore produce consistent changes in biological performance but influence the safety margin with which an acceptable field performance is obtained.

The study described in this report particularly examined the scope for manipulating the magnitude and distribution of spray deposits in cereal crop canopies with existing commercial sprayer designs. The work aimed at relating measured droplet trajectories, size and velocity distribution produced by different sprayer designs to the spray deposit distribution in the crop canopy and the risk of off-target contamination by drift. The effects of the different deposit distributions achieved on the action of both herbicides and fungicides was assessed in replicated field trials. A high resolution of sprayer performance was aimed at by monitoring spray deposit distribution and the biological performance of the applied pesticide separately.

It was recognised that features of commercial sprayer design influence performance parameters other than those related to the spray distribution in the crop canopy. In particular, factors such as boom size, forward speed and spray volume rate influence the overall work rate which in turn have important implications for improving the opportunity for making a timely application and reducing dose rates. This was not assessed directly in the project work since all spray treatments were applied to field plots on the same day. However, some consideration of the effects of work rate and timeliness has been included in the discussion of the results of the project work.

Materials and Methods

The application systems

The spray application systems studied in the first three years (Table 1) of the project were selected to provide contrasting values for droplet size and velocity. The reference system used a hydraulic nozzle producing a medium quality spray and delivering 200 l/ha. The Ciba Geigy "Crop Tilter" system (No. 6) used a similar nozzle inclined rearward at 20° to the vertical. System No. 2 used a 110° flat fan hydraulic nozzle which produced a fine quality spray at 100 l/ha. The other systems compared used the Cleanacres Airtec twin fluid nozzle at two settings and the Delavan WRW Superjet swirl nozzle.

The Airtec twin fluid nozzle was operated at two settings of air and liquid pressures, chosen in line with the manufacturer's advice at that time to produce both medium and fine spray qualities. Subsequent measurement of droplet sizes showed that these sprays had physical characteristics that were very different from conventional flat fan nozzles and gave spray qualities that could not be classified by the system developed by the British Crop Protection Council (BCPC) (Doble et al., 1985).

Table 1. Application systems studied in 1987-1989

Treatment no.	Application system	BCPC spray quality	Application rate (l/ha)
1	Hydraulic 110° fan nozzle	Medium	200
2	Hydraulic 110° fan nozzle	Fine	100
3	WRW "Superjet"+	Medium	100
4	"Airtec"* twin fluid	"Nominally fine"	100
5	"Airtec"* twin fluid	"Nominally medium"	100
6	"Crop Tilter"†	Medium	200

* Supplied by Cleanacres Machinery Ltd, Hazleton, Northleach, Cheltenham, Glos GL54 4LZ.

\+ Supplied by Country Workshop Ltd, Unit 1, Swannybrook Developments, Swannybrook Farm, Kingston Bagpuize, Nr Abington, Oxon OX13 5NE.

† Supplied by Ciba-Geigy Agrochemicals, Whittlesford, Cambridge CB2 4QT.

All the application systems were mounted on a Frazier Agribuggy. The hydraulic and air circuits were arranged such that each spray treatment could be selected independently to spray the 5 m plot on one or other side of the 12 m boom (Figure 1) (Miller, 1988). All systems used a nozzle spacing of 0.5 m and the Airtec and hydraulic nozzles were arranged to spray vertically downwards. The nozzles used with the Crop Tilter were manufactured so that, when mounted vertically, the spray fan was directed backwards at 20° to the vertical. In the case of the WRW Superjet, measurements were made with the nozzle directed 45° rearwards. Some additional measurements were made with this nozzle spraying 15° rearwards, following a modified recommendation from the suppliers.

For the second phase of the contract in years four and five, two commercial air-assisted sleeve boom sprayers with 12 m booms were compared with the same reference hydraulic fan nozzles. Each machine was used with two levels of air assistance (Table 2) and, for one machine design, the effects of angling the air and spray backwards and forwards were also assessed.

Spray characterisation

Droplet size and velocity distributions were measured using a Particle Measuring Systems size analyser with a laser-based probe (Lake and Dix, 1985; Miller, 1988). This system measures the size and velocities of individual particles interrupting the sampling beam. Nozzles were set up in the sizing chamber to operate at the same flow rates as those measured on the spraying vehicle. Airtec droplets captured in a petri dish of silicone oil were photographed through a projecting microscope. Some measurement of spray droplet size and velocity were also made with a phase Doppler spray analyser.

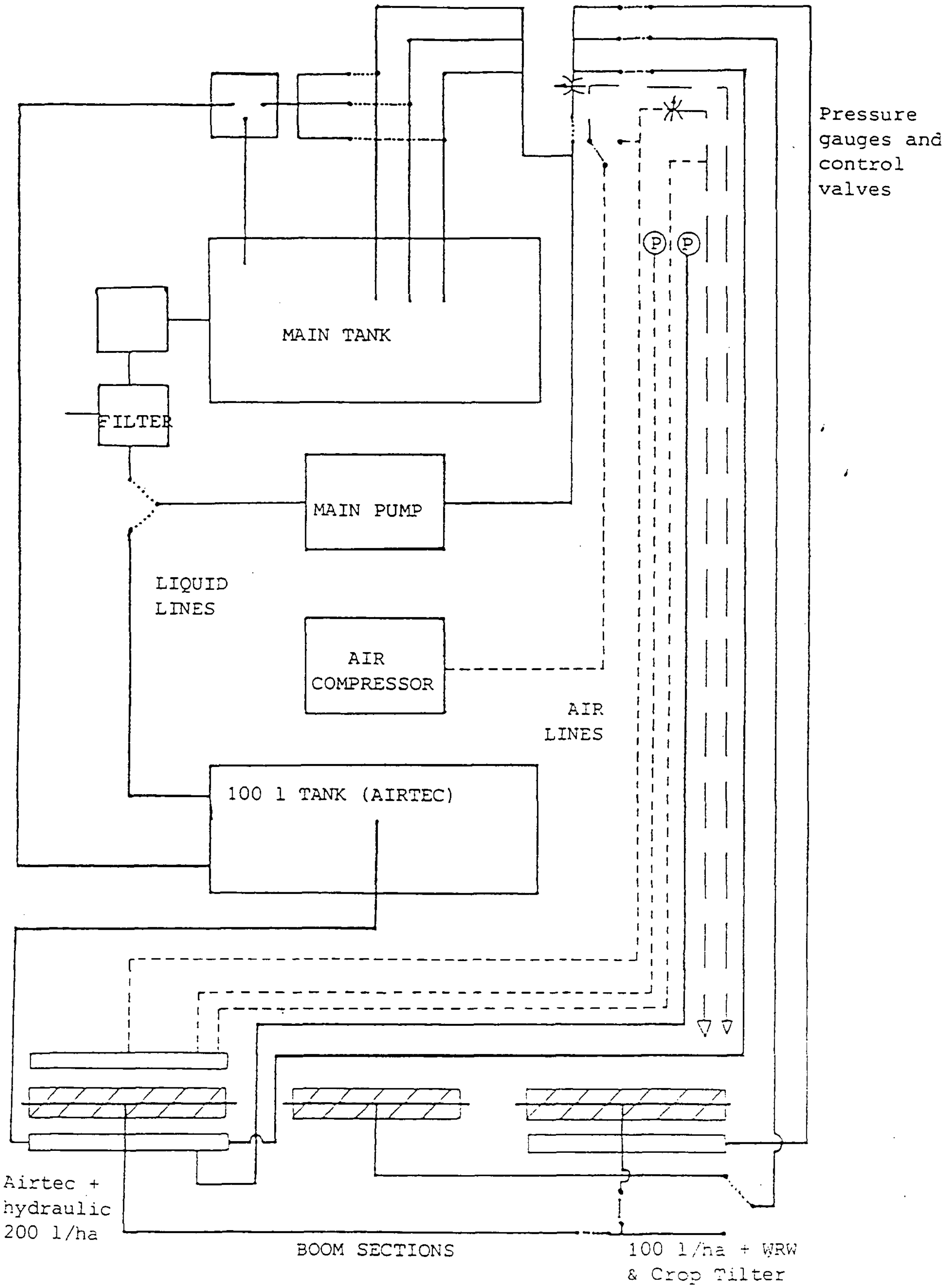
Spray drift measurements - field

Off-target contamination and drift were measured using techniques developed over a number of years by the staff at ADAS (now CSL) Application Hazards Unit, Harpenden (Gilbert, 1988). For the spray drift and bystander contamination aspects of the work, the sprayers traversed a track aligned nominally at right angles to the prevailing wind (Miller and Tuck, 1991). The machines were operated at 8 km/h with tracer dyes enabling spray collected on sampling surfaces to be extracted and quantified by spectrophotometric techniques. Spray deposits on the ground were measured under the spray boom, and up to 8 m downwind. Thereafter, airborne droplets were collected on 2 mm diameter polythene lines supported to a height of 10 m on carbon fibre masts situated 8, 20 and 50 m downwind. To study the effect on bystanders, volunteers fitted with protective clothing and respirators quantified the amount of drift which would have been inhaled. For each trial, up to ten traverses of the track were made.

Table 2. Sprayer settings and treatment codes for the air assisted spraying trials in 1990-91

Treatment Code	1	2	7	8	9	10	11	12
Sprayer	Hardi Standard	Hardi Standard	Hardi Twin	Hardi Twin	Hardi Twin	Hardi Twin	Degania	Degania
Nozzles used	FF 4110-20	FF 4110-12	FF 4110-12	FF 4110-12	FF 4110-12	FF 4110-12	Albuz cone yellow	Albuz cone yellow
Spacing	50	50	50	50	50	50	25	25
Pressure (bar)	3.4	3.5	3.5	3.5	3.5	3.5	1.5	1.5
Flowrate (l/min)	1.69 *1.16*	0.79 *0.8*	0.79 *0.8*	0.79 *0.8*	0.79 *0.8*	0.79 *0.8*	0.41 *0.42*	0.41 *0.42*
Spray speed (km/h)	8.57 *9.0*	8.57 *9.0*	8.57 *9.0*	8.57 *9.0*	8.57 *9.0*	8.57 *9.0*	9..47 *9.73*	9..47 *9.73*
Spray volume (l/ha)	233.6 *213.33*	110.6 *103.67*	110.6 *103.67*	110.6 *103.67*	110.6 *103.67*	110.6 *103.67*	103.9 *103.67*	103.9 *103.67*
Boom height (cm)	45	45	45	45	45	45	50	50
Air assistance	None	None	Low	High	High	High	Low	High
position	-	-	Vertical	30° backwards	Vertical	60° forwards	Vertical	Vertical
Air speed (m/s at outlet)	-	-	8.1 +/- 1.3	21 +/- 3.6	21 +/- 3.6	21 +/- 3.6	21.2 +/- 1.4	31.3 +/- 2.8

Fig 1 Hydraulic layout for spraying vehicle including air lines



Weather conditions at the time of spraying were recorded at 10 second intervals from the following sensors mounted on a 10 m mast: anemometers (cup type) at 10.0, 6.1, 3.3, 1.4 and 0.6 m; temperature difference sensors between 2.1 and 6.1 m, 2.1 and 3.3 m, and 2.1 and 1.1 m wind vane at 7.0 m; wet and dry bulb psychrometer at 4.5 m. The analysis of the weather conditions was synchronised directly with the drift collection.

Measurements with the twin-fluid, swirl and fine hydraulic flat fan nozzles were made when operating over a grass stubble nominally 100 mm tall and with a boom height of 600 mm. On each occasion, two nozzle systems were compared. The reference nozzles sprayed from half of the boom with one coloured dye while the test nozzle sprayed a contrasting dye from the other side of the boom.

Comparative drift measurements with the Crop Tilter system and the reference nozzle set-up could not be made simultaneously by spraying two different tracer dyes because of the need to operate in a standing cereal crop with the boom at a lower height with the Crop Tilter system. Experiments were therefore conducted in a wheat crop canopy approximately 900 mm tall, by first completing six double passes along the spray track with one system spraying from a 5 m boom on one side of the sprayer, and then resetting the boom height and completing another six double passes with the other system on the other boom section with a different tracer dye (Miller and Tuck, 1989). The need for flushing the sprayer between treatments was eliminated by arranging a pressurised canister system to feed the 5 m boom sections fitted with the reference nozzles. This minimised the time required and hence the possibility of changes in the meteorological conditions during changeover.

Drift measurements with the air-assisted machines also could not be made with direct comparisons with the reference system spraying simultaneously because of the imbalance to both air flows and boom stability that would have resulted from air- assistance on one side of the boom only. Measurements with these machines were, therefore, made when spraying from the full 12 m width of the boom, and alternate passes down the sampling track were made with the air-assisted machines and the reference nozzles operated on a conventional sprayer behind an equivalent tractor and spraying contrasting coloured dyes.

Additional measurements of drift were made at Silsoe Research Institute during November and December 1991 with the Hardi machine to assess the effects of angling both air and spray in the backward and forward directions (Miller and Tuck, 1991). Visual observations made while spraying the field plots, particularly the herbicide trial at Bridgets Research Centre where there was a strong cross-wind, had indicated that angling the air and spray forward had substantially increased drift. This was thought to be because the airstream was behind the spray, so that when angled at 55° forward, the airstream tended to lift the spray above the target and so give increased drift with this setting.

The experiment was conducted over a grass surface approximately 100 mm tall with the boom set 700 mm above the ground. Drift was measured 8 m down wind of the end of the boom only using methods and sampling techniques as described above but with drift deposits on each line quantified by spectrophotometric techniques in the Central Laboratory at Silsoe Research Institute.

Spray drift measurements - wind tunnel

Additional experiments on the relative quantities of spray drift were also carried out under the controlled conditions of the wind tunnel at the Institute of Arable Crops Research (IACR), Long Ashton (Herrington and Hislop, 1989). The work was done with the tunnel filled with a tray grown winter wheat crop at GS 45 which was approximately 900 mm tall. The application systems used were as in field trials (Table 1) but with the Delavan WRW Superjet set at two alternative angles (15° and 45°).

Nozzles were positioned 450 mm above the crop. Drift was collected 7 m downwind on horizontal lines of Bri-nylon 2 ply knitting yarn (Hayfield Textiles Ltd). This was found to be the most convenient and effective collecting surface. These lines were stretched between elastic supports fixed to the tunnel walls at 50, 150, 250, 350 and 450 mm below the nozzle height, the lowest being at crop height.

Wind speeds were measured with a hot wire anemometer (PSI Ltd) at a standard reference point at nozzle height 3.5 m downwind of the nozzles. All work reported here was conducted at 2, 3 and 4 m/s. Temperature and percentage relative humidity were recorded at the start of each set of wind speeds.

The spray solution for all drift work in the wind tunnel was 0.025% sodium fluorescein and 0.1% Agral 90 in tap water. The spray boom was static 2 m from the tunnel's air inlet and perpendicular to the direction of air flow. Three nozzles of each of the systems examined in the field, spaced at 500mm and were activated for 30 seconds. The wind was maintained for a further 15 seconds after the end of spraying before the drift collecting lines were recovered.

After every spray run, each drift collecting line was separately placed in a bottle and extracted with 40 ml of 0.05M sodium hydroxide containing 0.5% Triton X 100 wetting agent. These samples were kept in the dark to prevent any photodegradation prior to measurement of fluorescein against known standards using a Perkin Elmer LS2 fluorimeter with excitation and emission wavelengths of 450 nm and 510 nm respectively. The results are presented as the weight of tracer collected per gramme of tracer sprayed to take account of the different volumes emitted from the various nozzles used. (Western et al, 1985).

Airflow measurements within the crop canopy

The air flow conditions below the booms of the two machines at the two air settings used for each machine were made in the 1990 spraying season using a three-dimensional sonic anemometer (Miller and Tuck, 1991). These measurements were to establish whether there were differences between the two machines in respect of the maximum air velocity at the flexible duct outlet and the rate of decrease in velocity with distance below the boom as more air was entrained into the jet.

A knowledge of air movements within the crop canopy should enable a better understanding of the possible changes in spray deposition from using air-assisted sprayers and studies of such air movements form part of the research programme at Silsoe Research Institute and Long Ashton Research Station. A triple-split film probe (Dantec Ltd) was used for measuring the airflows in two directions within a spring barley crop canopy (ie in a vertical plane and horizontally in the direction of travel) beneath both designs of sprayer. The sensor has the advantages of being robust and having stable calibration characteristics. The research work at Silsoe has been concerned with deriving suitable calibration techniques for this sensor particularly at the low air velocities that are likely to exist in the base of crop canopies (Miller and Tuck, 1991). A diagram of the sensing head is shown in Figure 2 with the field mounting and experimental arrangement shown in Figures 3 and 4. For the field investigation, the sensing probe was positioned at heights of 15, 100, 200, 300 and 400 mm above the ground in a crop canopy some 380 mm tall and under the centre of one side of the boom sprayer swath. The required instrumentation, control and logging equipment was installed in a portable instrumentation laboratory which was parked at the edge of the field with cables running in the base of the canopy from the sensing head to the monitoring equipment. Each air assisted sprayer was driven over the sampling area at a calibrated speed of 9.5 km/h and the output from the flow sensor was monitored for a period of 15 seconds at a rate of 30 Hz. Measurements were made for all of the settings used in the full-scale field trials (Table 2) with the same values for air velocity, spray direction, and boom height used as appropriate. All measurements with these air settings were made travelling in the same direction.

Figure 2 Triple-split film probe arrangement
(dimensions in mm)

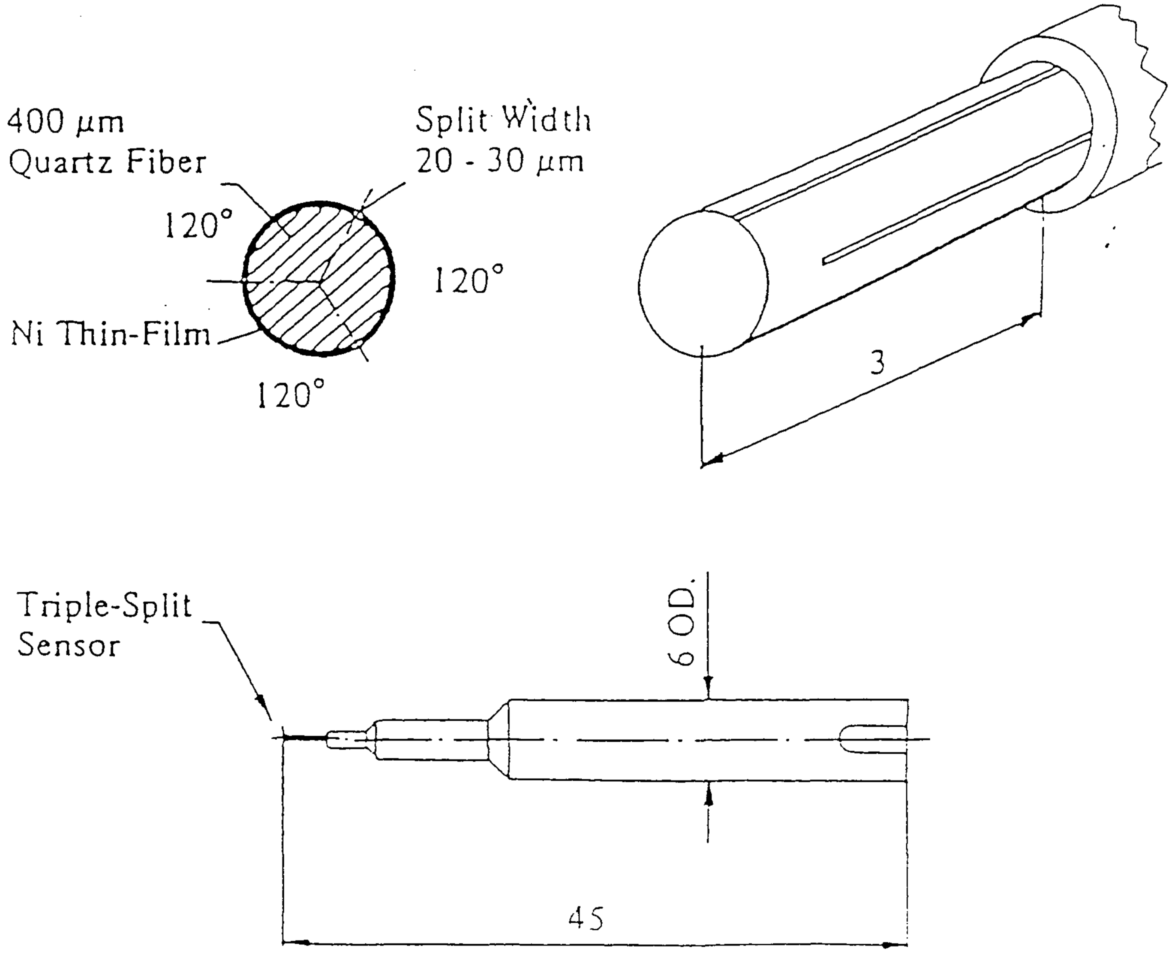


Figure 3 Mounting of triple-split film probe for measuring air flows within the crop canopy

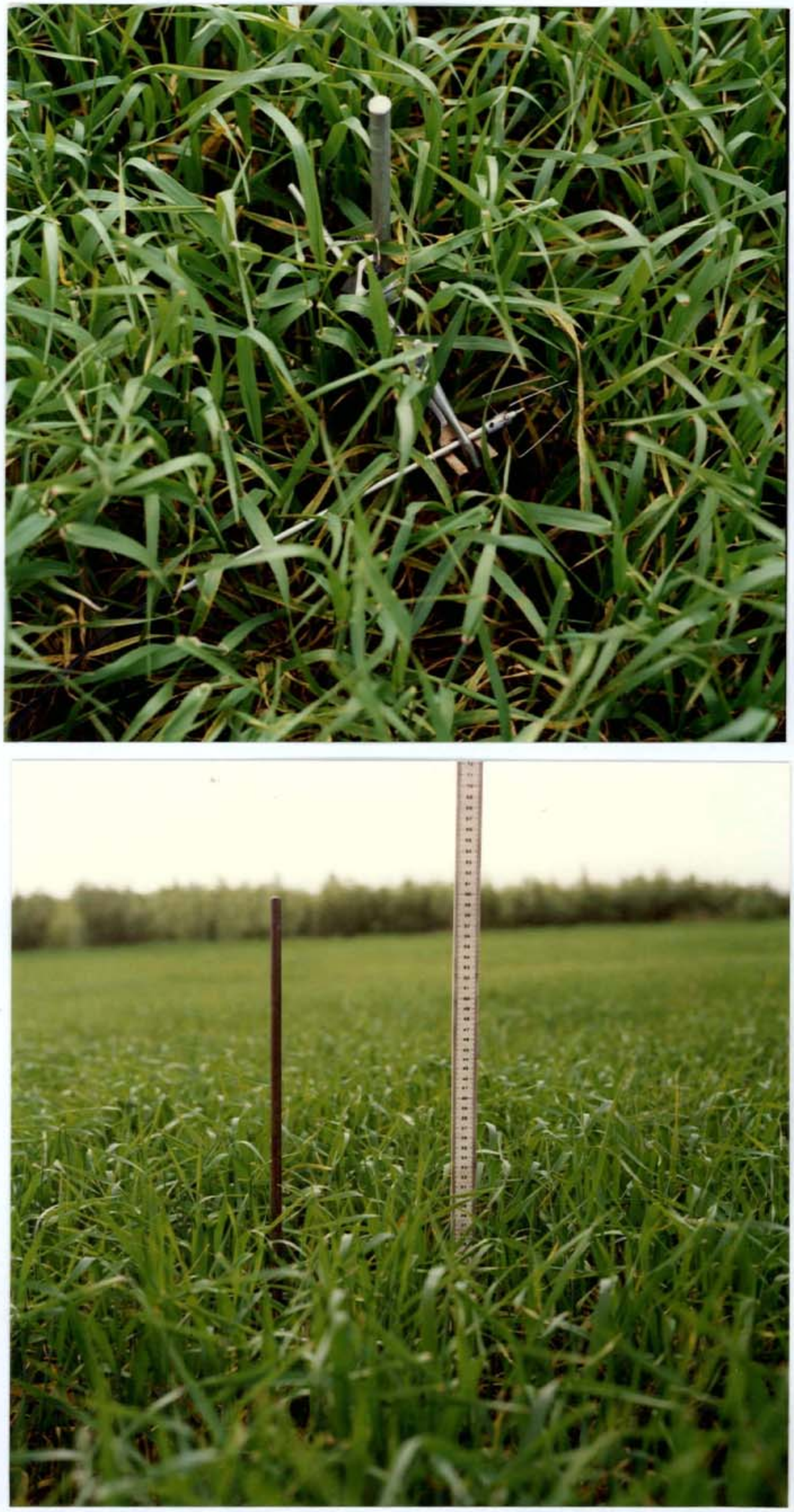


Figure 4 Field arrangement for measuring air flows within the canopy beneath each of the two spray designs

Field spray deposition - herbicides

Spray deposits on weeds were measured quantitatively by recovery of the fluorescent tracer Uvitex OB (Helios) added to the spray solution as an emulsifiable concentrate to give a dose of between 10 and 20g/ha (Herrington and Hislop, 1991). The concentration of tracer in all tank mixes was measured and the exact dose calculated from the nozzle flow rates and sprayer speed. All results are presented as the amount of tracer per unit dry weight or area of plant part sampled per gram of tracer applied per hectare to normalise for the different spray volumes used.

All field trial sites were laid out using a randomised block design with four replicate plots for each treatment as well as an unsprayed control. Each plot was 25 m x 5 m for the 1988 and 1989 trials and 25 m x 12 m for the 1990 and 1991 trials.

Weed samples for quantitative deposit analyses were collected from field plots once the spray deposit was dry, by taking weed plants from the centre of each plot. Details of experimental sites, sampled weed species and sample size are given in Table 3.

Deposits were extracted from weed surfaces in appropriate volumes of aromatic-free hexane containing Analar acetone, and quantified by fluorescence spectroscopy.

Qualitative analysis of spray deposits was conducted in 1988 (on upper and lower surfaces), and in 1989 (on upper surfaces only since deposits on lower surfaces were negligible by all methods of spraying). Samples for this assessment were collected and transported singly in 50 x 50 mm plastic pots to avoid cross-contamination. Photographs of the sprayed weed leaf surfaces illuminated by ultra-violet light were analysed using an Optomax V image analyser to give the percentage cover.

Field spray deposition - fungicides

Tracer dye techniques, using Uvitex OB, were also used to study spray deposits on cereal plants in the fungicide treatments quantitatively and qualitatively. Approximately 20 cereal plants were collected randomly from treated plots, taking care to avoid sampling at the edges of plots.

Cereal tillers for quantitative measurements were divided into seven plant parts and recovered deposits determined in terms of leaf area and plant weight. Qualitative assessments were made using a scoring system which described spray distribution in terms of quantity (dose) and quality (cover) of deposit on the ad- and ab-axial surfaces of the flag leaf and leaves 2 and 3.

Table 3. **Details of sites and sampling arrangements for the herbicide experiments**

Site	Spray date	Crop	Weed species sampled	Sample size (No. of samples & no. of weeds/sample)
Bridgets	11.4.88	W wheat	Field pansy (*Viola arvensis*)	6 x 5
Bampton Manor	11.5.88	S wheat	Field pansy (*Viola arvensis*)	6 x 5
Bridgets	18.4.89	W wheat	Field pansy (*Viola arvensis*)	6 x 5
Prescombe Farm Ebbescome Wake	17.5.89	S wheat	Common speedwell (*Veronica persica*)	6 x 5
Bridgets	9.4.91	W wheat	Red dead nettle (*Lamium purpureum*) Common speedwell (*Veronica persica*)	2 x 6
Headborne Worthy	16.5.91	S barley	Charlock (*Synapsis arvensis*)	3 x 8

Ground deposits were also measured at all fungicide sites using collecting surfaces (ie glass sides 75 x 25 mm or plastic discs 32 mm in diameter) placed between crop rows close to the quantitative sampling sites.

Field plot sizes for the fungicide experiments were 25 x 5 m in 1988 and 1989, and 25 x 12 m in 1990 and 1991, and were in a randomised block design including untreated controls.

Spray deposition - indoor track experiments

In a series of experiments in a spray chamber wind tunnel (Western et al, 1989), three nozzles from each of the application systems used in the field in 1987-1989 were mounted on a boom. Each system was evaluated for efficacy in initial deposition chemically and physically, and the biological effects of separate herbicide and fungicide applications determined. The crop used was winter wheat (cv. Avalon), grown in plastic trays 600 x 400 x 100 mm in four rows 100 mm apart.

For the herbicide trial, five pansy (*Viola arvensis*) weeds were transplanted between each row of wheat, giving 15 weeds per tray and sprayed at GS 31 of the host crop. Fungicides were applied at GS 39. Details of materials used and rates applied are given in Table 4.

Table 4. Materials used in herbicide and fungicide application - track sprayer experiments

Application	Product	Recommended product rate/ha	Active ingredient	Recommended dose (g ai/ha)				
				1	2	3	4	5
				Dose applied/ha				
Herbicide	Roundup (Monsanto)	2.5 l/ha	glyphosate	1200				
				x0.0625	x0.125	x0.25	x0.5	01.0
Herbicide+ plus tracer	Roundup Helios		uvitex OB +	For 100 l/ha applications, x1.0, 20 g/ha For 200 l/ha applications, x0.5, 20 g/ha				
Fungicide	Sportak	900 ml/ha	prochloraz +	405				
				x0.15	x0.31	x0.62	x1.23	
Fungicide* plus tracer	Sportak Helios		uvitex (powder)	For 200 & 100 l/ha applications, x1.23, 2 g/ha				

\+ Helios added as emulsifiable concentrate.

* Helios dissolved in Sportak at rate of 2 g/ha.

Inclusion of tracer in herbicide and fungicide applications facilitated quantitative and qualitative evaluation.

For each treatment spray run, four trays were used positioned end to end in line with the boom's centre nozzle. These were surrounded by guard trays to simulate a crop. Prior to spraying, each of the trays had been labelled according to their treatment, dose and plot replication.

The spraying of each pesticide was divided into two parts - for biological evaluation and for deposit evaluation.

For the biological evaluation, all sprayed trays were left to dry overnight before being transferred to an open ground standing area where they were then arranged in a randomised block design with four replicate plots for each treatment. The treated control trays then received natural weathering prior to the later biological evaluation for either herbicide or fungicide effect.

For deposit evaluation, applications were made using a spray liquid to which fluorescent tracer Helios (10 g/l ai) was added at the rate of 20 g/ha in the full dose herbicide spray liquid for the 100 l/ha applications, and at 10 g/ha in the half dose spray for the 200 l/ha applications. For the fungicide evaluation applications, Helios (powder) at the rate of 10 g/ha was dissolved in the Sportak formulation for the highest dose rate applications for both 100 and 200 l/ha applications.

Two of the four trays were used for quantitative analysis and two for qualitative assessments. To compare the different systems quantitatively, the actual tracer dose was calculated from samples of the tank mix and all deposits were converted back to a theoretical dose of 1 g Helios/ha, and are reported as ng/cm^2 for both herbicide and fungicide applications.

In the herbicide experiments, field pansy (*Viola arvensis*) was the target weed. Thirty weeds, 15 from each of two trays, were extracted separately - their areas were measured using the Optomax Image Analyser and the deposits calculated as ng/cm^2. For qualitative assessments, one upper and one lower leaf from each plant (30 plants) were removed. The ad-axial surface was photographed and percentage cover assessed as for field samples. Spray deposits at ground level were also measured using six pairs of glass slides (75 mm x 25 mm) in each treatment, placed near the quantitative samples.

Deposits were measured quantitatively by fluorescence spectroscopy. The concentration of the tracer in the tank was measured by sampling at the spray nozzle. These data were then used to calibrate a Perkin Elmer 2000 spectro fluorimeter. After extraction in a mixture of hexane and acetone, the fluorescence of each sample was measured.

For qualitative deposit analysis, leaves from pansy plants were selected at random and placed under ultra violet light. Both upper and lower leaves were photographed and the negative scanned using an Optomax V image analyser to give percentage cover. Samples from 20 random tillers from the fungicide trial were examined under ultraviolet light and scored on a scale 0-4. Upper and lower surfaces and the stems were scored separately.

In the fungicide experiments, 15 tillers from the two centre rows of the two selected trays were cut at soil level and divided into seven parts. Each of the parts sampled were extracted in a suitable volume of solvent and left in a coldroom overnight.

Fluorescence levels were read, and areas of stems, leaves and a representative sample of remainders were measured. The latter were then dried and weighed (as were the rest of the remainder sections), a correlation factor was calculated and equivalent areas calculated. Deposits are therefore reported as ng/cm^2.

Qualitative assessments were made by taking 15 tillers at random from the two centre rows from each of the two remaining trays (30 tillers); the flag, second and third leaves were scored as for field samples.

Biological efficacy - herbicides

Two herbicide trials were completed for each of the first three years of the study, with a further two trials in the final year using the sleeve boom sprayers (Freer, 1991). The same materials, a tank mix of Ally and Mecoprop were used throughout this series of eight experiments (Rutherford *et al*, 1989).

The trials, were of a randomised block design with treatments including an untreated control, replicated four times. They were conducted at ADAS High Mowthorpe, North Yorkshire; ADAS Bridgets, Hampshire, or on commercial farms in Hampshire and Wiltshire (Table 3 and 5) with crops of winter wheat, spring wheat or spring barley. At each site the various systems were used to apply a herbicide mixture (metsulfuron methyl + mecoprop or bromoxynil + ioxynil + mecoprop) before the first node was detectable (GS 31) in the spring. In 1987-1989, recommended herbicide rates and one third of the recommended rates were used. In 1991, the recommended rate and half the recommended rate was used with the air- assisted sprayers. Weed numbers were recorded prior to and approximately three weeks after application. A representative sample of above ground weed material was taken for a dry matter assessment.

The target weeds in this series of experiments were broad-leafed weeds and control was attempted in the spring in all cases. The weed species consisted of chickweed (*Stellaria media*), common field speedwells (*Veronica persica*), field pansy (*Viola arvensis*), cleavers (*Galium aparine*), Poppy (*Papaver rhoeas*), fumitory (*Fumaria officinalis*), red dead nettle (*Lamium purpureum*), and Venus' looking-glass (*Legousia speculum-veneris*). These weeds were at various stages of development, some having overwintered, and ranged from cotyledon stage to flowering plants at the time of spraying. The herbicides selected were chosen to give optimum control of the weed spectra present at that time.

Density of the crops varied from site to site. Generally, the spring crops were thinner and less advanced in their development than the winter wheats. Also, on the spring sites, the sizes and populations of weeds were smaller and less variable. Consequently the opportunity for control was greater in these spring grown crops. The winter wheat sites presented more difficult targets for the herbicide, as the crops were denser and generally more advanced in development. In addition, weed species were at later stages of development, although there again was a spectrum of sizes. Some of these weeds were not fully killed as they had passed the susceptible growth stage at the time of spraying. However, stunting and a reduction in their growth was observed and this was confirmed by the biomass assessment which is presented as the most illustrative overall assessment of efficacy. Much of the data presented in this report are from the reduced rate of herbicide where the ability of the machines to apply the contact-acting herbicides was tested most effectively.

Table 5 Herbicide Trial Sites and Weed Populations

Site	Year	Crop	Predominant weed	Mean plant density plants/m2
High Mowthorpe (old type)	1987	W wheat	Chickweed Poppy Cleaver	74 33 17
High Mowthorpe	1987	W wheat	Chickweed	
Bridgets	1988	W wheat	Field pansy Chickweed	180 12
Bampton Manor	1988	S wheat	Field pansy Chickweed	120 30
Bridgets	1989	W wheat	Field pansy Chickweed	152 198
Ebbesxombe Wake	1989	W wheat	Field pansy Common speedwell	65 50
Bridgets	1991	W wheat	Common speedwell Red dead nettle	11 10
Headbourne Worthy	1991	S barley	Charlock	104

Weed assessments were made by counting the number of each species of weed in a 0.1 m^2 quadrat at ten positions per plot. Weed dry weight was estimated by collecting the above ground weed matter in each quadrat and drying in an oven for 16 hours at 110°C.

Biological efficacy - fungicides

The first five spraying systems were studied in fungicide trials on winter wheat and winter barley in 1987, 1988 and 1989 (Lockley, 1990). The air-assisted sleeve boom sprayers were studied on winter wheat only in 1990 and 1991 (Lockley, 1991). The trials, which were of a randomised block design with treatments replicated four times, were sited on ADAS research centres (Bridgets and Rosemaund), or on commercial farms in Wiltshire and Dorset (Table 6).

At each site, the various systems were used to apply a single fungicide spray (Table 7), a mixture of propiconazole + fenpropidin (Radar + Patrol) at, or shortly after, full flag leaf emergence.

Table 6. Summary of sites for fungicide experiments

Site	Location	Year	Crop	Cultivar	Previous crop	Soil type
1	Bridgets	1987	W wheat	Brock	W wheat	Clay loam
2	Rosemaund	1987	W wheat	Avalon	Grass	Silty clay loam
3	Wool, Dorset	1987	W wheat	Avalon	Oilseed rape	Sand loam
4	Bridgets	1988	W wheat	Hornet	Peas	Silty clay loam
5	Rosemaund	1988	W wheat	Slejpner	W barley	Silt loam
6	Woodsford, Dorset	1988	W wheat	Mercia	Potatoes	Sandy clay loam
7	Bapton, Wiltshire	1988	W barley	Maris Otter	W wheat	Silty clay loam
8	Bridgets	1989	W wheat	Rendezvous	W wheat	Silty clay loam
9	Rosemaund	1989	W wheat	Hornet	Peas	Silty loam
10	Woodsford, Dorset	1989	W wheat	Slejpner	W wheat	Sandy clay loam
11	Fonthill Bishop, Wiltshire	1989	W barley	Pipkin	W wheat	Sandy clay loam
12	Bridgets	1990	W wheat	Hornet	W wheat	Silty loam
13	Rosemaund	1990	W wheat	Riband	Oilseed rape	Silty clay loam
14	Bridgets	1991	W wheat	Beaver	Grass	Silty loam
15	Salisbury, Wiltshire	1991	W wheat	Slejpner	W barley	Silty clay loam

Table 7. Fungicides, active ingredients and recommended dose rates

Fungicide	Active ingredient	Amount ai in product	Dose rate product/ha
Radar +	propiconazole	250 g/litre	0.5 litr
Patrol	+ fenpropidin	750 g/litre	0.75 litre

In 1987-1989, fungicide was used at both full and half dose. In 1990 and 1991, the systems were compared at half dose only, although a full dose spray with the conventional hydraulic nozzle system was maintained as a reference. Disease levels were recorded at GS 75, approximately six weeks after application, and all trials were taken to yield. Grain quality (specific weight and thousand grain weight) was determined on samples retained from each plot.

Table 8. Methods of application, spray quality, volume of application and fungicide dose rates used in 1987-1989

Method of application	BCPC spray quality	Application volume (litres/ha)	Fungicide dose rate
Untreated control			
Hydraulic 11004 nozzle	Medium	200	Full
Hydraulic 11004 nozzle	Medium	200	Half
Hydraulic 11002 nozzle	Fine	100	Full
Hydraulic 11002 nozzle	Fine	100	Half
Airtec twin fluid	Nominally med	100	Full
Airtec twin fluid	Nominally med	100	Half
Airtec twin fluid	Nominally fine	100	Full
Airtec twin fluid	Nominally fine	100	Half
Delavan WRW Superjet	Medium	100	Full
Delavan WRW Superjet	Medium	100	Half
Crop Tilter inclined 11004	Medium	200	Full
Crop Tilter inclined 11004	Medium	200	Half

A randomised block design incorporating 14 treatments (including two untreated controls) with four replicates was used in 1987-1989 (Table 8). Plot dimensions in the first three years of the project were 5m wide x 25m long, and for the work in 1990-1991 with air-assisted sprayers, were 12 m wide x 25 m long.

Disease levels were recorded at each site immediately prior to fungicide application and again, in all plots, at the milky ripe stage taking 10 randomly selected tillers per plot and assessing foliar and stem base diseases (as appropriate) and green leaf area. Leaf diseases were assessed as the percentage of leaf area affected using the MAFF Manual of Plant Growth Stages and Diseases Assessment Keys. In the analysis, leaf 1 refers to the flag leaf. Data were subjected to analysis of variance.

Results

Physical Spray Characteristics

Measured droplet size distributions, when compared with those of the British Crop Protection Council, reference nozzles, confirmed the spray quality classification for the systems used (Table 9), with the exception of the twin-fluid nozzle - see below. There was a difference in numerical data between the results for the PMS and PDA spray analysers, with the PMS giving less resolution in droplet size and the percentage of spray volume in droplets <100 µm. This is in agreement with the findings of other researchers (Hobson et al, 1990), and underlines the approach taken in the BCPC nozzle classification schemes.

Table 9. Summary of droplet sizes, velocities and spray classification

Spraying system	VMD (µm)	% vol < 100 µm	Diameter @ 90% vol	µm @ 10%	Mean vertical velocity	BCPC spray category	Pressure (kPa)	Flow rate (l/min)
Hydraulic nozzle F110/1.6/3.0	254 (246)	2.2 (5.2)	338 (491)	164 (125)	3.8 (11.4)	Medium	300	1.60
Hydraulic nozzle F110/1.6/3.0	240 (246)	2.2 (10.3)	323 (491)	163 (99)	3.1 (5.2)	Fine	300	0.80
Hydraulic nozzle Delavan WRW Superjet HC/0.76/2.75	269 (213)	0.6 (5.3)	364 (481)	184 (120)	1.2 (1.6)	Medium	275	0.76
Airtec 1.4/3.0	332 -	0.6 -	461 -	213 -	2.2 -	Not classified	300L* 140A*	0.53
Airtec 0.7/2.0	360 -	0.3 -	479 -	224 -	1.8 -	Not classified	200L 70A	0.53
Hardi 4110-12	- (190)	- (10.7)	- (447)	- (98)	- (8.2)	Fine	360	0.8
Degania Albuz Yellow	- (225)	- (6.3)	- (337)	- (118)	- (3.8)	Fine	150	0.4

* L = liquid   A = air

Bracket figures measured with PDA, others measured with PMS.

Measured vertical velocities were the arithmetic means for all droplets with the PMs but were weighted to account for spray volume in the case of the PDA results. Mean velocities from the cone nozzles as expected and particularly with the wide angle spray from the Superjet WRW nozzle.

Measurements of the droplet size and velocity distribution showed that the wide-angled cone nozzle (Delavan WRW sold as the Country Workshops Superjet 100) gave a lower percentage of the spray volume in drops < 100 μm when compared with either the fine or medium spray quality flat fan nozzles. However, the mean droplet velocity measured 350 mm below the nozzle orifice was only 37% of that from 110° flat fan nozzle operating at a comparable output flow rate.

Measurements also showed that the spray from the twin-fluid nozzle contained some apparently large droplets travelling relatively slowly when compared with the equivalent size of droplet from the conventional flat fan nozzles. Measurements of the velocities of droplets at two positions in the spray fan enabled an estimate of the "air inclusions" in individual droplets to be obtained and the results suggested that droplets above some 120 μm in diameter had some 30% of their volume occupied by air. This was subsequently confirmed within the project work by obtaining photographs of the spray droplets captured on an oil surface and photographed through a projecting microscope (Fig. 5) and by further studies undertaken by the nozzle manufacturer (Cleanacres Machinery Ltd). There was evidence that the quantity of air "included" in individual droplets tended to increase with droplet size and as the nozzle settings produced coarser sprays. However, it was not possible in the scope of this study to quantify these effects in detail.

This project showed that individual spray droplets produced by the twin-fluid nozzle contained "air inclusions" and were therefore physically different from droplets generated by conventional flat fan nozzles.

Measurements of the droplet size distribution produced by both air-assisted sprayers operating at 100 l/ha showed that both were producing fine quality sprays. Measurements of the interaction between the generated sprays and the air-assisting flows showed that, with both machines, the larger drops produced by the nozzles penetrated further into the air stream, such that when operating statically, there was a gradient of droplet size across the air/spray curtain. This effect was more pronounced when sampling below individual nozzles rather than between nozzles and is summarised in Fig. 6.

Measurements of the air velocity leaving the flexible duct via the slot on the Hardi "Twin" and the outlet holes on the Degania sprayer gave mean values of 21.0 and 31.3 m/s respectively when operated with the maximum air setting, and 8.1 and 21.2 m/s when operated at the low air setting used in the field trials. The uniformity of air velocity distribution along the boom was reasonably good, with coefficients of variation in the range 9.0 to 17.1% for both machines.

Measurements of air velocity made dynamically with a sonic anemometer at the level of the top of the crop showed that the peak air velocity as the machines passed over the sampling point had reduced to approximately 7.5 and 6.0 m/s for the Hardi and Degania sprayers respectively, when operating at the maximum air flow setting. The air flow from the Hardi sprayer was more directed as influenced by the nozzle exit slot design whereas there was evidence of an increased air entrainment from the Degania machine giving a broader air flow pattern.

Measurements within the crop with a small heated-film probe showed that both machines gave significant air movements at the maximum air flow setting, even when measurements were made in the base of a dense cereal canopy some 380 mm tall. A typical plot of air movement in both the vertical and horizontal directions is shown in Fig. 7. There was some evidence to show that air movements within the crop resulting from the operation of the Degania were larger than for the Hardi machine.

Figure 5. Photographs of drops from the twin-fluid nozzle captured on a silicone oil surface and photographed through a projecting microscope

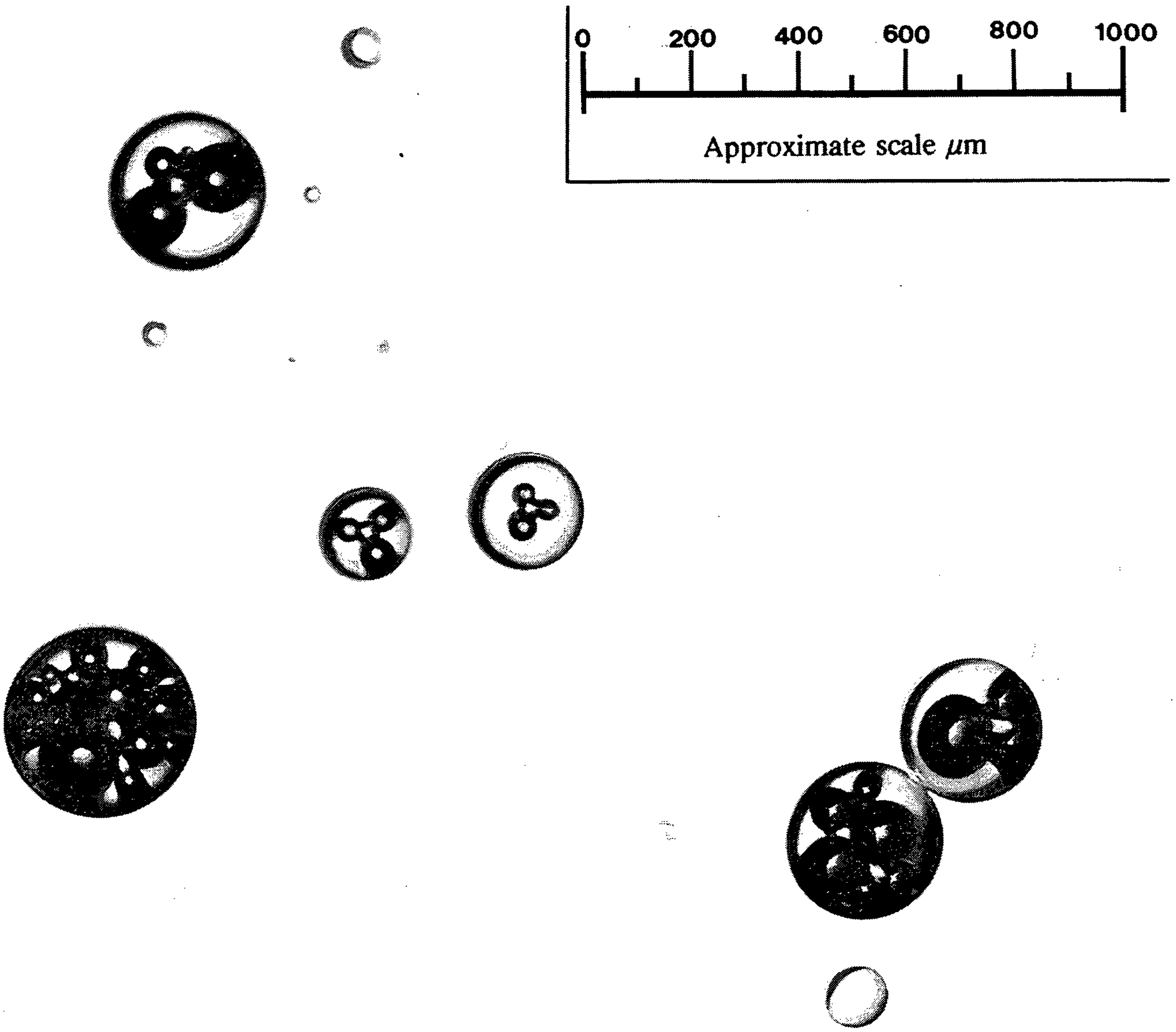
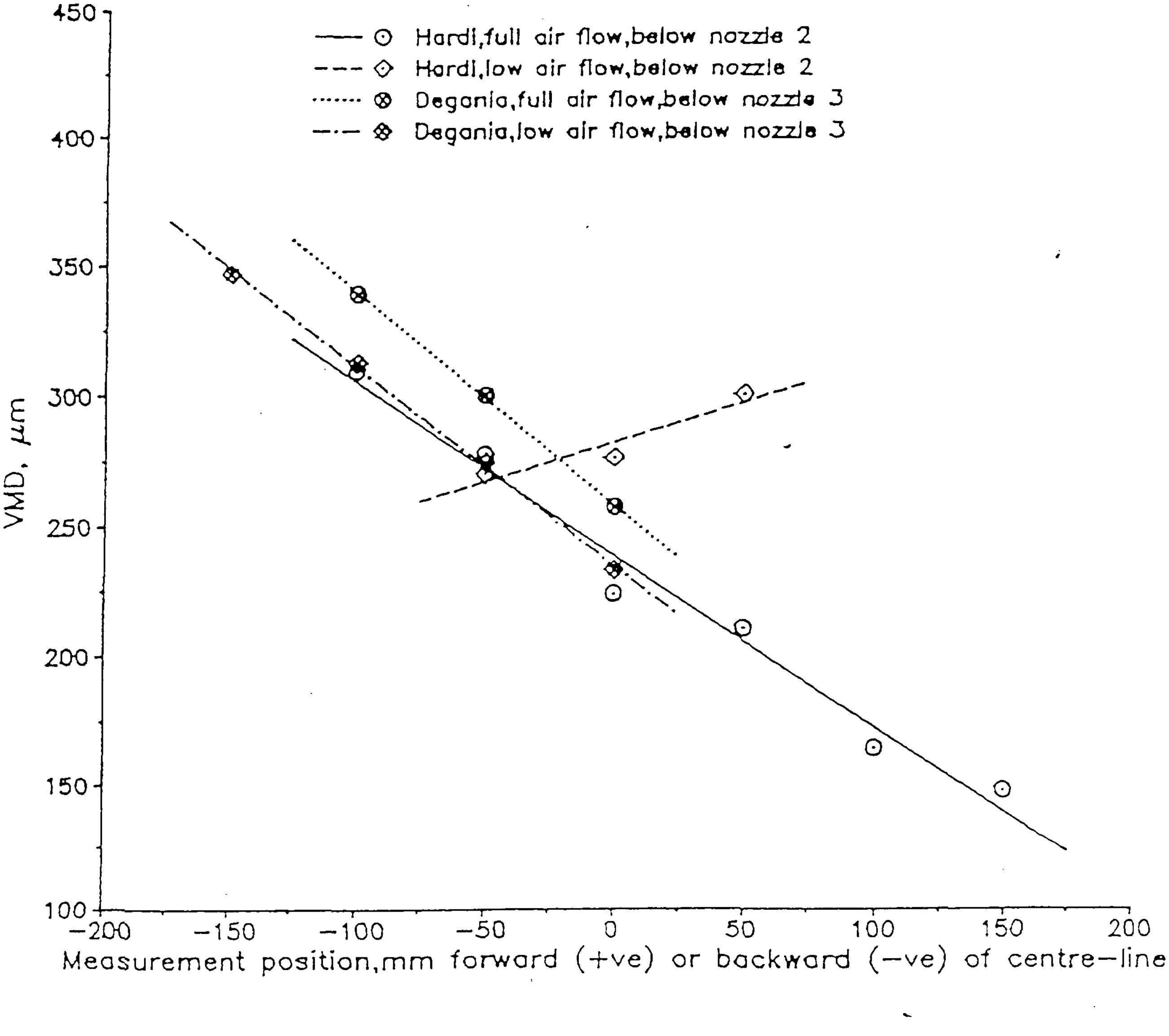


Figure 6. The variation of volume median diameter with position in the spray 500mm below the nozle on the air-assisted sprayers



Spray drift measurements - (1987-1989)

Measured drift volumes for the boom mounted nozzle systems operating over a grass stubble approximately 100 mm tall, in a range of wind speed conditions, have been plotted in Fig. 8.

Fig. 8 shows linear regression lines fitted to the combined data over the three measurement seasons. The percentage of nozzle output collected 8.0μm down wind of the end of the boom after a single pass of the sprayer has been correlated with the mean wind speed measured at a height of 2 m. The drift from the fine flat fan hydraulic nozzle applying 100 l/ha was approximately double that from the larger orifice flat fan nozzle applying a medium spray at 200 l/ha. The wide angled hollow cone nozzle gave very similar drift values to those for the fine flat fan nozzle despite having a larger mean droplet size and a lower percentage of spray volume in droplets less than 100 μm in diameter. This probably relates to the lower velocities of droplets from the wide angle cone nozzle. Drift from the two settings of the twin-fluid nozzle was very low for nozzles operating with flow rates in the range 0.50 to 0.65 l/min but with the finer of the settings giving the higher drift values as expected.

Detailed measurements of the atmospheric conditions during all of the drift measurements were made so as to define wind velocity and temperature profiles together with measures of atmospheric stability. The linear regression of drift against wind speed was not improved by incorporating any factors relating to atmospheric stability.

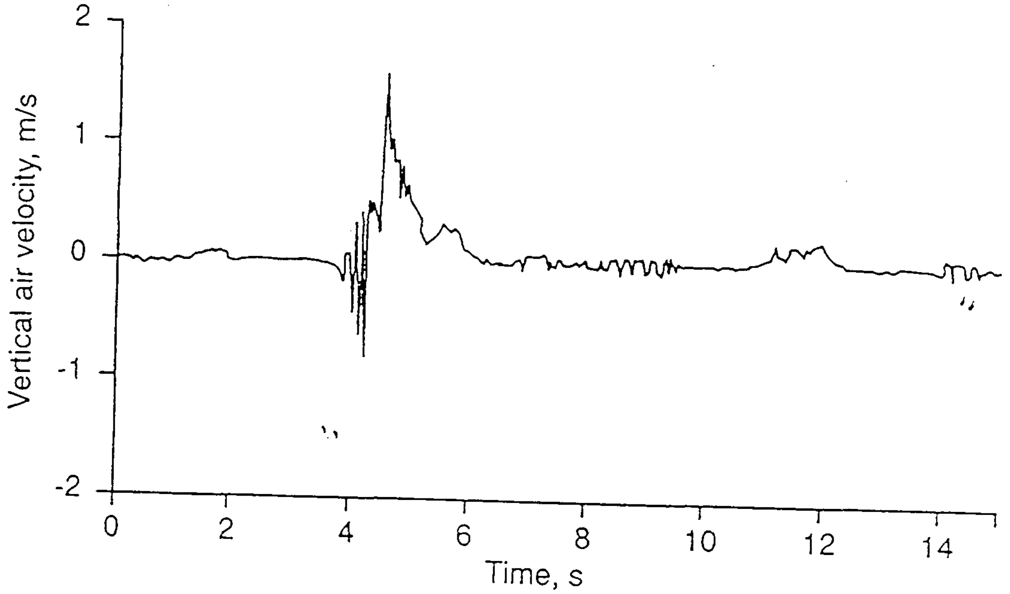
The comparison between the Crop Tilter and the standard nozzle made over two years in a wheat crop approximately 900 mm tall. Fig. 9 showed that this system could reduce drift by a factor of approximately two when compared with conventional nozzles used to treat the same crop. This reduction related mainly to the lower boom height used with the Crop Tilter system. The reaction of the deflected crop tended to keep some spray airborne when using the Crop Tilter but this effect was very small in relation to the drift reduction obtained by operating with a lower boom height. The drift from the conventional flat fan nozzle operating above the taller crop (Fig. 9) was greater than when above the simulated short crop (Fig. 8) and this is in agreement with results from computer simulation models (Hobson et al., 1990)

Spray drift measurements - field experiment 1990-1991

Measurements made over a barley crop approximately 1 m tall showed that the air-assisted machines operating at 100 l/ha have approximately 35% less drift than the conventional sprayers operating at 200 l/ha.

Measurements of drift with the Hardi machine showed that when the spray and air were angled forwards then the drift was increased although this is probably a function of the nozzle and air duct arrangement on the Hardi sprayer.

Figure 7. **Measured air velocities 250 mm below the top of a cereal crop canopy**



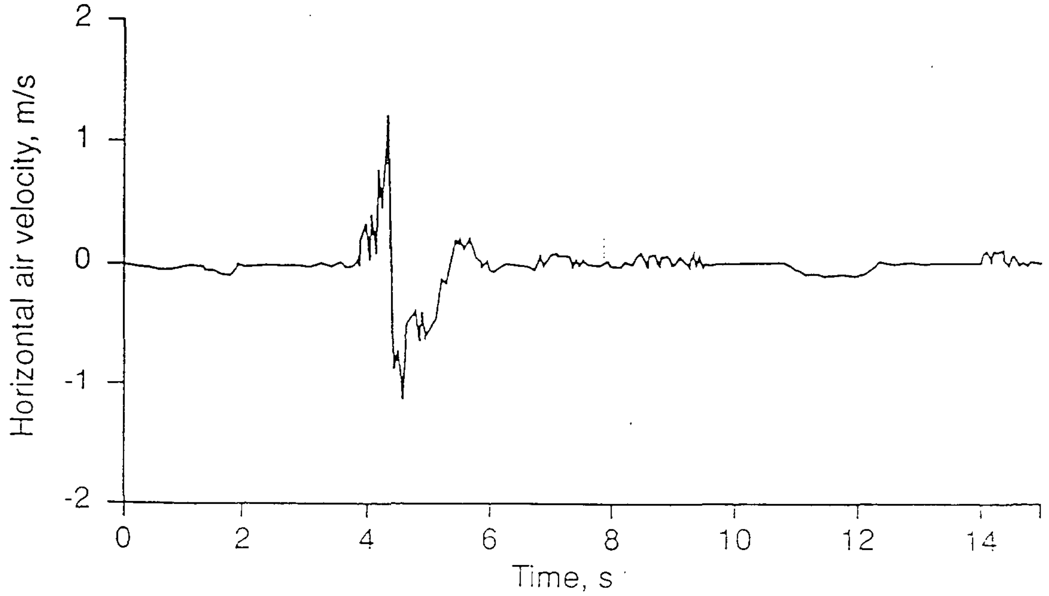


Figure 8. Volume of spray drift collected 8 m downwind of a single pass of the sprayer fitted with nozzle systems used in 1987-89

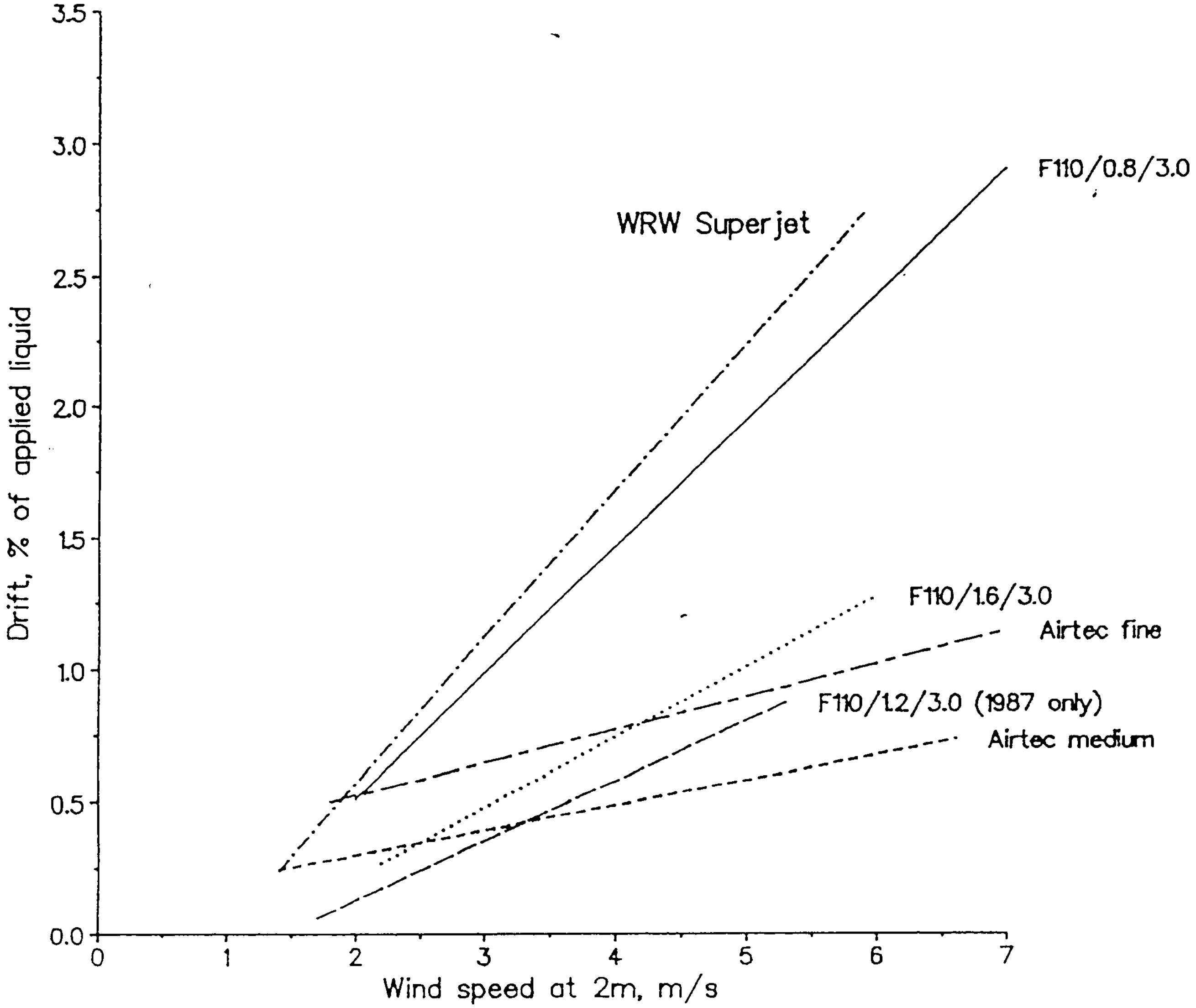
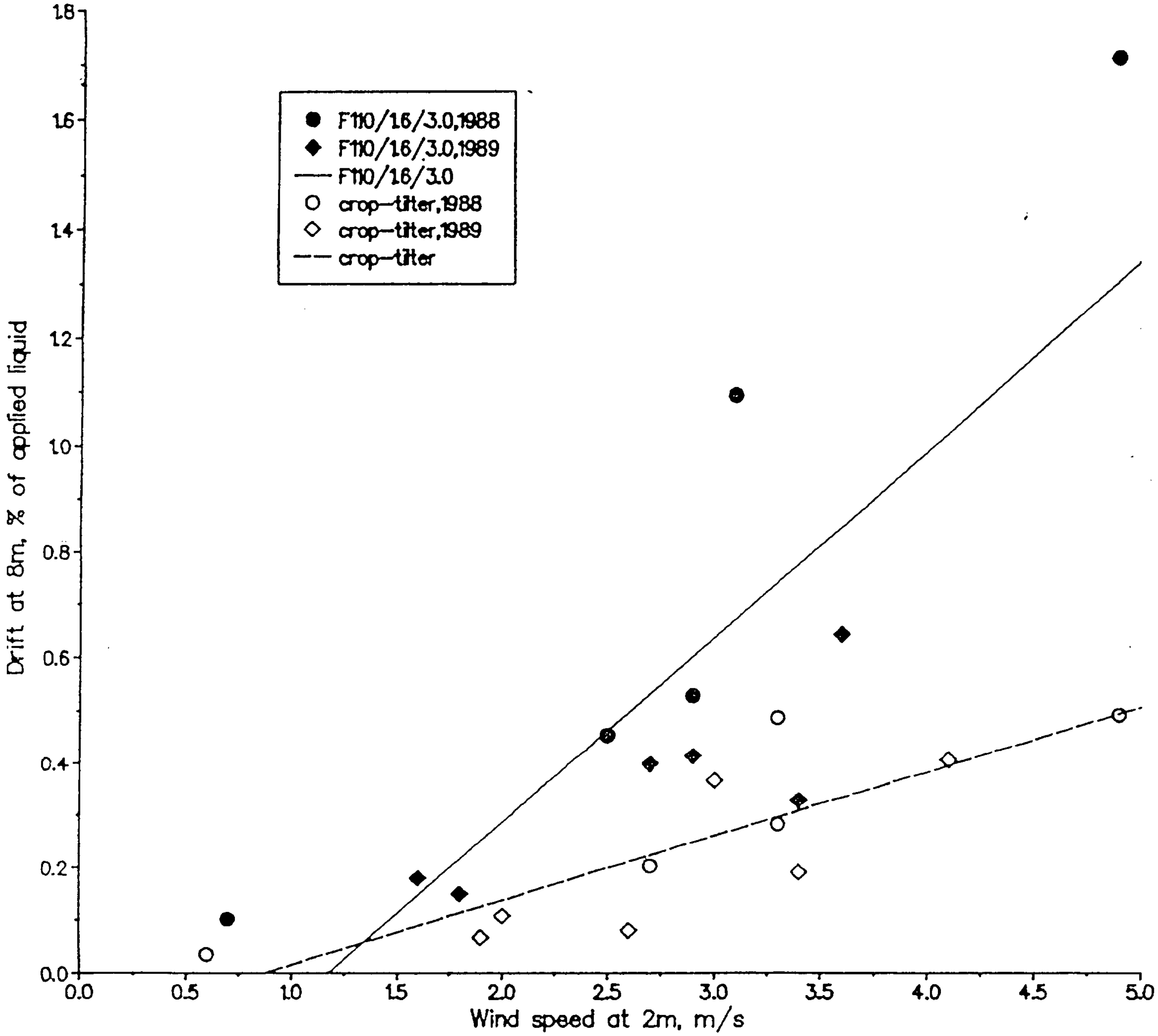


Figure 9. Volume of spray drift collected 8 m downwind of the standard nozzle system and the Crop Tilter operating in a wheat crop approximately 1 m tall



Spray drift measurements - indoor spray chamber

Only non air-assisted spray systems as used from 1987 to 1989 could be examined in the spray chamber experiments. All spray systems produced increasing drift with increasing wind speed (Figure 10). Treatment 2 (a fine nozzle) and treatment 3 (hollow cone Superjet angled at 45°) produced the most drift and were very similar despite the fact that the Superjet produces a much coarser spray. The same atomiser angled at 15° produced drift intermediate between that recorded for the 45° angling and treatment 1. The twin fluid nozzle operated as specified for treatments 4 and 5 produced less drift than treatment 1 (medium quality spray). The only anomaly in this study was the somewhat greater drift from treatment 4 (nominally defined as medium) compared with treatment 5 (nominally fine). The Crop Tilter (treatment 6) produced very little drift under the track spray conditions (Fig. 10) and this was probably because the unit was statically mounted in the wind tunnel.

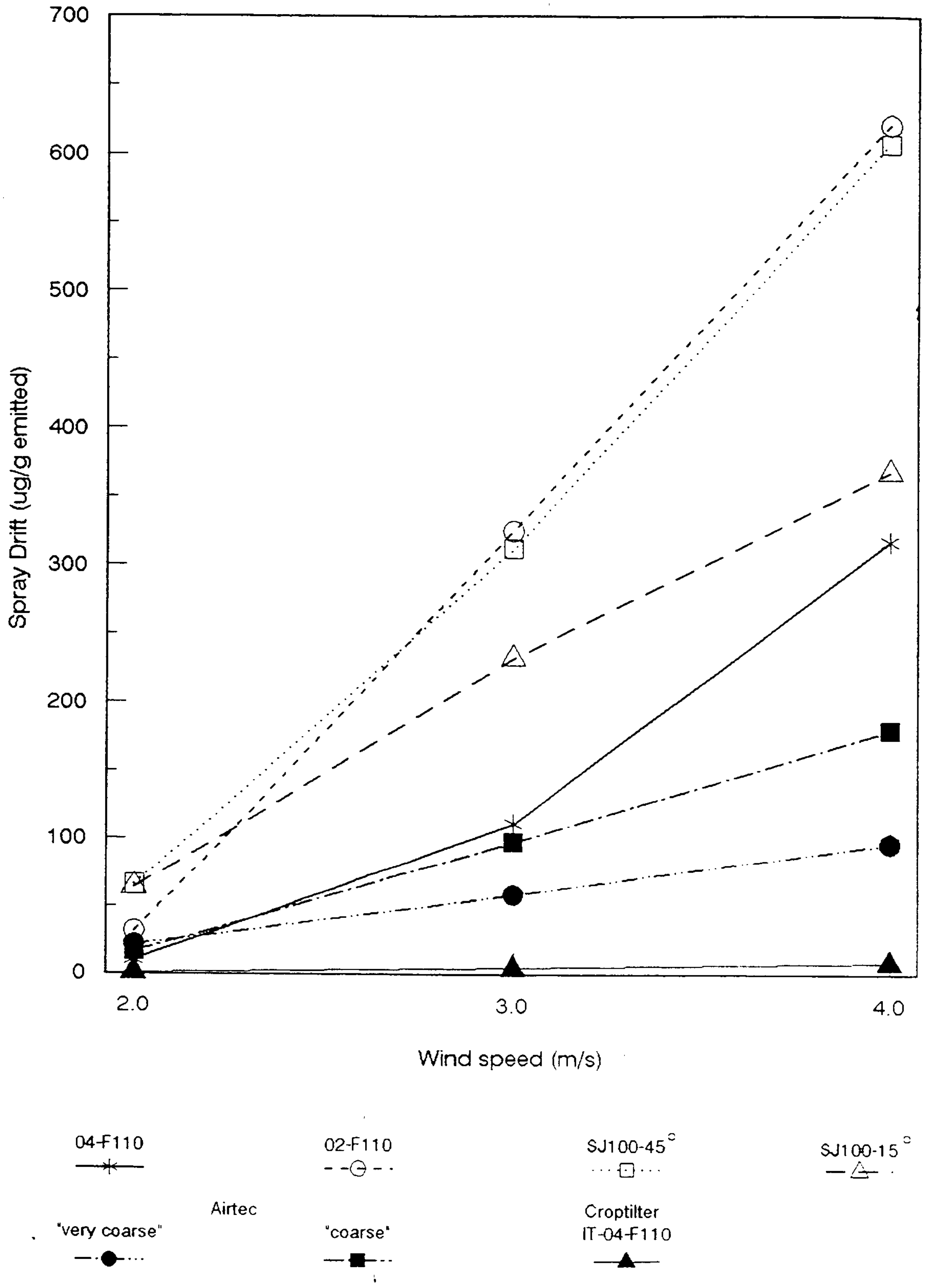
Spray deposition - qualitative assessments of deposits

A total of 11 spray occasions was assessed using either photography, image analysis or visual scoring systems of the targets under ultra violet irradiation. There was enormous variation recorded because of either weed or crop differences between sites. Herbicide deposits on weeds at ADAS Bridgets in 1988 showed that the greatest foliar coverage was with treatment 1 (hydraulic/medium/200 l/ha) with c 30% mean cover compared to all other methods which ranged from 5 to 15% However, at Prescombe in 1989, treatment 1 (hydraulic/medium/200 l/ha) gave amongst the lowest percentage cover with c 15%. Treatment 5 (Airtec nominally medium) gave amongst the highest percentage cover at this site (c 60%) and was very similar to treatment 3 (Superjet), but these observations were reversed in 1988.

For the fungicide applications, cover consistently declined with increasing depth in the canopy. There was no consistent evidence that cover was related directly to application volume e.g. comparing treatments 1 (hydraulic/medium/200 l/ha) and 2 (hydraulic/fine/100 l/ha). Treatment 6 (Crop Tilter) gave amongst the highest coverage figures at several sites but in the upper canopy this was accompanied by 'smearing'. Under controlled conditions in the spray chamber at Long Ashton, treatments 3 (Superjet), 4 (Airtec nominally fine) and 5 (Airtec nominally medium) gave the most variable cover and there were indications that this might also be true of some of the field sites.

Air-assisted applications in 1990 were not consistently different from the non-air assisted (treatments 1 and 2) but there was some indication the deposition from treatment 11 (Degania low air option) was equal to, or slightly greater than the full air options with either spray machines.

Figure 10. Spray drift variation with wind speed measured 7m downwind from selected nozzles (over crop spray nozzle height 45cm - except Crop Tilter)



Spray deposition - quantitative assessments of deposits

Herbicides

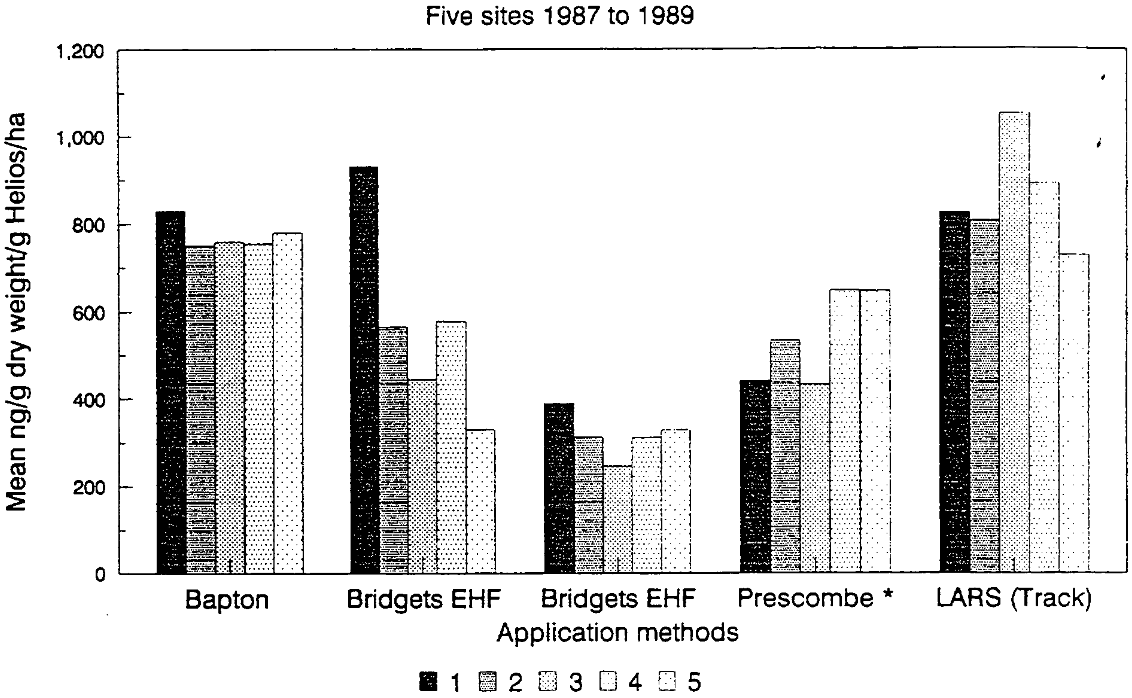
Mean deposits of tracer (ng/g dry weight/g tracer applied/ha) recovered from weeds in four field experiments conducted in 1987-1989 are illustrated in Fig. 11. These results indicate that, in general, deposits at individual sites using the different applicator method were similar and that few significant differences were detected for each spray occasion. Differences identified in the detailed analyses presented previously Rutherford et al, 1989) were not reproduced consistently from site to site or year to year.

Differences in the overall mean deposits summarised in Fig. 11 probably relate to the variable nature of the crop and weed noted throughout the trials. Bearing in mind the normal dose response curve of weeds to herbicides common in field trials, these results suggest that there is unlikely to be any clear biological difference between the spraying systems. There was no evidence that any of the spray application methods are likely to give consistently higher deposit levels than the 200 l/ha reference system.

Overall mean deposits ng/g dry weight/g Helios applied/ha and coefficients of variation for all spraying methods and sites during the 1988 and 1989 herbicide trials are presented in Table 10. There were no significant differences between mean deposits achieved with the different application systems.

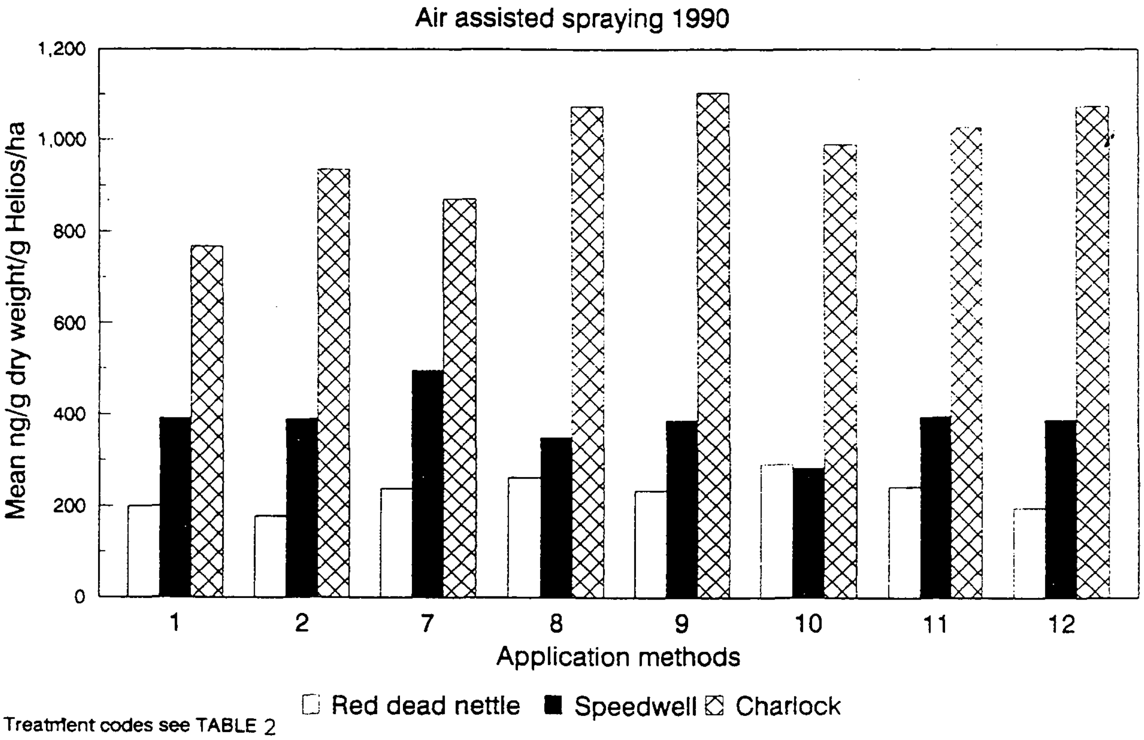
The above generalisations were supported by bio-assays done in conjunction with deposit measurements in the spray chamber at Long Ashton in 1989. In these experiments doses ranged from the normally recommended field rate to 1/16th of this dose and, although all application methods produced some dose response reactions, there were no significant differences between the application methods themselves.

Figure 11. Mean deposits ng/g dry weight/g Helios applied/ha on weeds Five sites 1987 to 1989



Treatment codes see TABLE 8
Tardget weed Pansy except PRESCOMBE * where it was Speedwell

Figure 12. **Mean deposits ng/g dry weight/g Helios applied/ha on weeds Air assisted spraying 1990**



Treatment codes see TABLE 2
Weed target BRIDGETS EHF Red dead nettle and Speedwell
Weed target HEADBOURNE Charlock

Details of the experiments at ADAS Bridgets and Headbourne Worthy with the air-assisted sprays in 1991 are included in Tables 3 and 5. Table 2 contains code numbers identifying the various spray parameters to read in conjunction with Fig 12.

At ADAS Bridgets, samples of red dead nettle weeds, representing an essentially vertical target, and common speedwell, representing a horizontal target, were taken, while at Headbourne Worthy, relatively large charlock weeds were the spray target. The relative magnitudes of spray deposition on red dead nettle and speedwell was similar for all methods of spraying except for treatment 10 (Hardi full air nozzles 60° forward) where the greatest deposit was recorded for red dead nettle (291 ng/g dry weight) probably at the expense of spray penetration since the smallest deposit for speedwell (284 ng/g dry weight) was recorded for this method of spraying. However, as in the experiments in previous years, many of the apparent differences were not statistically significant and no one spray treatment was superior to any other when deposits of all three weed species were compared jointly. It should be noted that in the windy conditions prevailing when sprays were applied at ADAS Bridgets, the full air volume assisted sprays (with vertical nozzles) produced deposit coefficients of variation approximately half those on all other treatments. These results are indicative that air-assistance can modify spray deposition.

Table 10 . Overall mean spray deposits on target weeds for the different treatments used in the 1988 and 1989 herbicide trials

Treatment Number	1	2	3	4	5
Nozzle	F110/1.6/3.0	F110/0.8/3.0	Superjet 100 WRW 1/4	Airtec Nominally medium	Airtec Nominally fine
ng/g wt/g Helios ap./ha	683	592	586	636	561
CV (%)	24	37	42	19	27

Fungicides

This section summarises fungicide measurements on cereal crops for the period 1987-1989 when non-air assisted spraying systems were compared, and for 1990 when air-assisted sprays were also applied. Code numbers identifying all treatments are given in Tables 1 and 2. Details of the fungicide treatments are given in Tables 7 and 8. Table 6 identifies the sites treated, and provides additional information on crop, soil type, and previous crop. To simplify presentation, results are given separately for winter wheat and winter barley for 1987-1989, and for winter wheat sprayed with air-assistance in 1990.

An initial analysis on data from individual winter wheat sites showed in 1987-89 no consistent effect on spray deposition due to application methods. Close examination of the raw figures suggested that this was due to small differences in tiller development at the time of spraying. A further analysis was conducted after dividing the crops into two distinct groups based on the area (cm^2) of the flag leaves (Table 11).

Table 11 . Mean total area (cm^2) of flag leaves at winter wheat sites 1987-1989

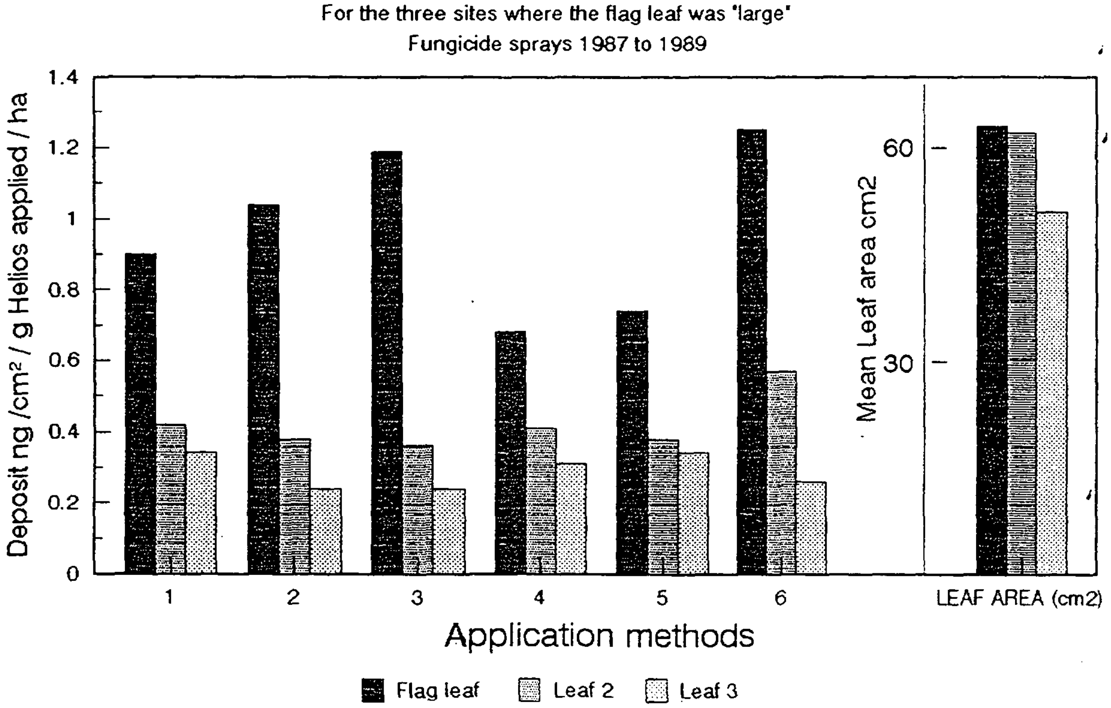
Year	Site	Mean total area (cm^2)of flag leaf	"Group"
1987	Wool	61.99	Large
1988	Woodsford	60.43	Large
1988	ADAS Bridgets	37.97	Small
1989	ADAS Bridgets	33.99	Small
1989	ADAS Rosemaund	41.43	Small
1989	Long Ashton (track sprayer)	67.96	Large

An analysis of variance then included flag leaf size as a variable. Results of the combined analyses were compared with results from each site to test whether flag leaf size had affected differences in deposit values found between sites. In all cases, it was found that, although flag leaf size was an important factor, there were still unexplained differences between sites. The following sections are therefore concerned with general conclusions rather than a detailed résumé of the analysis. Mean deposition patterns for leaves in the two flag leaf groups are given in Figs 13 and 14.

Within the "large" flag leafed group, the Crop Tilter (treatment No. 6) increased (generally significantly) deposits on the upper plant parts (ie flag leaf and stems 1 and 2). Deposits on the flag leaf from the Crop Tilter were similar to those given by the hollow cone nozzle (treatment 3) (fig. 13). These two application methods also gave greater deposits than other spray systems in the "Small" flag leaf group (Figure 14). Deposits on stem 1 from the Crop Tilter were greater than those from all other application devices (Figs 15 and 16). The relatively small foliar deposits for both groups of plants sprayed with the twin-fluid nozzles (twin-fluid nozzle treatments 4 and 5) are conspicuous in Figs 13 and 14 although the effects were not statistically different.

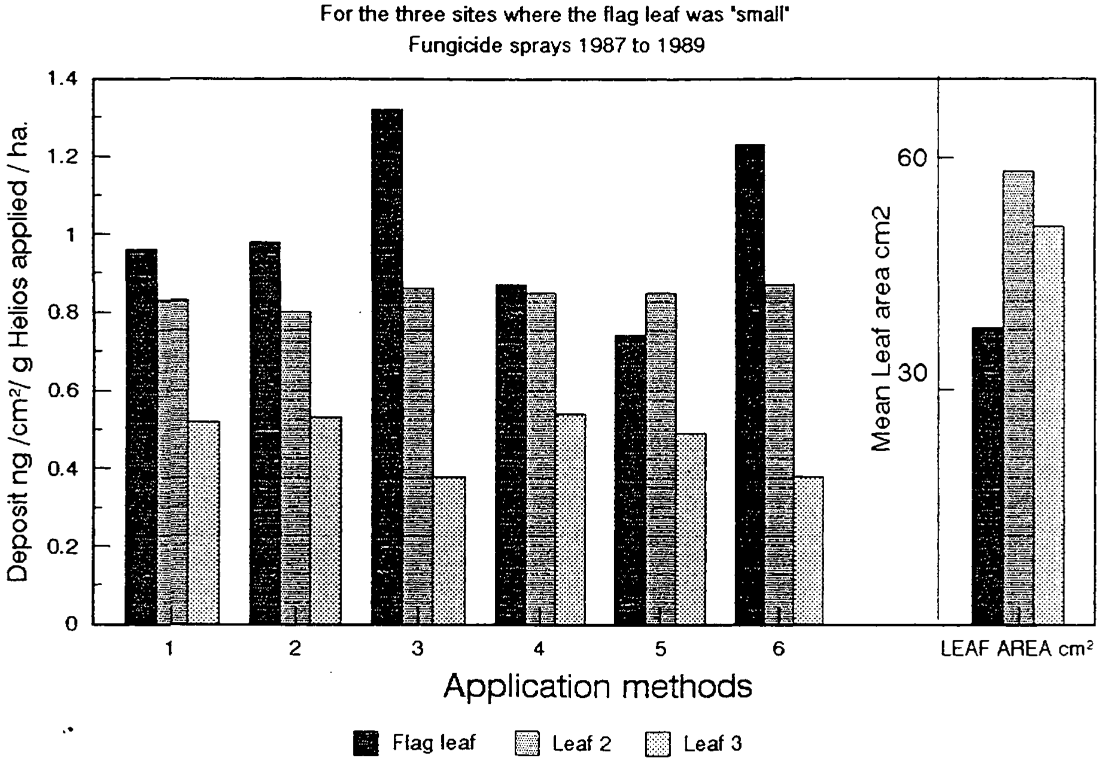
A comparison of Figs 13 and 14 clearly shows that for all application methods when the flag leaf is "large" the second and third leaves have similar small deposits whereas, when the flag leaf is "small", the differences in deposit are much reduced with more spray penetrating the canopy.

Figure 13. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha) **for the three sites where the flag leaf was 'large'**
Fungicide sprays 1987-89



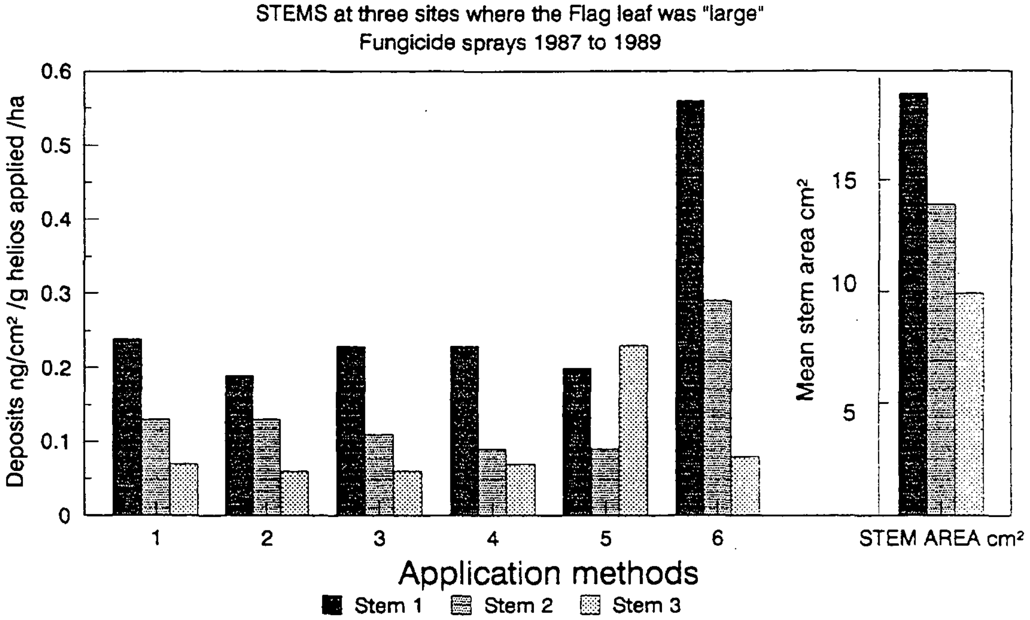
Treatment codes see TABLE 1.

Figure 14. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha) **for the three sites where the flag leaf was 'small' Fungicide sprays 1987-89**



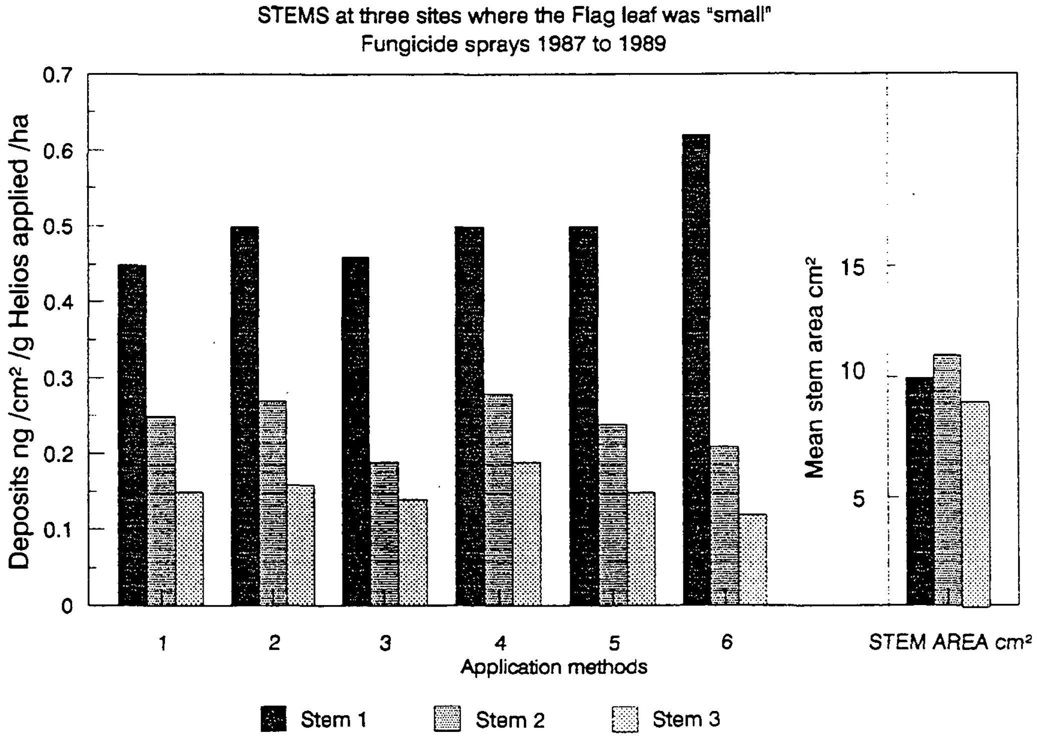
Treatment codes see TABLE 1

Figure 15. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha)
Stems at three sites where the flag leaf was 'large'
Fungicide sprays 1987-89



Treatment codes see TABLE 1

Figure 16. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha) **Stems at three sites where the flag leaf was 'small' Fungicide sprays 1987-89**



Treatment codes see TABLE 1

Deposits on whole tiller (ie leaves and stems combined) were not statistically different for all methods of application for the "small" flag leaf group while, for the "large" group, only the Crop Tilter (treatment 6) applications produced a small but significant increase in deposit.

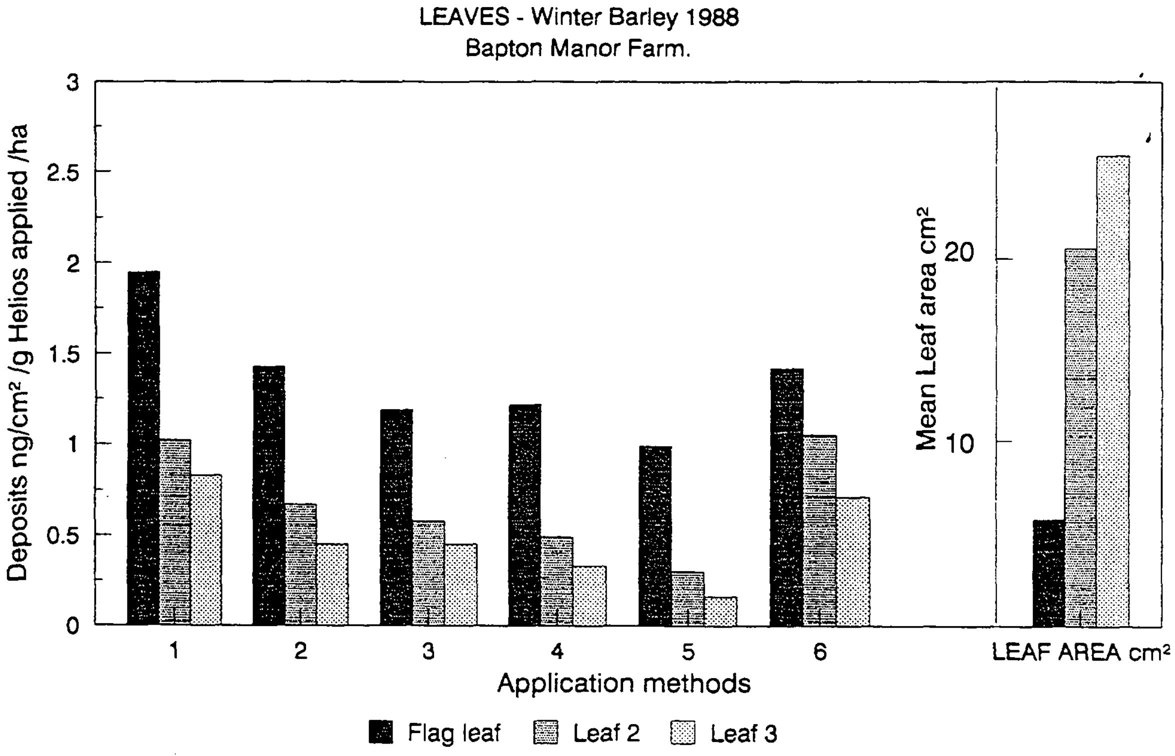
Deposits on winter barley in the 1987 and 1989 experiments are summariesd in Figs 17 and 18for the crops with "larger" and "smaller" flag leaves respectively. However, it has to be realised that even the "larger" flag leaf on the barley crop is very much smaller than that of the average "small" flag leafed winter wheat. Thus the deposits on barley on an area basis are greater than for wheat. Stem deposits are shown respectively in Figs 19 and 20. One of the more striking differences in Figs 17 and 18 and in 19 and 20 is the difference in deposition achieved with the standard 200 l/ha application (treatment 1). However, at Fonthill, where the deposits recorded are unusually low, misapplication occurred and it was necessary to resample a day late - thus the figures are unreliable.

Unfortunately there were only two trials on barley so it is impossible to comment further or to draw firm conclusions. If treatment (hydraulic/medium/200 l/ha) comparisons are discounted, there are still unexplained differences particularly evident in Figs 19 and 20 where the deposits on stem section 2 relative to sections 1 and 3 are unusually high.

Results from the two spray trials with the air assisted sprayers in 1990 could not be pooled because at Rosemaund the flag leaf was not fully exposed at time of spraying. Thus Fig. 21 summarising foliar deposits does not include a deposit per unit area for this leaf. Values are given as deposit expressed as ng/g dry weight/g Helios applied/ha. At the Bridgets site (treatment 11) the Degania at the low air setting deposited substantially greater amounts on the young flag leaf, with the result that this treatment produced the highest whole tiller deposits (ie including the stem data in Fig. 22).

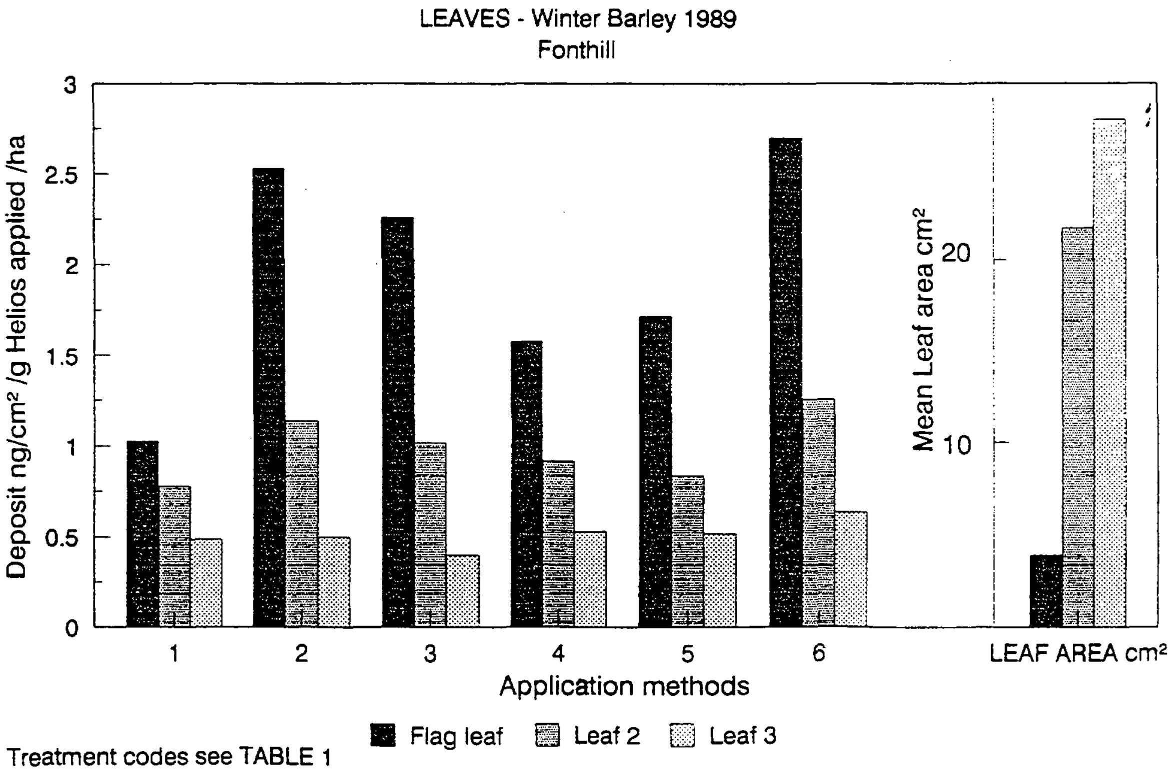
Although the data at two sites could not be pooled, it is apparent that the Degania sprayer operating with both low and full air (treatments 11 and 12) deposited more spray than any other method, and that the low air option (treatment 11) was probably superior.

Figure 17. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha)
On leaves - Winter Barley 1988
Bapton Manor Farm



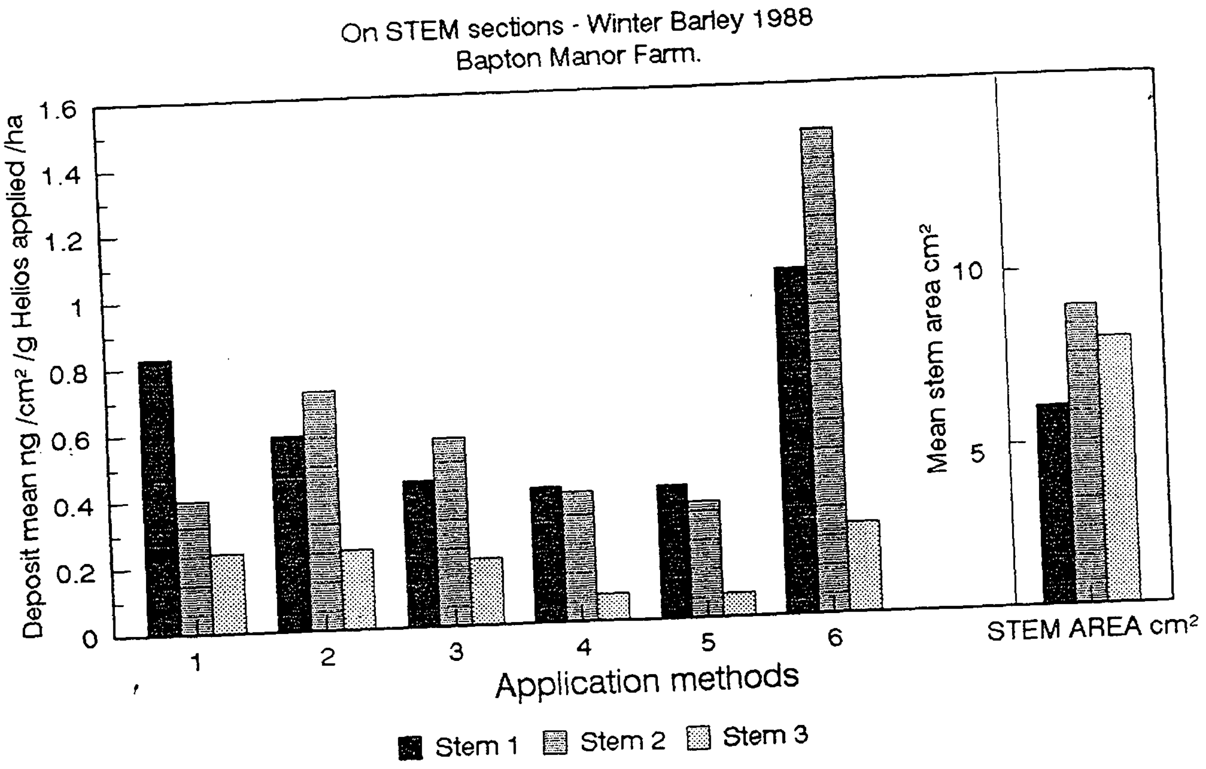
Treatment codes see TABLE 1

Figure 18. **Mean spray deposits** (ng tracer/cm^2/g tracer applied/ha)
On leaves - Winter Barley 1989
Fonthill



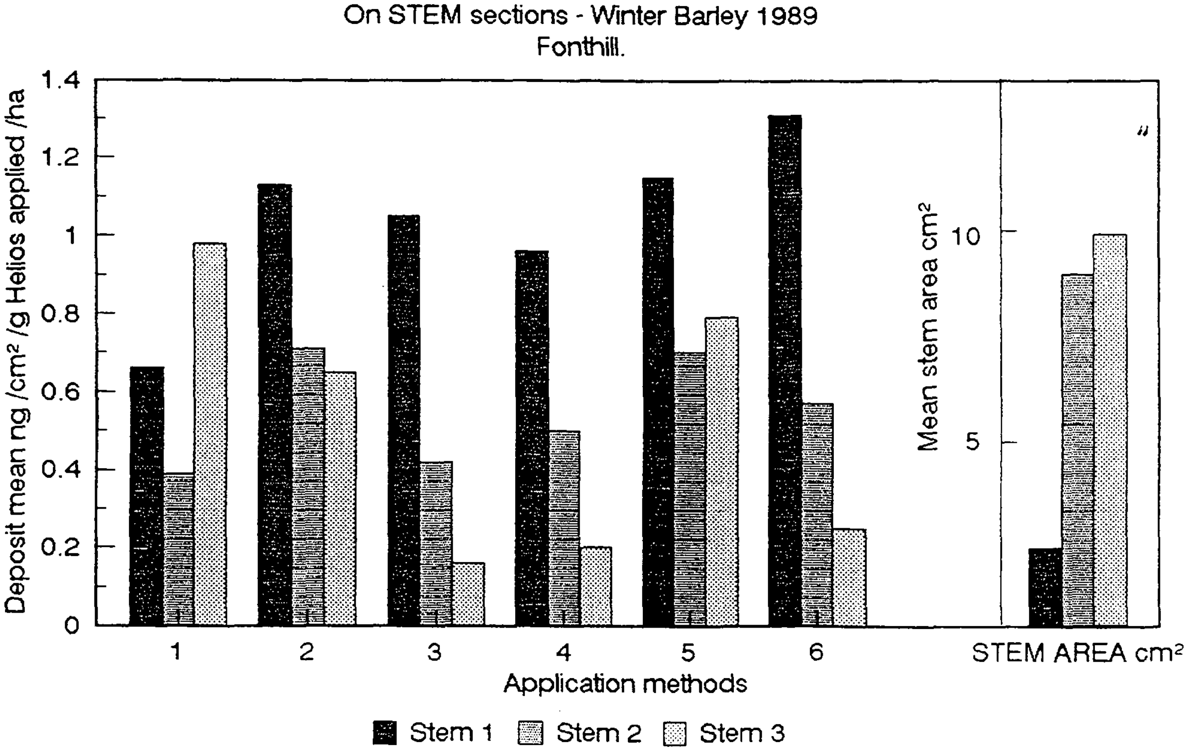
Treatment codes see TABLE 1

Figure 19 **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha) **On stem - Winter Barley 1988** **Bapton Manor Farm**



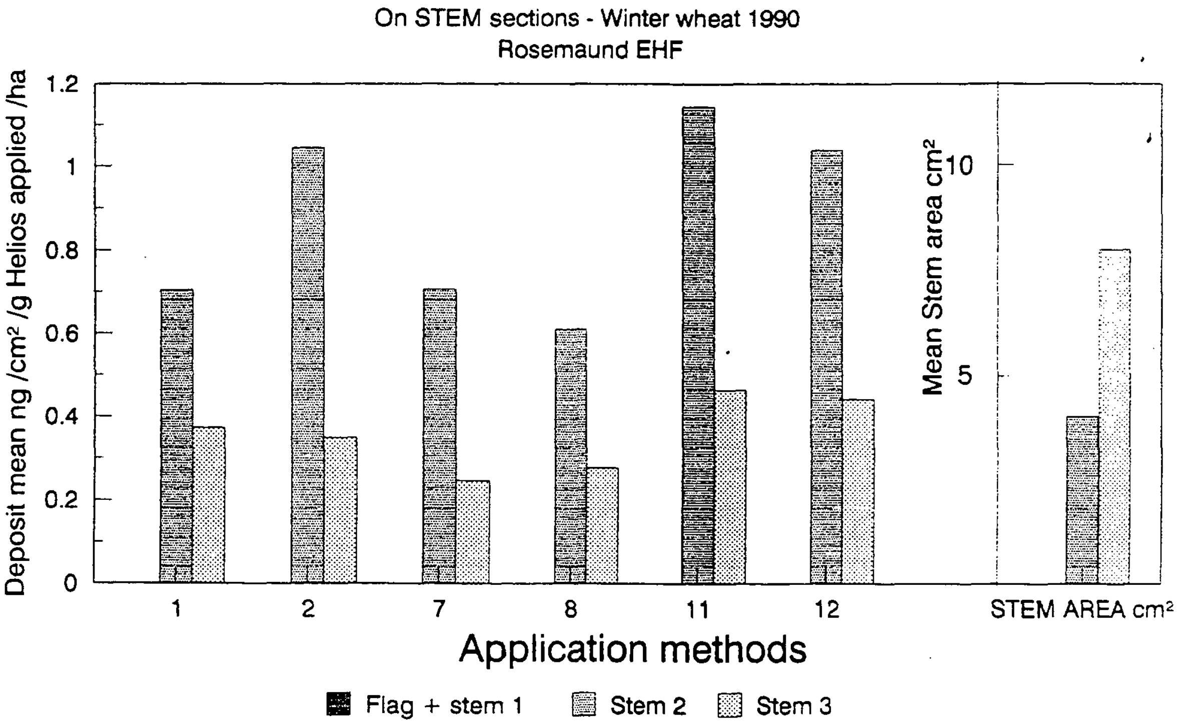
Treatment codes see TABLE 1

Figure 20. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha)
On stem- Winter Barley 1989
Fonthill



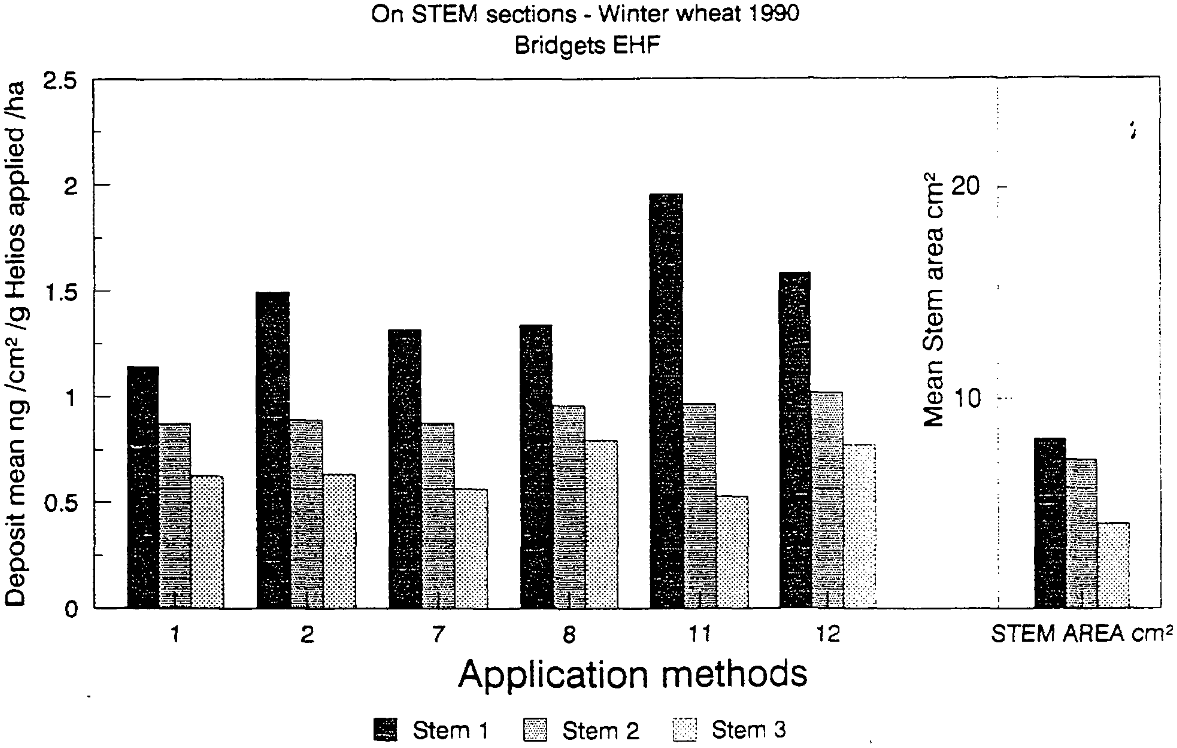
Treatment codes see TABLE 1

Figure 21. **Mean spray deposits** (ng tracer/cm^2/g tracer applied/ha)
On stem- Winter Wheat 1990
Rosemaund EHF



Treatment codes see TABLE 3
No records for stem 1 per unit area

Figure 22. **Mean spray deposits** (ng tracer/cm²/g tracer applied/ha)
On stem- Winter Wheat 1990
Bridgets EHF



Treatment codes see TABLE 3

Biological efficacy - herbicides

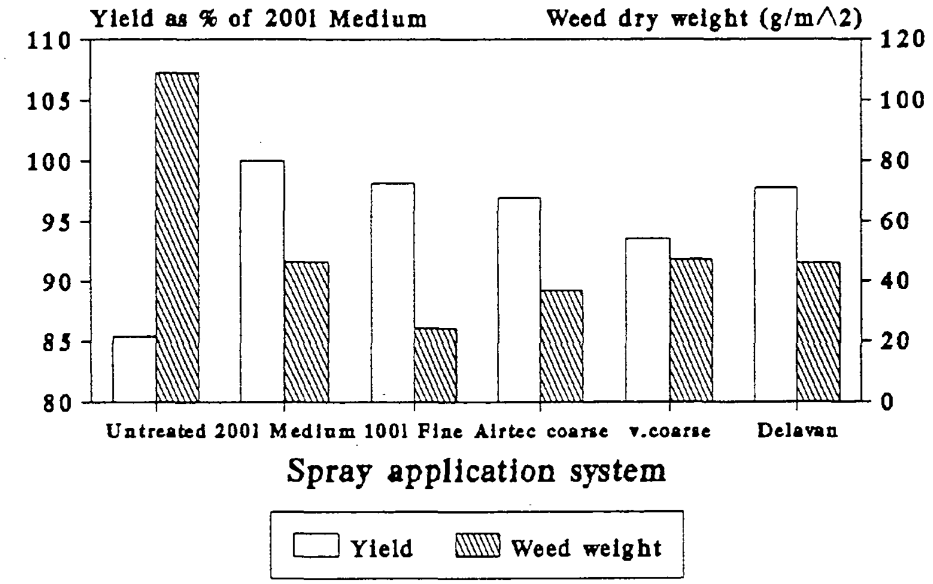
Some differences in weed control were observed at the reduced rate of herbicide when the fine hydraulic nozzle system or the Delavan WRW Superjet were used at 100 l/ha. Control of individual species sometimes highlighted differences in the systems. When a weed was particularly difficult to control due to its advanced stage of development, differences became more obvious. For example, when the reduced rate was used at the Ebbesbourne Wake site where field pansies were poorly controlled by all treatments, only the reference flat fan hydraulic nozzle at 200 l/ha spray volume reduced the population significantly. Compared with the other systems, the reference sprayer with flat fan nozzles operating at 200 l/ha produced the best overall control of weeds.

Variations in weed dry weight produced by the different application methods were small and not statistically significant.

Yield responses from the removal of weeds were generally small despite high numbers of weeds and considerable competition at some sites. At High Mowthorpe in 1987, Bridgets and Bampton Wake in 1988, there was a mean response of 0.72 t/ha overall but no difference with rate of chemical or the application system used. This picture was mirrored by the 1989 trials. The 1991 trials backed up the previous trial results. There was little or no yield advantage from using air assistance when applying herbicides.

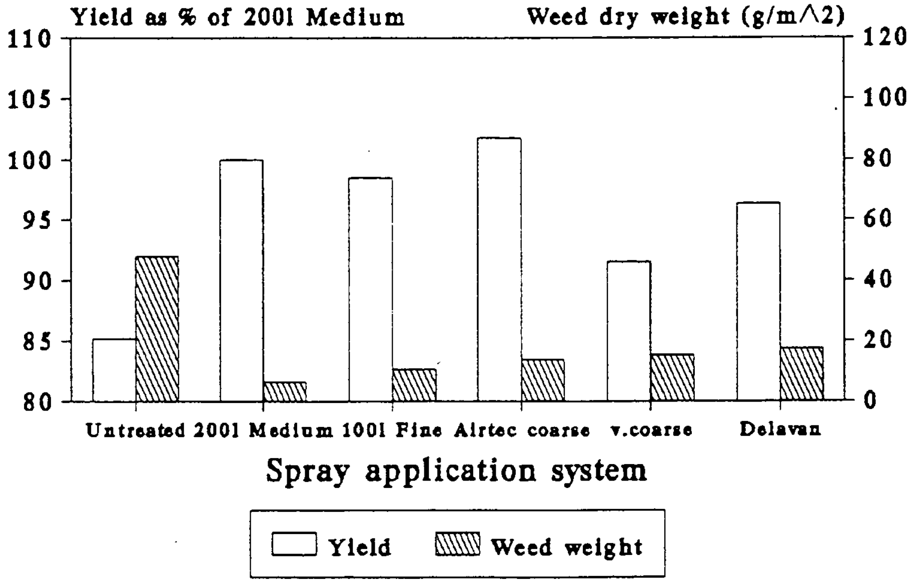
Grain yields in the herbicide plots are presented in Figs 23 to 26. There were no significant yield differences compared with the standard 200 l/ha medium quality spray, even when using one third of the recommended rate of herbicide in the standard system (Rutherford et al., 1989).

Figure 23a. High Mowthorpe Old Type winter wheat 1987 yield and weed weight



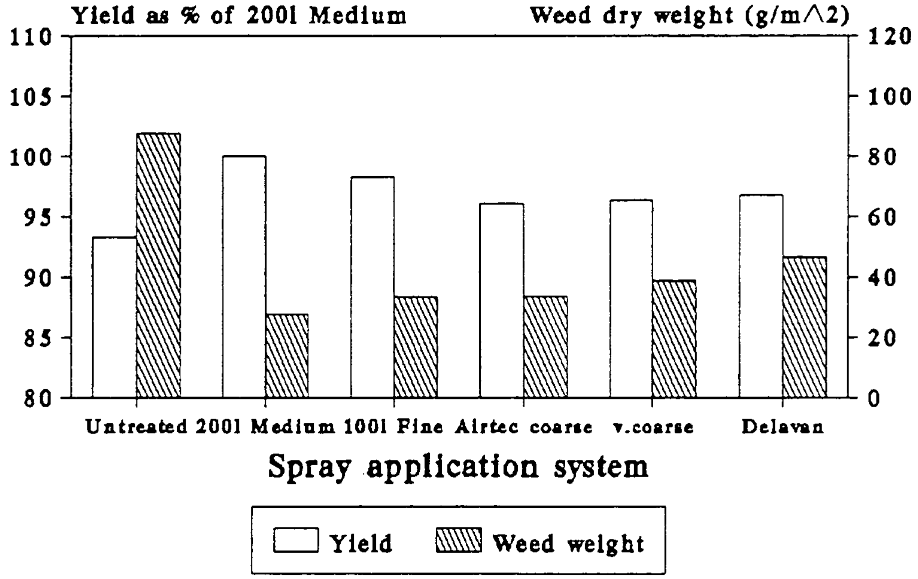
100 = 6.29 t/ha

Figure 23b. High Mowthorpe Smithfield winter wheat 1987 yield and weed weight



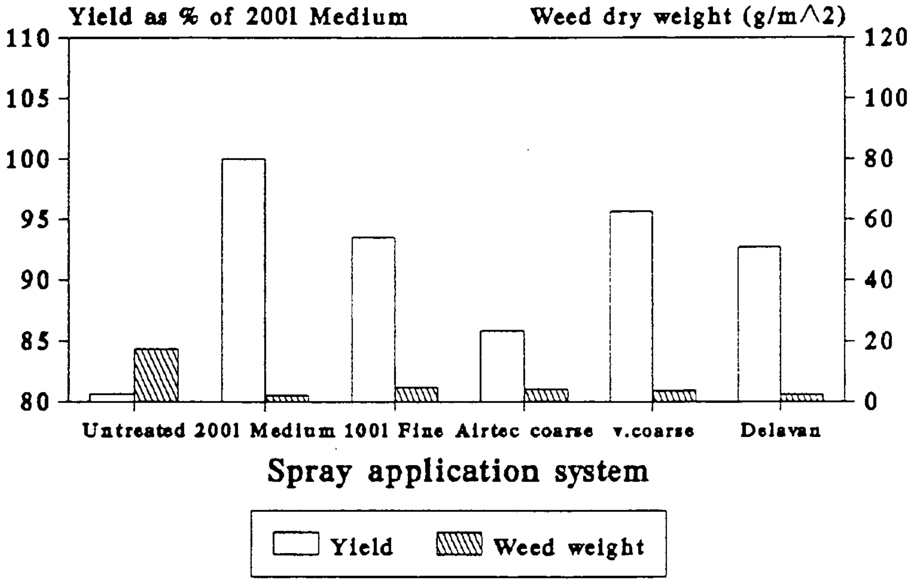
100 = 6.56 t/ha

Figure 24a. **Bridgets New Hampshire winter wheat 1988 yield and weed weight**



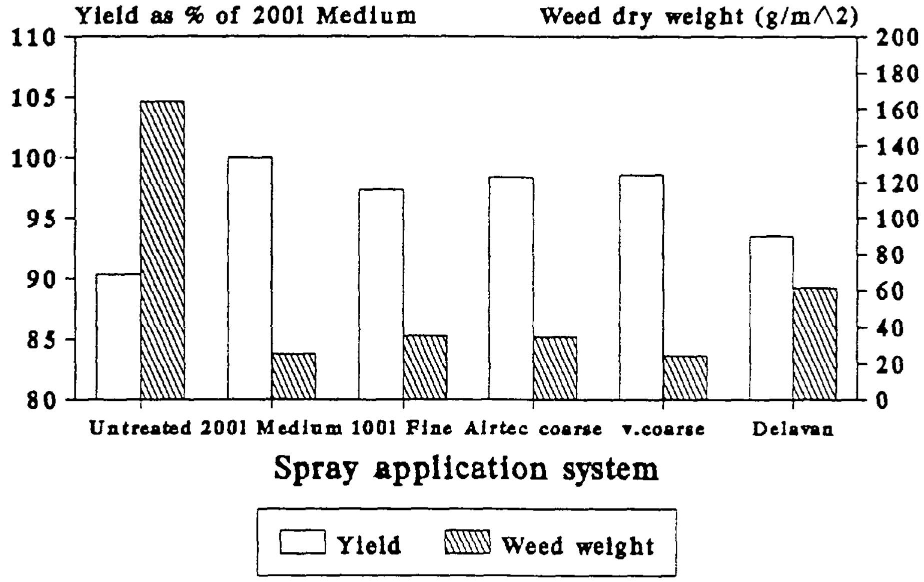
100 = 6.91 t/ha

Figure 24b. Bapton Manor Farm spring wheat 1988 yield and weed weight



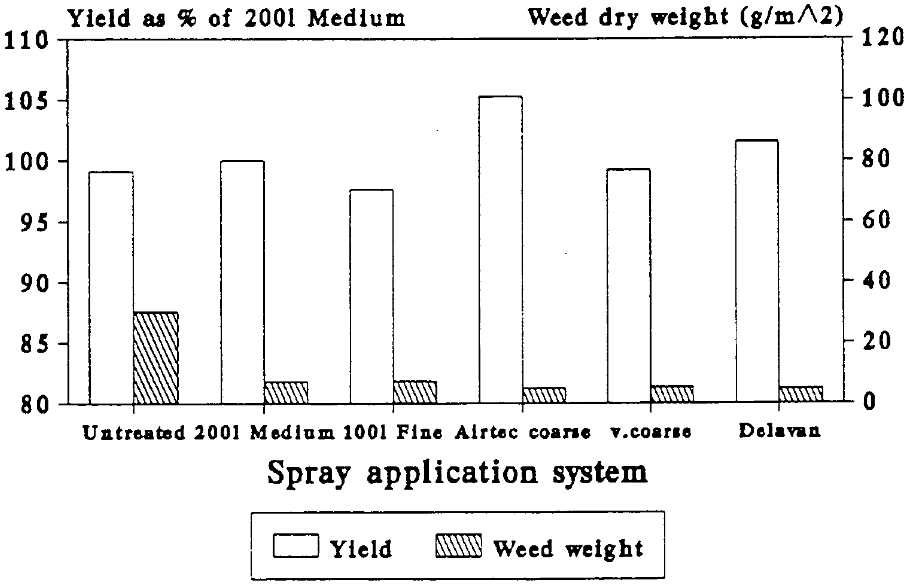
100 = 4.80 t/ha

Figure 25a. Bridgets Ohio winter wheat
1989 yield and weed weight



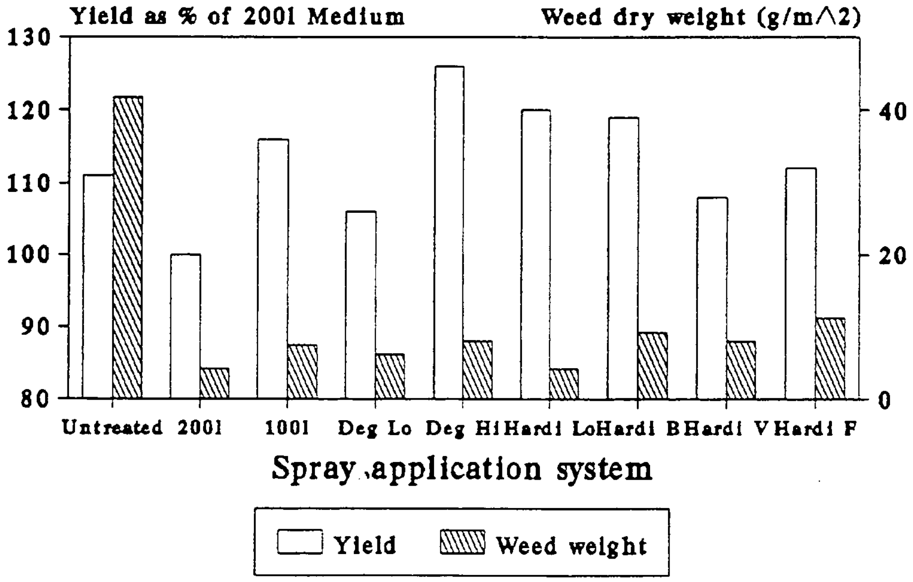
100 = 8.87 t/ha

Figure 25b. Ebbesbourne Wake spring wheat 1989 yield and weed weight



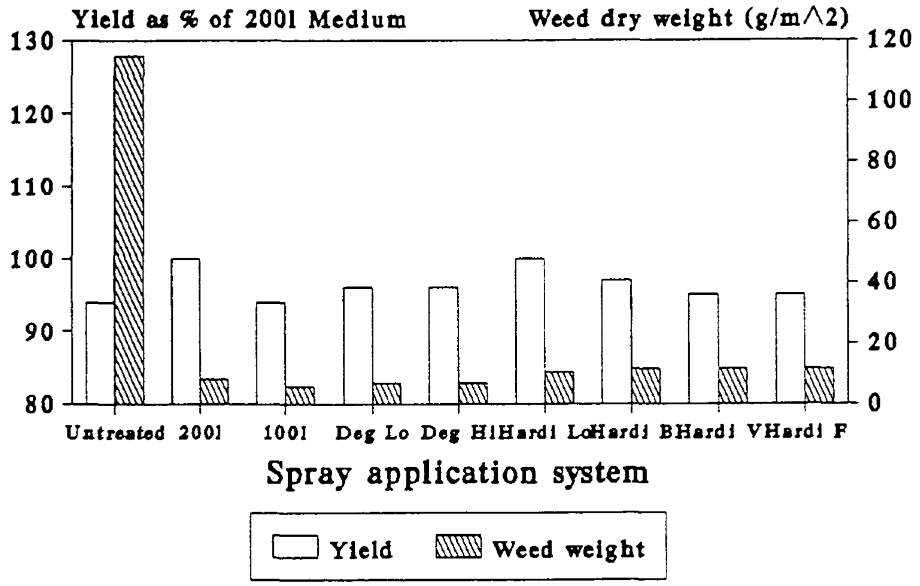
100 = 7.49 t/ha

Figure 26a. **Bridgets North Georgia winter wheat 1991 yield and weed weight**



100 = 4.54 t/ha

Figure 26b. Headbourne Worthy spring barley 1991 yield and weed weight



100 = 4.18 t/ha

Biological efficacy - fungicides

Brown rust (*Puccinia hordei*) was the main disease in the winter barley trials in both years. All methods of spray application gave similar control of this disease with the exception of half dose treatments on leaf 2 in 1988 when the Superjet and the Airtec 'nominally fine' sprays failed to significantly reduce brown rust levels (Fig. 27).

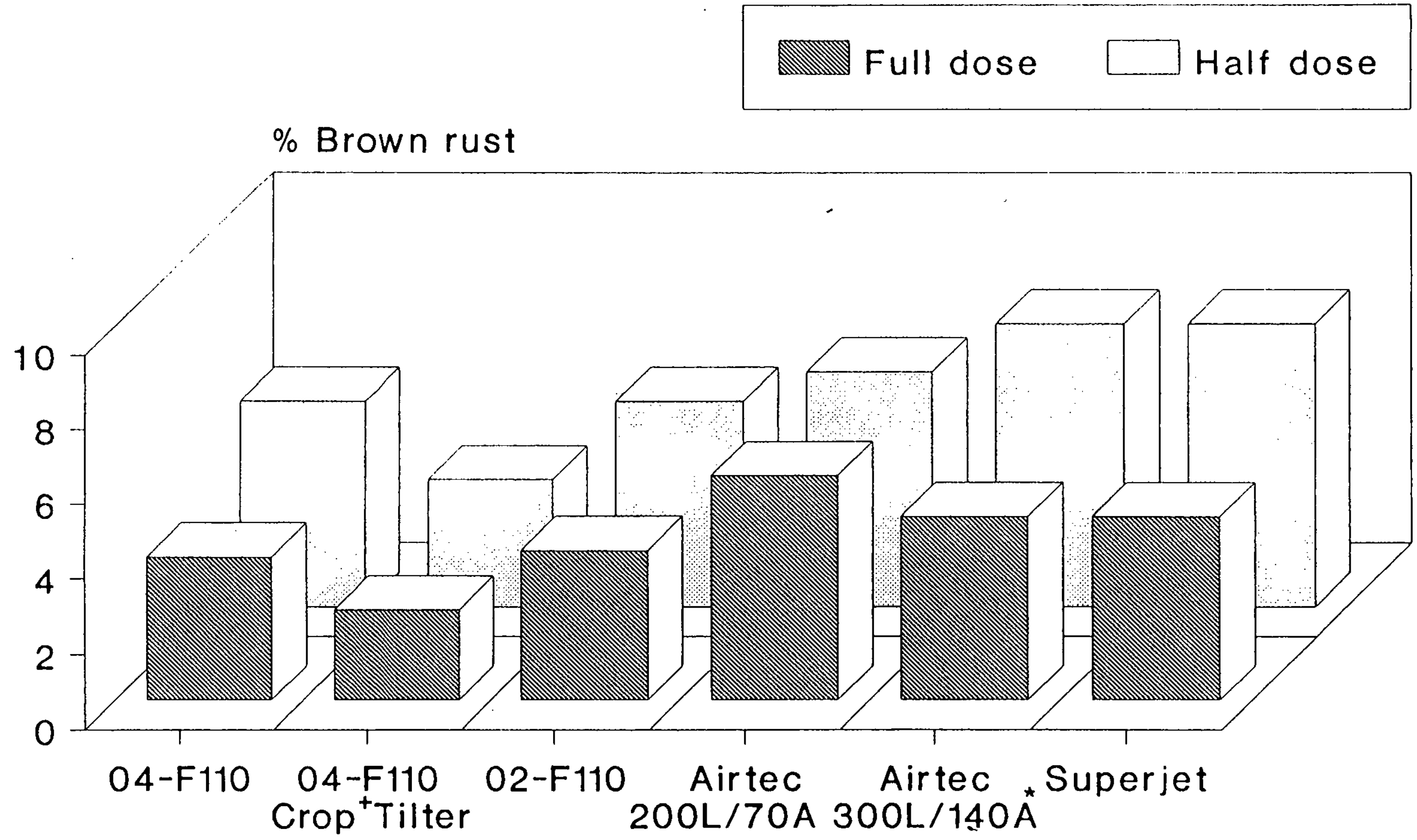
Similar significant yield increases were given by all systems at comparable dose rates in 1988, although there were no differences between application systems. In 1989, all sprays increased yield, but none did so significantly. This was probably due to the summer drought restricting potential yield responses (Table 12).

Table 12 . Untreated yield and yield increases (t/ha) for each winter barley site (wiltshire) 1988-89

	1988	1988	1989	1989
Untreated	4.51		8.7	
Method of application	Full	Half	Full	Half
Hydraulic 200 l/ha	0.61	0.37	0.80	0.69
Hydraulic 200 l/ha + Crop Tilter	0.67	0.32	0.98	0.72
Hydraulic 100 l/ha	0.62	0.44	0.46	1.0
Airtec 'nominally medium'	0.63	0.35	1.09	0.87
Airtec 'nominally fine'	0.50	0.64	0.81	0.43
Superjet	0.61	0.32	0.75	0.81
LSD (5%) overall	0.2		NS	

Septoria tritici was the main disease of winter wheat at the three sites in 1987. The conventional system applying full dose fungicide at 200 l/ha gave the most effective overall control on the flag leaf, significantly better than the Airtec - 'nominally fine' spray and the Crop Tilter at full dose (Fig. 28). At half dose, the Crop Tilter and the Superjet gave the better control of *Septoria tritici.*

In 1988, disease levels with winter wheat were variable. However, moderate levels of *Septoria tritici* were recorded at the Dorset site (site 6). All methods of application gave equally effective control of flag leaf septoria when applying a full dose of fungicide. At half dose, however, while the 200 l/ha hydraulic nozzle treatments continued to give good disease control, levels of *Septoria tritici* were higher with the 100 l/ha spray. In 1989 disease levels were very low due to prolonged drought conditions.



untreated ▪ 8.7%
LSD 1.98

* Liquid & Air pressure (kPa)

Figure 27. **Mean percentage area of leaf 2 affected by brown rust at GS 75**
Bapton Wiltshire 1988

The mean yield data over the three sites for each year are presented in Table 11. In 1987, all methods of application except the hydraulic 100 l/ha fine spray increased mean yield at full fungicide dose. At half dose, some systems (the Airtec 'nominally medium' spray, the Superjet and the Crop Tilter) gave yields which were significantly lower than the standard 200 l/ha spray.

All systems, regardless of dose rate, significantly increased mean yield in 1988. There were no significant differences between systems at full dose, but at half dose, the Airtec 'nominally fine' spray gave a lower yield increase that the standard 200 l/ha spray.

Yield effects in 1989 were low and non-significant due to the very low levels of disease and the effects of the drought.

Table 13 . Untreated yield and yield increases (t/ha) for each winter barley site (wiltshire) 1988-89

	1987	1987	1988	1988	1989	1989
Untreated	7.07		7.47		6.98	
Method of application	Full	Half	Full	Half	Full	Half
Hydraulic 200 l/ha	0.83	0.72	1.29	1.32	0.36	0.32
Hydraulic 200 l/ha + Crop Tilter	0.93	0.17	1.62	1.37	0.29	0.22
Hydraulic 100 l/ha	0.34	0.56	1.54	1.03	0.24	0.23
Airtec 'nominally medium'	0.66	0.23	1.39	0.93	0.05	0.04
Airtec 'nominally fine'	0.61	0.52	1.19	0.8	0.11	0.17
Superjet	0.55	0.1	1.55	0.94	0.39	0.03
LSD (5%) overall Comparing doses	0.39 0.499		0.41 0.562		NS	

When the yield data are meaned over all sites for the three years 1987-89, none of the application methods differed significantly from the standard 200 l/ha spray at full fungicide dose, but at half dose, the Airtec treatments and the Superjet spray gave significantly lower mean yield increases than the standard (Fig. 29).

In the winter wheat trials in 1990-91 *Septoria tritici* developed at each of the sites in both years, although the epidemic in 1991 was slow to start. In 1990, all sprays significantly reduced the level of Septoria tritici when assessed at GS 77, and half dose treatments, irrespective of the level of air assistance, gave a similar level of control (Fig. 30). There was a significant effect of dose, however, the full dose standard giving better control than the half dose.

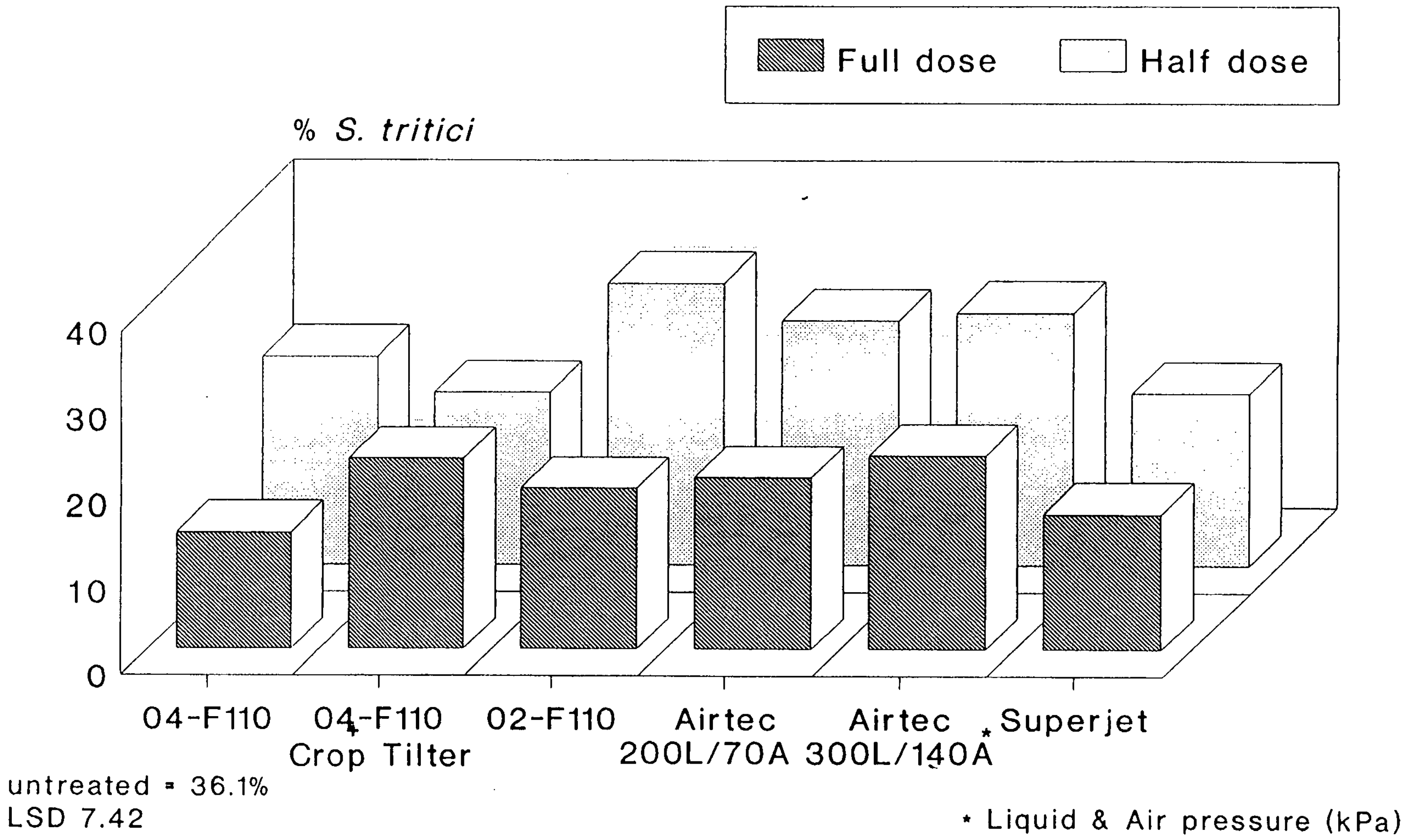
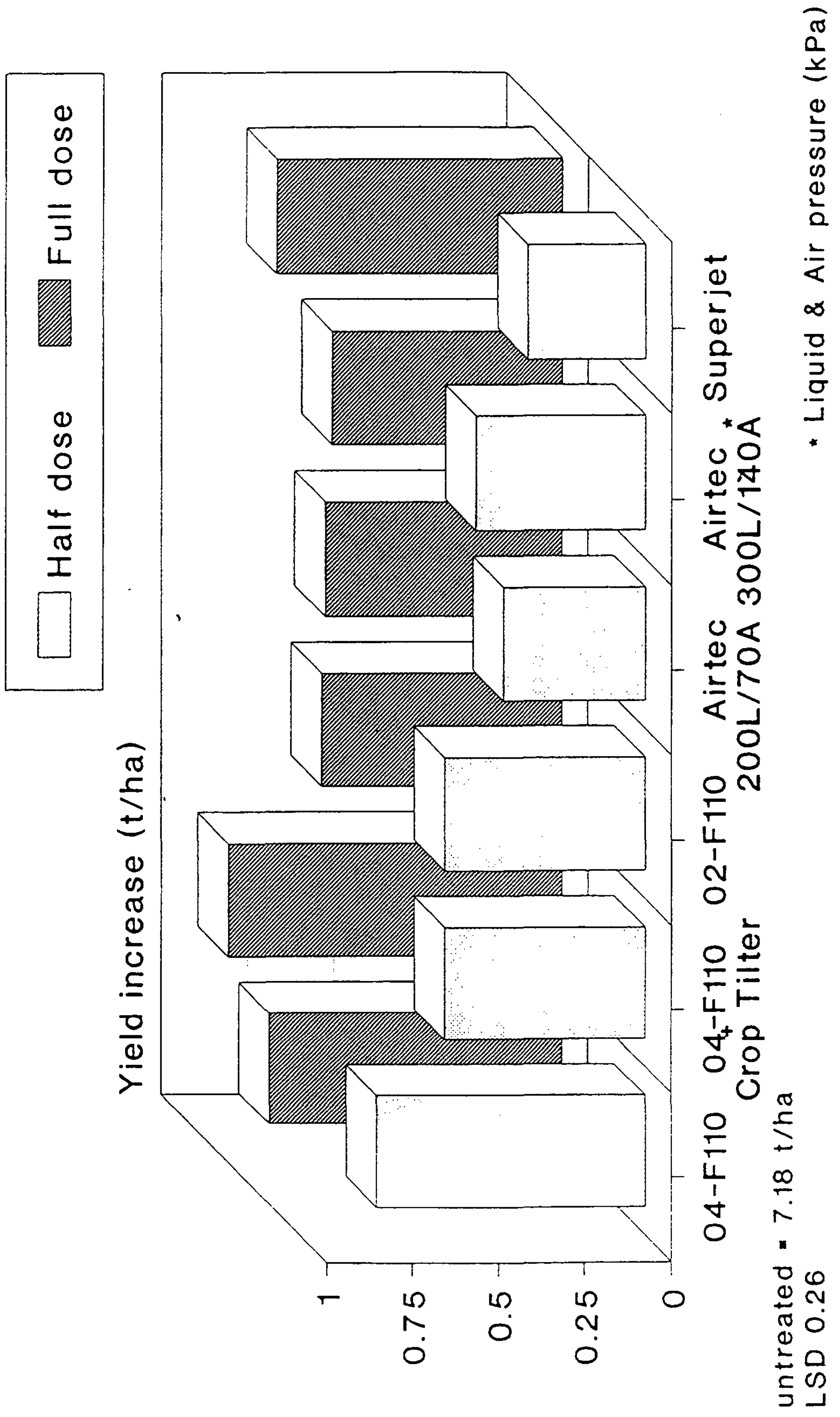


Figure 28. Mean percentage flag area affected by *Septoria tritici* at GS 75 three sites 1987

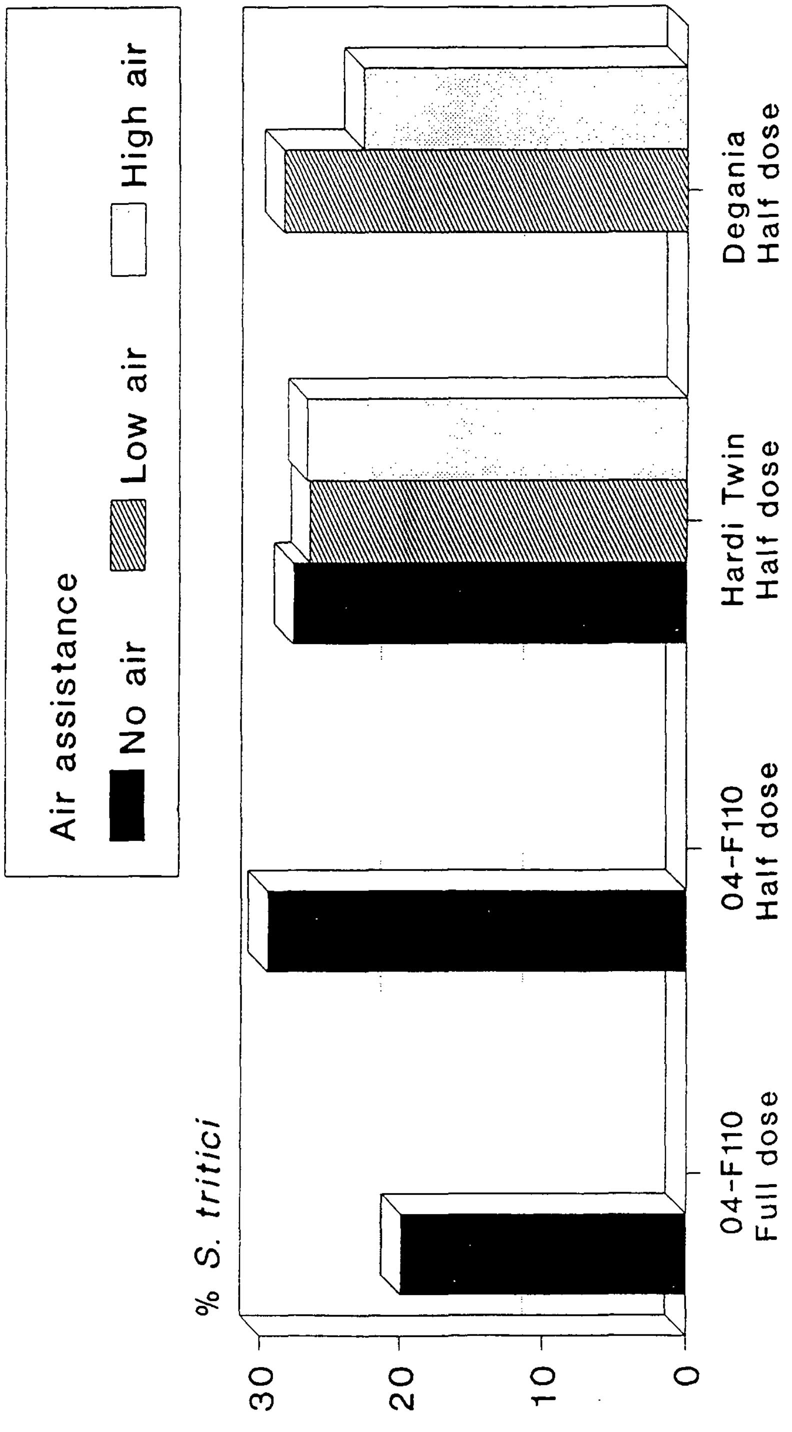
Figure 29. Mean yield increases (t/ha) for all wheat sites over three years 1987-89



untreated = 7.18 t/ha
LSD 0.26

* Liquid & Air pressure (kPa)

Figure 30. Mean % area leaf 2 affected by *Septoria tritici* at GS 75-77 four sites 1990-91



untreated ▪ 51.2%
LSD (5%) 3.9

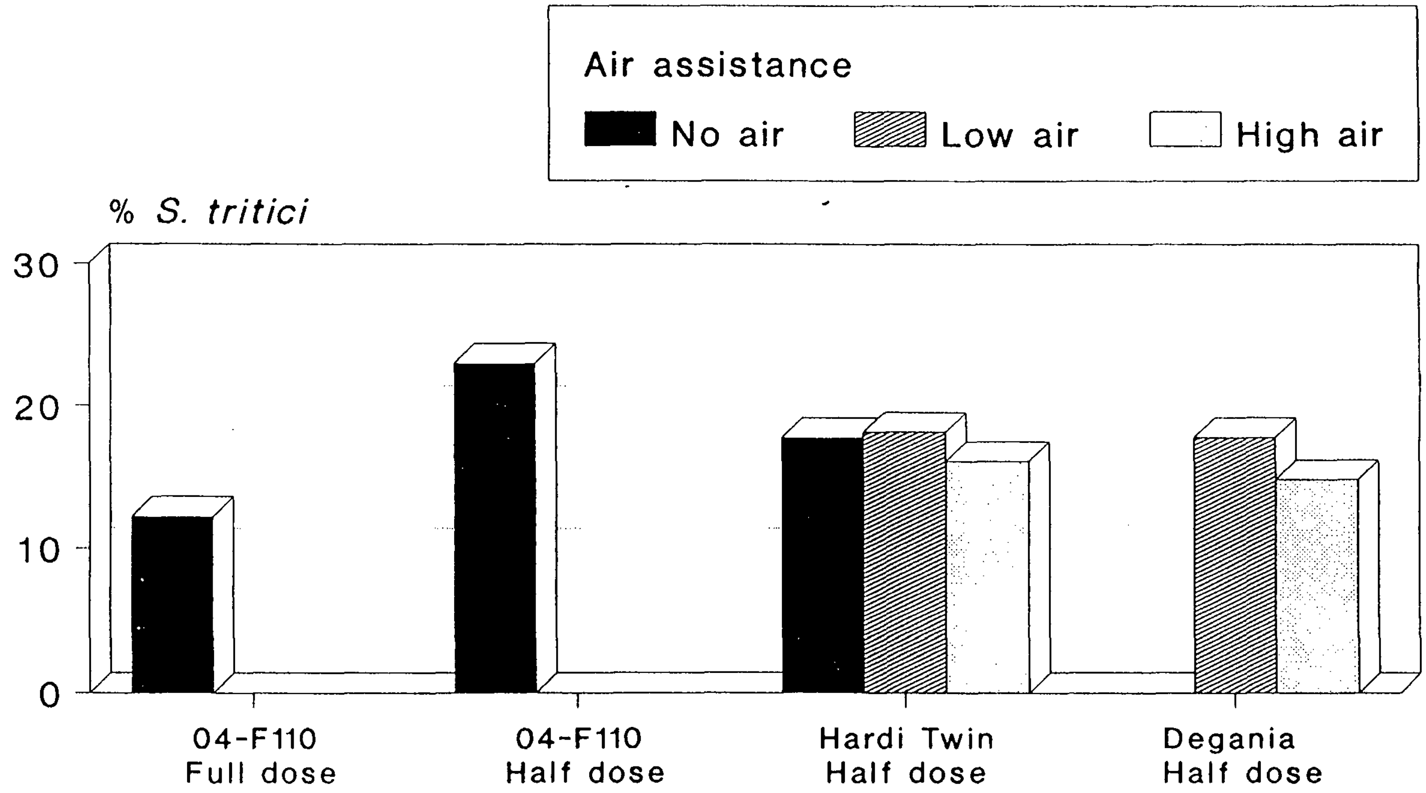
Significant effects on *Septoria tritici* levels were detected from increasing the airflow with the Degania sprayer in 1991, but only at the Bridgets site. Levels of *Septoria tritici* on both the flag leaf and leaf 2 were reduced from 52.3% and 75.1% respectively to 37.5% and 59.4% in the Degania high air treatment compared with the low air setting. A similar improvement in green leaf area was also detected on the flag leaf (but not on leaf 2) at Bridgets when the Degania sprayer was operated at the high air setting.

The effect of the high air setting with the Degania was also demonstrated in septoria control on leaf 2, but not leaf 1, when meaned over all the sites for the two years (Fig. 31). The high air setting gave a significant reduction in Septoria tritici infection from 28.4% to 22.7% with the low air setting. This was the only example of air assistance having an overall significant effect over the four sites. Fungicide dose also significantly affected septoria on both leaves, the full dose standard application giving the best control (Figs 30 and 31).

The standard 200 l/ha spray at full dose gave a significant yield advantage over the half dose sprays at both 200 l/ha and 100 l/ha (without air assistance) when meaned over all sites for the two years. The Degania sprayer at the high air setting gave the greatest mean yield increase of the half dose 100 l/ha treatments, but this superiority was not significant (Fig. 32). There were no overall significant differences in grain quality as determined by specific weight and thousand grain weight.

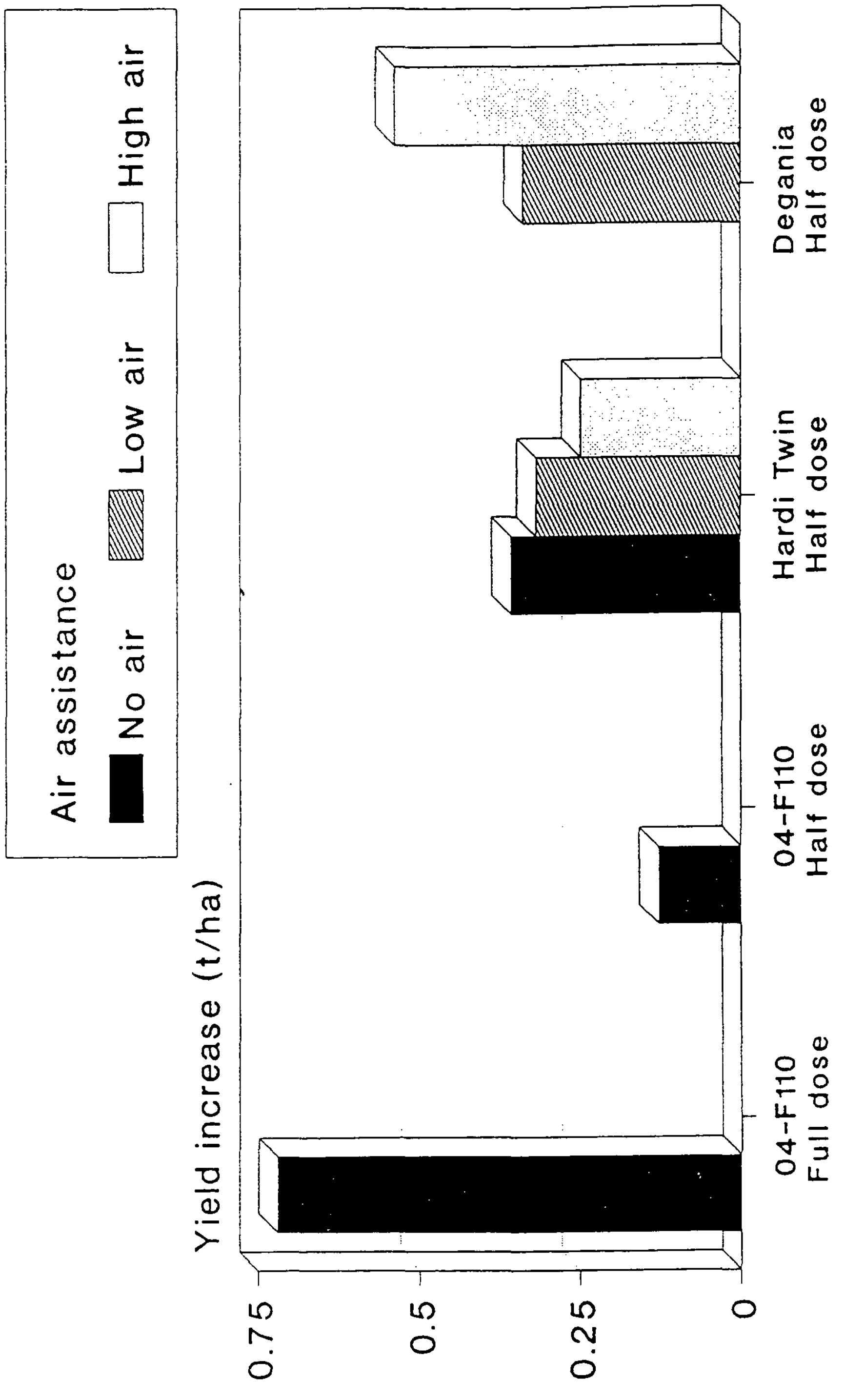
In 1991, two additional treatments were examined with the Hardi Twin Sprayer. In addition to operating the sprayer at the high air setting with the boom spraying in the normal vertical plane, the boom was modified so that it could be angled forward 60° and rearward 30°. No significant effect was detected, either in disease control/green leaf area or yield/ grain quality, from angling the boom at either site.

Figure 31. **Mean percentage flag leaf area affected by *Septoria tritici* at GS 75-77four sites 1990-91**



untreated ▪ 31.5%
LSD (5%) 3.85 (comparing doses only)

Figure 32. Mean yield increases (t/ha) for all sites over two years 1990-91



untreated ▪ 7.04 t/ha
LSD (5%) 0.295 (comparing doses with conventional sprayer)

Discussion

Physical spray characteristics

Droplet size and velocity distributions

This project showed that individual spray droplets produced by the twinfluid nozzle contained "air-inclusions" and were therefore physically different from droplets generated by conventional fan nozzles.

The spray qualities for the flat fan and hollow cone nozzles, were determined by comparing the measured droplet size distributions plotted in cumulative volume from with those of reference flat fan nozzles measured in the same way (Miller, 1988). Because of the "air inclusions" in the spray from the twin-fluid nozzle it was not possible to determine the spray qualities in the same way for this type of nozzle. At the time when this work was conducted, there was no defined method for ascribing a quality to the sprays produced with different air and liquid pressures into this nozzle. However, since this part of the project was completed some further work by the nozzle manufacturer and other researchers (Miller et al., 1991; Western et al, 1989), has provided data that give some basis for the classification of spray qualities from this nozzle type. A research project funded by the Ministry of Agriculture, Fisheries and Food has examined the definition of a test protocol to extend the existing classification and include elements relating to the "driftability" of sprays from different nozzle designs. The use of this protocol, when integrated into an extended nozzle performance classification scheme should facilitate an improved description of the behaviour of sprays with "air-included" droplets, particularly with respect to spray drift. However, more work will be required to quantify the effects of this type of droplet structure on spray deposition on leaf surfaces.

With air-assisted sprayers, the interaction between air and spray below the boom is important to ensure a uniform volume distribution (patternation) at target level. This is achieved by both machines studied by arranging that the spray from the nozzle has obtained a uniform distribution before it meets the air stream. In the case of the Hardi sprayer, the droplet velocities leaving the nozzle are relatively high with a mean velocity based on spray volume of 8.3 m/s measured 350 mm away from the nozzle. Droplets, therefore, penetrate the air stream and give a reasonably uniform spray volume distribution at target level. With the Degania machine using a hollow cone nozzle, mean velocities of 3.8 m/s were measured and hence the penetration into the air stream would be smaller. This is accounted for on the sprayer by using a nozzle spacing of 0.25 m rather that the 0.5 m used on the Hardi machine.

Air flows from the air-assisted machines

The structure of the airflow created by the two machines was different in that at the maximum air setting, the Hardi sprayer used a velocity of 21.0 m/s directed through a slot whereas the Degania used a velocity of 31.3 m/s directed through a row of holes. It is likely that the arrangement on the Degania gave a larger entrainment of air into the original jet causing it to slow more rapidly and such that at the top of the crop, there was a larger total flow into the canopy compared with the Hardi machine where the flow was more directed.

Both machines gave air movement in the crop that would be expected to alter droplet trajectories and hence change deposit distribution patterns within the crop. Towards the top of the canopy, air velocities from the Hardi sprayer tended to be the higher, whereas in the centre and lower portions of the crop canopy higher velocities were recorded with the Degania sprayer. Measurements of spray deposits on artificial targets within a crop canopy also showed that the use of air could increase spray deposition and that angling the air and spray stream could increase the capture on vertical targets.

Spray drift

Spray drift from the flat fan nozzle producing the fine spray quality was approximately double that from the reference flat fan nozzle operating at the higher flow rate and producing a medium quality spray. In this case, since the nozzle design and spray release conditions were directly comparable, the difference in drift relates directly to differences in the droplet size distribution. The wide angle hollow cone nozzle gave drift volumes approximately equal to those from the fine flat fan nozzle and this result relates to the lower droplet release velocities from the hollow cone nozzle design.

Drift with the fine setting of the twin-fluid nozzle operating at circa 70 l/ha was approximately equal to that from the reference flat fan nozzle operating at 200 l/ha. Lower drift volumes (ie less than that from the reference nozzle) were recorded with the nominally medium quality spray from this nozzle. The relatively low drift from the twin-fluid compared with the reference flat fan nozzle probably relates to:

(i) the lower percentage of spray volume that is in small droplets (< 100 m) with the twin-fluid nozzle;

(ii) an increased air flow close to the anvil orifice in the twin- fluid design, as air used internally as part of the spray formation process leaves the nozzle;

(iii) a difference in the nature of the interaction between horizontal and vertical air flows close to the nozzle because there is no solid liquid sheet formed initially in the twin-fluid design.

The presence of "air-inclusions" within individual droplets increases the relative effects of air drag on such droplets and hence the tendency for them to drift. However, "air-inclusions" were not found in droplets < 100 μm in diameter in the spray from the twin-fluid nozzle and such droplets would not normally contribute to spray drift.

There was good relative agreement between the field drift measurements (Figs 8, 9 and 10) and those made in the spray chamber at Long Ashton, with the exception of data for the Crop Tilter which was not well simulated in the wind tunnel situation.

Results from the field measurements with the air-assisted sprayers showed that the use of air assistance would reduce drift when operating at 100 l/ha to less than that from conventional sprayers operating at 200 l/ha. Angling the air forwards tended to increase drift when compared with the vertical air flow, probably due to the increase in trajectory length, the tendency for the air and spray stream to be reflected at the more acute angle and the position of the air stream behind the spray on the Hardi machine.

Spray deposits

Results from this study showed that existing commercial spray application systems provide some scope for manipulating spray deposition patterns on crop and weed targets. The Crop Tilter, for example, substantially increased spray deposits on crop stems in the winter barley crop at Bapton Manor Farm and there was evidence of increased deposits in some of the plots treated with the air-assisted sprayers. However, differences between deposit distributions were not consistent and repeatable and it is possible that parameters, including those relating to crop structure and weather conditions at the time of spraying, also influenced deposit distributions. This was further investigated when deposits on winter wheat sprayed in 1987-1989 were re-analysed to account for the size of the flag leaf at the time of spraying. This was a direct effect of crop size and in other experiments differences due, for example, to crop foliage density were also noted. Further work is required to identify the relationships between the conditions when high levels of spray deposition were achieved and the performance of the spray application system.

The fact that these studies did not identify consistent significant differences in spray deposition for the different application methods examined is consistent with other work. However, these results must not be interpreted to indicate that all systems will be equally effective and safe in the field. In practice, the logistics and timeliness of pesticide applications are important considerations (see below). If a 100 l/ha application takes less time to complete than one at 200 l/ha and if the former treatments fit into a suitable"weather window" while the latter does not it is entirely possible that the lower volume application will produce superior biological results even though it produces equal or even slightly smaller deposits. On the other hand, a reduced volume application with "fine" hydraulic nozzles will produce more drift in increasing wind conditions and spraying will have to stop sooner than when a coarser nozzle is used.

Air-assisted spraying of arable crops is a relatively recent approach and there is ample evidence from this and other work that air-assistance can reduce drift from a given nozzle used without air-assistance. Some of the design combinations examined in this study have given indications of better deposition. The measurements of air movement within the crop canopy beneath the air-assisted sprayers showed that horizontal air velocities throughout the canopy were likely to be large enough to influence the deposition patterns, particularly of small droplets, giving increased deposits and coverage. Differences in deposition recorded here (Rutherford et al., 1989) and elsewhere (Cooke et al 1990) were rather small and unlikely to be clearly reflected in improved biological performances because of generally limited response in the field to large changes in pesticide dose. For example it is not uncommon in field experiments to find that there is little biological difference between recommended (full dose) and on half pesticide doses. This was highlighted in the LARS track sprayer experiment where a fourfold difference in herbicide dose was necessary before a significant biological effect was recorded. If similar differences are required for biological effects to be seen from fungicide applications it is unlikely that clear and consistent differences will be found as a result of work reported here.

Biological efficiency - herbicide

A wide range of systems has been studied over a five year period. Eight separate experiments done in winter and spring cereal crops with a range of broad-leafed weed infestation have all given a very similar result. The conventional 200 l/ha medium quality hydraulic spray proved an effective option in this series of experiments and the performance of alternative systems did not consistently better that achieved by this reference system. Considerable logistical and timeliness advantages can be obtained by using 100 l/ha spray volume without seriously reducing the efficacy of the herbicide.

Biological efficiency - fungicide

This work represents one of the few scientific comparisons of biological efficacy of fungicide sprays applied to cereals by various spray application systems. Although a wide range of systems has been studied none was proved to be significantly superior in terms of disease control to the standard 200 l/ha spray applied by conventional hydraulic nozzles such as the 04-F110. Most of the systems investigated offered the facility of reducing the total volume of spray applied to 100 l/ha without the common problems of blocked nozzles or increased spray drift usually associated with the use of smaller hydraulic nozzles applying 100 l/ha.

Providing disease control is not compromised with the reduced volume, such systems would offer advantages to farmers in improving work rates and timeliness of sprays.

The use of the Crop Tilter aimed at better penetration of the crop canopy by the fungicide spray and so hence better disease control, particularly on lower leaves. Although occasionally, the system appeared to improve disease control (eg brown rust or barley at Bapton, 1988) the effect was never significant. In 1987, although yield was not impaired, overall control of flag leaf septoria was significantly poorer when the Crop Tilter was used at full dose, suggesting that more fungicide was applied to lower leaves at the expense of the flag leaf.

The fine flat fan nozzle gave good disease control on the flag leaf at the Dorset site in 1988 but was occasionally less effective on leaf 2. When used at half dose, the spray from this nozzle occasionally resulted in lower yield increases compared with the standard 200 l/ha medium spray quality half dose treatment (Bridgets 1988).

When used with full dose, the 'nominally fine' and 'nominally medium' sprays from the twin-fluid nozzle gave acceptable disease control but when used at half dose, some observations (Dorset, 1987 and 1988, and Rosemaund, 1989) indicated that disease control can be inferior to the standard 200 l/ha system. This was reflected in the mean yield results for the nine sites (1987-89). The settings used for the twin-fluid nozzle were selected from the manufacturer's recommendations when the project work commenced. The information gained by the manufacturer relating to the physical structure of spray produced by this nozzle design, some of which came from the work reported here, resulted in a revised operating chart defining application rate and spray qualities produced by this nozzle. The new air and liquid pressures now recommended for the Airtec twin fluid nozzle to produce fine and medium quality sprays may, therefore, alter the efficacy of fungicides applied with the system.

When used at full fungicide dose, the Superjet - WRW Delavan gave satisfactory disease control, which was similar to that given by the standard 200 l/ha medium quality spray. It was particularly effective on the flag leaf, but was occasionally less effective on leaf 2 when used at half dose.

The Degania generally gave slightly better disease control than the non-air assisted half dose standard medium quality 200 l/ha spray, but the effect was not significant. There was no significant yield advantage from the use of air assistance, although the high air flow gave the greatest yield increase of the 100 l/ha half dose sprays.

The 'Hardi Twin' Sleeve Boom Sprayer provided a similar arrangement to the Degania and an opportunity to investigate air assistance more fully since the sprayer was designed to be operated with or without air assistance. In addition, the machine enabled the air-stream and nozzles to be angled forward or rearward. The trials showed no significant effect from air assistance or angling the air-stream, either in terms of disease control or yield benefit.

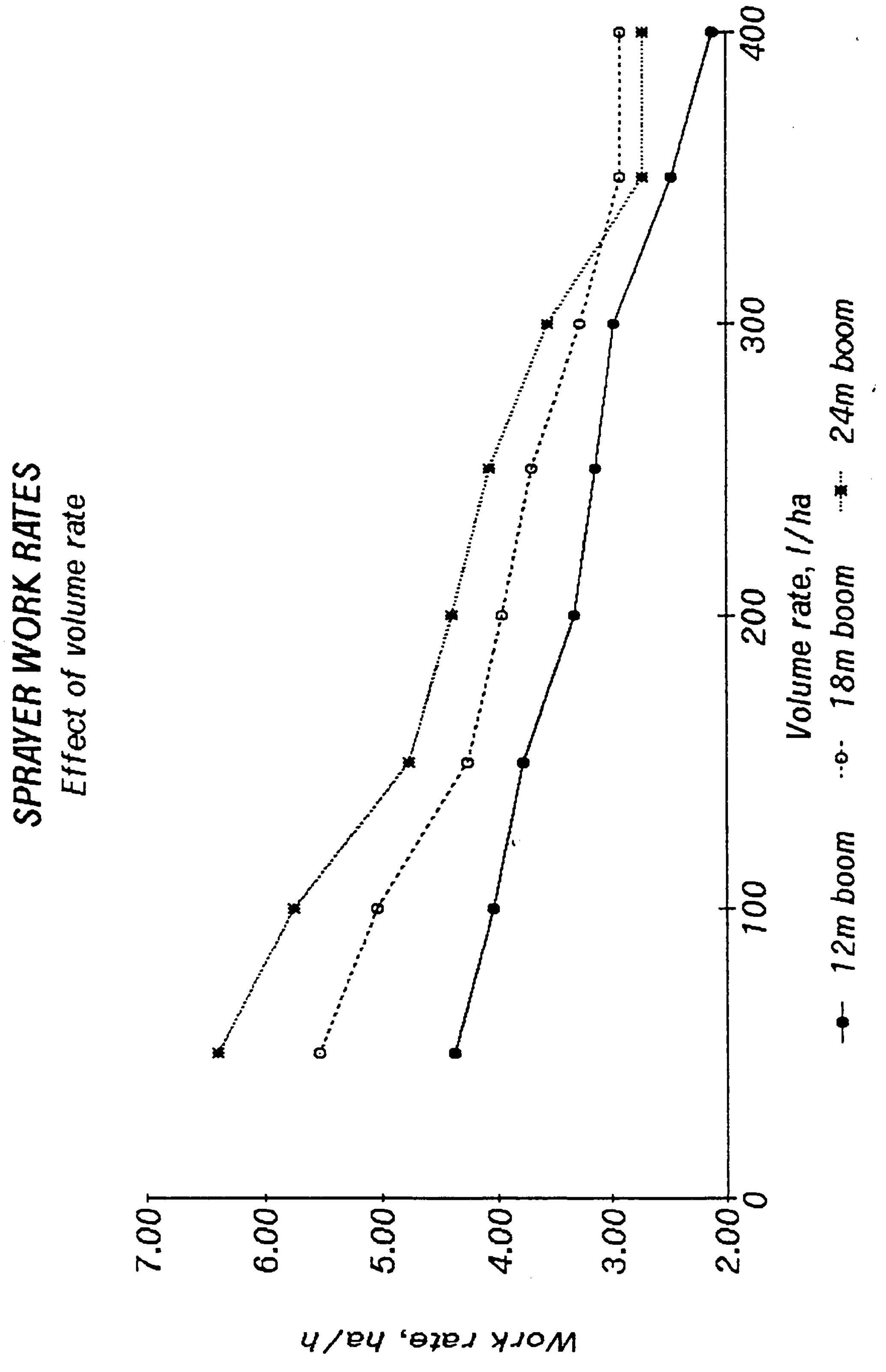
In each of the 15 trials, a broad-spectrum fungicide mixture was used. The results have shown that when full recommended doses of such fungicides are applied, they give effective disease control with each of the application systems studied. There was no indication that any of the systems were significantly more effective than the standard 200 l/ha hydraulic nozzle giving a medium quality spray when fungicide was reduced by 50%. While the ability to apply fungicides in 100 l/ha rather than 200 l/ha is attractive to many farmers because of improvements in work rates, the chances of poorer disease control are generally greater when fungicide dose is reduced at 100 l/ha than at 200 l/ha.

General discussion

Most of the spraying systems evaluated in this study operated at volume rates of around 100 l/ha compared with the standard hydraulic nozzle system at 200 l/ha, and gave generally comparable performances in terms of deposit level, distribution and biological response. The reduction in volume rate would increase work rates because of the reduction in filling times. It is expected that higher work rates will then increase the opportunities for making a timely spray application and this in turn will provide scope for dose rate reductions. In all of the comparative trials in this study, treatments were applied on the same day and hence any timeliness advantages from reduced volume rates have not been assessed. The effect of volume application rate on overall sprayer work rates predicted by a computer simulation model for a typical farm operating system is shown in Fig. 33. A reduction in volume rate from 200 to 100 l/ha, typical of many of the systems investigated in this study, increases work rate by between 21.6 and 30.6%, with the largest increases being for the larger sizes of sprayer. Increases in work rate of this proportion could be expected to give substantial improvements in the timeliness of spray applications which may be further improved if the machine is able to operate in higher wind speeds with no increase in the risk of spray drift. The improvements in timeliness will be a function of parameters relating to the spraying operation, and practical work is required to verify and quantify the timeliness advantages by accurately monitoring sample spray application programmes.

The results of this project have shown that the use of air-assistance and twin-fluid nozzles on boom sprayers can, when operating at 100 l/ha, give levels of drift significantly less than those from flat fan nozzles operating at the same volume rate and, in some cases, less than the standard sprayer operating at 200 l/ha. For the former to gain the maximum advantages from the potential improvement in timeliness from low volume systems that, by the use of air-assistance for example, give low drift, it is important that codes of practice recognise that the risk of drift is related to the detail sprayer configuration and, where appropriate, facilitate spraying at higher wind speeds. In this way, it will be possible to exploit the advantages of improved timeliness to give dose reductions when appropriate that will result in an improved financial return and more than justify the increased costs of the air-assisted sprayer.

Figure 33. The effect of volume application rate on sprayer work rates for different sizes of sprayer predicted by a computer simulation model



The results have also shown that the risk of drift from a particular nozzle design cannot be solely related to the droplet size distribution produced by the nozzle. The drift from the wide angle cone nozzle, for example, was equal to or greater than that from the flat fan nozzle operating at the same volume flow rate, even though measurements showed that the cone nozzle produced a spray with a smaller percentage of volume in droplets <μ100m in diameter. This probably related to the lower vertical droplet velocities from the wide angle cone nozzle. The "driftability" of agricultural spray nozzles is currently being examined in different wind tunnel conditions in tests similar to those reported in Fig. 10 of this report, with the objective of defining measurement protocols that will extend the existing British Crop Protection Council (BCPC) nozzle classification and provide a direct indication of the risk of drift. It is planned that the extended classification will also relate to the twin-fluid nozzle which results from this project have shown, cannot be effectively classified by the existing scheme. However, this extended classification will relate only to "driftability". The behaviour of droplets with air-inclusions is expected to be different from that of conventional spray droplets, particularly on impact with leaf surfaces, and although the results from this study have shown that overall deposits obtained with the system are broadly comparable with those from other spraying systems, further work is required to define the behaviour of this form of droplet on impact with target surfaces.

The highest level of airborne drift from any of the application systems studied measured 8 m downwind of the end of the spray boom was less than 3.5% of sprayer output when working in wind speeds (measured 2 m above the ground) of up to 7.0 m/s (25 km/h). Many of the systems studied gave downwind drift values at 8 m of less than 1.5% of sprayer output per single pass of the sprayer.

Further work is also now required to determine the advantages of improved timeliness in terms of dose/biological response function for the common herbicide and fungicide treatments. This approach would explore the performance of the different application systems applying different dose rates with different timings related to the expected work rates, particularly of the low volume rate systems.

Differences in spray deposit distribution achieved by different application systems were generally small but there was evidence in this study that differences could be achieved by changes to the physical characteristics of the spray and the delivery conditions. This was particularly true of the results for the Crop Tilter (eg stem fungicide deposits shown in Fig. 15) and for some of the air-assisted treatments. The measurements of air velocity in the canopy below air-assisted sprayers also suggested that deposit distributions would be changed by the air-assistance. There is a need for further research to obtain an improved understanding of spray behaviour within the canopy and to identify mechanisms that could modify spray deposition patterns in a controlled manner. Small changes to total deposits and deposit distributions are unlikely to give improved biological responses at high dose levels but, if consistently achieved, do provide a basis for dose rate reductions without increasing the risk of treatment failure.

The standard system used for the comparison work described in this report operated at 200 l/ha whereas most of the systems studied were operating with volume application rates in the order of 100 l/ha. The potential advantages of low volume systems and the fact that this was not explored in the trials programme has been discussed above. Some of the effects of volume rates can be seen by comparing the 200 and 100 l/ha applications made with flat fan nozzles in this work, although there is a spray quality interaction since these sprays were applied as medium and fine spray qualities respectively. The higher volume rate, medium quality sprays tended to give improved weed and disease control but differences were rarely significant. It should be noted that some chemicals do not have label recommendations relating to application volumes of less than 200 l/ha.

Conclusions

(i) Relating to the application system studied in the first three years of the project:

(a) The spray produced by the twin-fluid nozzle had air-inclusions in droplets greater than approximately 120 μm in diameter and hence the spray from this type of nozzle could not be classified directly by the existing spray quality classification scheme.

(b) The use of the twin-fluid nozzle and the Crop Tilter significantly reduced spray drift when compared with flat fan nozzles operating at 100 and 200 l/ha respectively.

Spray drift from all of the systems measured 8 m downwind from the sprayer and in wind speeds up to 25 km/h was less than 3.5% of sprayer output. For the twin-fluid nozzle at 100 l/ha and conventional system at 200 l/ha was less than 1.5% of sprayer output over this range of wind speeds.

(c) Differences between spray deposit distribution and biological response from spray applications made with the different systems were small and generally not statistically significant. Some changes in deposit pattern could be achieved, for example, by using the Crop Tilter but it is likely that other factors relating to the crop and weather conditions at the time of application also influence system performance.

(d) The use of volume rates of 100 l/ha rather than 200 l/ha can increase work rates by between 20 and 30%, depending on the spraying system and this should lead to improvements in timeliness and provide opportunities for dose rate reductions.

(ii) Relating to the use of air-assistance on boom sprayers:

(a) The use of air-assistance significantly reduced spray drift such that when operating with air-assistance at 100 l/ha, the drift was less than that from a conventional non air-assisted sprayer operating at 200 l/ha.

(b) Measurements of the air movements within crop canopies below the air-assisted sprayers suggested that the horizontal air velocities were sufficient to alter spray deposit patterns in the crop canopy. Direct deposit measurements and the associated biological response also showed some effects due to air-assistance but the effects were not statistically significant.

(c) The timeliness advantages relating to the use of lower volume rates discussed in (i)(d) above are also relevant. These may be further enhanced by the ability of the air-assisted sprayer to operate in higher wind speed conditions without an increased risk of spray drift.

Overall conclusions from the study are therefore:

- The overall performance of the spraying systems studied was comparable to that of the conventional 200 l/ha flat fan nozzle system. The use of lower volume rates gave the potential for increased work rates and improved timeliness.

- The air-assisted sprayers and the twin-fluid nozzles enabled the use of the lower volume of 100 l/ha with significantly reduced spray drift compared with conventional nozzles at the same volume rate.

- When herbicides and fungicides were used at both recommended and reduced doses, weed and disease control, together with subsequent grain yield, varied to some extent but differences between application systems were rarely significant.

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N.B. Reference copies of the Annual Interim project reports included in the above reference list are held in the library at Silsoe Research Institute and can be inspected by arrangement with the librarian.

Acknowledgements

This project required the successful collaboration of many staff from ADAS, CSL and the AFRC. In particular, Messrs B Freer and D Lockley and colleageus in ADAS; Dr P Miller and colleagues at Silsoe Research Institute; Dr E C Hislop and colleagues at the Institute of Arable Crops Research, Long Ashton; Dr A Gilbert, Applications Hazard Unit, CSL, Harpenden.

The funding by the Home-Grown Cereals Authority for this project is gratefully acknowledged.

The manufacturers of the two air assisted sprayers, Hardi Sprayers and Ferrag Ltd, are also thanked for their support in supplying the machines and technical advice during this work.

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CONTENTS

PART II: HGCA-FUNDED WORK IN SCOTLAND

SUMMARY

Several spray application systems were tested for efficacy and deposition on barley or wheat crops over four seasons. A number of alternative jet types and spray qualities were studied in 1988 and 1989, then attention switched to air assisted spraying in 1990 and 1991. The application systems were used to apply herbicide and fungicide sprays, while applications of tracer materials allowed estimation of the rates and distributions of spray deposits.

Response to the herbicide treatments was fairly uniform except where the chemical rate was reduced. There was evidence of improved weed control from reduced dose herbicide sprays when air assistance was applied. Swirl (cone) jets also gave improved weed control from reduced dose treatments in a open, spring sown crop.

Fungicide response, as measured by crop yield, was also fairly uniform. There are indications that applications on spring barley by a twin fluid nozzle in a 'medium' spray quality produced lower yield than applications by swirl jets. A small yield gain was evident from air assisted treatments on spring barley. Results from trials on winter wheat crops showed no consistent response.

Tracer tests on cereal crops at advanced growth stages revealed differing patterns of spray deposit at upper, middle and lower stem levels. This is accentuated on the lower stems, where swirl jets registered the lowest rate of deposition of the systems studied. Deposition on the lower parts of the stems was increased by air assistance applied to a 200 *l*/ha medium spray. Ground deposits from a 100 *l*/ha fine spray were reduced by air assistance when the spray bar was angled towards the rear, and spray distribution on the plants was biassed towards the upper strata.

1. INTRODUCTION

Developments in spray delivery systems are often promoted as a means of cutting chemical bills while carting less water and reducing spray drift. Several such developments were introduced during the 1980's, with little or no independent research to verify their merits compared to the long established flat fan type hydraulic nozzle. To provide objective information on their performance, the Home-Grown Cereals Authority has funded studies into the effects of various alternative spray application methods on crop response, operator safety and environmental contamination.

At SAC the aspects under examination were spray efficacy and deposition on cereal plants. The work was coordinated with a similar project being undertaken in England by ADAS (part I of this report). This part covers the investigations at SAC between 1988 and 1991.

A number of spray application systems came under investigation over the duration of the project. It was agreed that in Scotland the emphasis should be on the overall reliability of these systems. The SAC base at Bush Estate (altitude 190 m) in Midlothian lies within easy reach of a convenient spread of sowing dates, varieties and weed competitors.

In 1988 and 1989 the application systems studied included the 'benchmark' flat fan jets at 200 *l*/ha in a medium quality spray, fan jets at 100 *l*/ha in a fine spray, hollow cone 'Superjet' jets at 100 *l*/ha in a medium spray, and twin fluid 'Airtec' jets at 100 *l*/ha in both medium and fine spray qualities. These replicated exactly the systems under investigation by ADAS.

The project was extended into 1990 and 1991 to study the effects of air assisted spraying. The recently introduced sleeve boom type sprayers distribute an air curtain across the boom from a centrally mounted fan. One model, the Hardi Twin, was chosen to be representative of the type. This machine is fitted with flat fan nozzles at the standard 50cm spacing, allowing it to operate as a conventional sprayer when the fan is turned off. A further feature is the provision of adjustment to the air slot/spray bar angle. In the 1990 trials, only one air speed and boom angle combination was used for air assisted treatments. Additional variables introduced in 1991 for the air assisted treatments included two air outlet slot angles and two air velocities, representing the range of adjustment provided on the Hardi Twin sprayer.

Treatments were applied for both weed and disease control, and a tracer material was applied alone at a late growth stage. Both full and reduced chemical rates were included in the early years, but in later trials full rates were omitted other than a reference conventional treatment. Assessments were made of weed populations, disease levels, spray deposition and yield.

2. MATERIALS AND METHODS

2.1 Application details for treatments in 1988 and 1989

For convenience these application systems are collectively referred to as Group 1. Spray qualities refer to the standard classifications used by the British Crop Protection Council (BCPC). All the application systems were mounted on a modified Lely Junior sprayer with a fixed type, 12m wide boom. The sprayer was carried by a 65 hp tractor.

Table 1. Group 1 sprayer settings.

system code	BCPC code	volume (*l*/ha)	pressure liq/air (bar)	nominal spray quality	boom height (cm)	speed (km/h)
F200m	F110/1.60/3	200	2.0	medium	35	8.0
F100f	F110/0.80/3	100	2.0	fine	35	8.0
WRW100m	HC120/0.64/2	100	1.9	medium	50	8.0
TF100m	twin fluid	100	2.0/0.7	medium	50	6.6
TF100f	twin fluid	100	3.0/1.4	fine	50	6.9
CT200m	F110/1.60/3 + Crop Tilter	200	2.0	medium	10	8.0

The 'Crop Tilter' was only used for the later sprays in 1989, once the crops were at least 50cm tall. Prior to this, plots allocated to CT200m were treated by system F200m.

Spray quality data was obtained from manufacturers' literature. Drop sizing tests at the AFRC Institute of Engineering Research (now Silsoe Research Institute) have indicated that the twin fluid nozzles were producing much coarser sprays than expected at the pressures originally recommended (Rutherford et al, 1989).

As there was some uncertainty about the correct boom height to use with the swirl (WRW) and twin fluid jets, all the jets were tested over a spray patternator at a series of boom heights. The results of these tests are given in Appendix I. For each system, the minimum boom height giving a coefficient of variation under 20% was selected for subsequent pesticide treatments.

2.2 Application details for treatments in 1990 and 1991

All sprays were applied by a 12m boom Hardi Twin sprayer mounted on an 80 hp tractor. The settings used in 1990 are referred to as Group 2a, and those used in 1991 as Group 2b.

Table 2. Group 2a sprayer settings.

#system code	BCPC code	volume (*l*/ha)	pressure (bar)	nominal spray quality	air speed (m/s at outlet)	boom height (cm)	speed (km/h)
R200m	F110/1.08/2	200	3.0	medium	0	40	8.0
F200m AF200m/VL	F110/1.08/2	200	3.0	medium	16	40	8.0
F100f AF100f/VL	F110/0.60/2	100	2.5	fine	16	40	8.0

Table 3. Group 2b sprayer settings.

#system code	BCPC code	volume (*l*/ha)	pressure (bar)	spray quality	air speed (m/s at outlet)	*boom orientation (see below)
R200m	F110/1.08/2	200	3.0	medium	0	vertical
F100f	F110/0.60/2	100	2.5	fine	0	vertical
AF100f/VL		100	2.5	fine	16	vertical
AF100f/AL		100	2.5	fine	16	45° to rear
AF100f/VH		100	2.5	fine	28	vertical
AF100f/AH		100	2.5	fine	28	45° to rear
AF200m/VL	F110/1.08/2	200	3.0	medium	16	vertical$^+$

Suffix 'A' denotes air assisted; 'R' denotes the reference system. The letters following '/' indicate boom angle ('V' = vertical, 'A' = angled to rear), and fan speed ('L' = low, 'H' = high) respectively.

+ This treatment was only used for deposition tests, and not for any pesticide applications.

* There is an included angle of 20° between the spray bar and the air slot which trails it. 'Boom orientation' here refers to the spray bar angle.

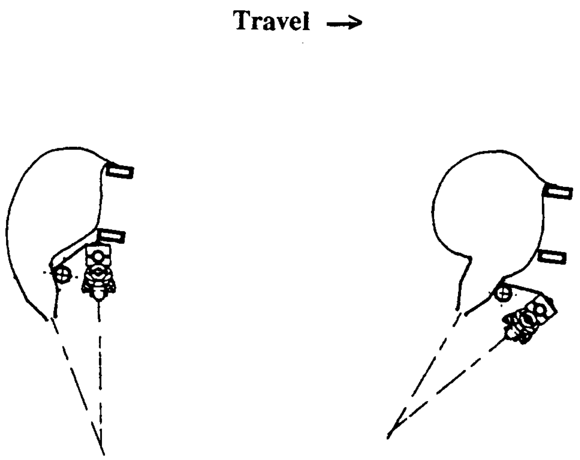

Figure 1. Boom orientation: ’V’ ’A’

A list of suppliers names and addresses for all the application equipment is in Appendix VII.

2.3 Trial sites and treatments

In 1988, two parallel sets of trials were conducted. The crop chosen was spring barley, partly due to its relative importance in Scotland, and partly to ease managing a number of sites by selecting a spread of sowing dates. In the first, 6 sites at different locations and in different varieties were laid out in a simple non-replicated, large plot format, with both herbicides and fungicides applied in the same area. The second trial consisted of separate replicated blocks laid out in the same field at Glencorse Mains, one for herbicides and the other for fungicides. Details of the sites and pesticide applications are given in Table 4. A four replicate randomised block design was used for each.

Table 4. Trial site details, 1988.

site name:	Carberry	Meadowfield	Halls	Hermiston	Thornton	Section 5	Glencorse
layout:	1 rep	1 rep	1 rep	1 rep	1 rep	1 rep	4 reps
plot size:	30m x 24m	30m x 24m	30m x 24m	30m x 24m	24m x 24m	24m x 24m	20m x 12m
variety & date sown:	Triumph 4 Mar	Camargue late Mar	G. Promise mid April	Camargue 1 April	Triumph 7 April	Golf 5 April	Golf 5 April
herbicides:	Ally + Duplosan						
rates:	full	full	full	full	full	full	full + $^{1}/_{3}$
GS; date:	21; 6/5	24; 10/5	31; 7/6 +	22; 18/5	21; 13/5	31; 27/5	31; 1/6
fungicides:	Corbel	Tilt Turbo	Corbel	Corbel	nil	Corbel	Corbel
rates:	full	full	full	full		full	full + $^{1}/_{2}$
GS; dates:	32; 25/5	59; 23/6	31; 7/6 65; 19/7	59; 24/6		45; 10/6	45; 10/6
harvest date:	10/8	22/8	15/9	31/8	(not assessed)	11/9	14/9

full rates: Ally 30 g/ha, Duplosan 2.3 *l*/ha, Tilt Turbo 1.0 *l*/ha, Corbel 1.0 *l*/ha.

In the light of the 1988 results, in 1989 one site with a known weed problem was chosen for a replicated herbicide trial, in spring barley. A switch from spring barley to winter wheat for fungicide applications was made to allow the use of the Crop Tilter, and also hopefully to provide a sterner test due to the spread of yellow rust in wheat. A further change from the previous year was to concentrate the fungicide trials in fewer sites of known good yield potential. Three were selected, each replicated in four randomised blocks. Details of the sites and pesticide applications are given in Table 5.

Table 5. Trial site details, 1989. Plots dimensions 12 m x 15 m.

site name:	Carberry	Hermiston	Trefoil	Glencorse
plot nos:	24	24	48	20
variety & date sown:	Mercia mid Sept	Sleipner mid Oct	Mercia early Nov	Golf early April
herbicides:	-	-	-	Ally+Duplosan
rates:				10g/ha,0.77l/ha
GS; date:				30; 7/6
fungicides:	Sportak Alpha	Tilt Turbo	Tilt Turbo	-
rates:	full	full	full + $^1/_2$	
GS; dates:	32; 26/4	32; 5/5	31; 3/5	
	Tilt Turbo+Bravo	Sportak Alpha	*Corbel+Radar	
	full	full	full + $^1/_2$	
	55; 30/5	36; 19/5	61; 23/6	
	Corbel			
	full			
	58; 15/6			
growth regulators:	-	Arotex Extra	Arotex Extra	-
rates:		1.75l/ha	1.75l/ha	
GS; dates:		32; 5/5	31; 3/5	
harvest date:	(not assessed)	23/8	2/9	4/9

full rates: Tilt Turbo 1.0 *l*/ha, Bravo 1.0 *l*/ha, Sportak Alpha 1.5 *l*/ha, Corbel 1.0 *l*/ha, *Corbel 0.75 *l*/ha, Radar 0.5 *l*/ha.

In 1990 three trial sites were laid out in winter wheat, each fully replicated. Fungicides were applied at all three, but as spring germinating weeds were not generally expected to be competitive, the herbicide trial was restricted to one site with a known weed problem. Assessments were made of weed populations, disease levels, spray deposition and yield. An estimate of spray drift was also undertaken at the same time as the deposition tests. Details of the sites and pesticide applications are given in Table 6. A four replicate randomised block design was used at each site.

Table 6. Trial site details, 1990. Plots dimensions 12 m x 18 m.

site name:	Hermiston	Thornton	Glencorse
variety & date sown:	Riband mid Sept	Riband early Oct	Mercia late Oct
herbicides: GS; date:	Ally 39; 18/5		
fungicides: GS; dates:	Tilt 250EC 36; 17/5	Tilt Turbo 36; 14/5	Tilt 250EC 39; 18/5
	Corbel & Radar 61; 20/6 & 73; 19/7	Corbel & Radar 61; 19/6 & 71; 20/7	Corbel & Radar 55; 19/6
harvest dates:	31/8	8/9	8/9

dose rates:	Ally	Tilt 250EC	Tilt Turbo	Corbel	Radar
standard (R200m)	30 g/ha	0.5 *l*/ha	1.0 *l*/ha	0.5 *l*/ha	0.25 *l*/ha
reduced	10 g/ha	0.25 *l*/ha	0.5 *l*/ha	0.25 *l*/ha	0.12 *l*/ha

The 1990 herbicide trial indicated an effect on herbicide activity. Confirmation was sought in 1991 by increasing the number of weed control trial sites to two, and the crop chosen reverted to spring barley. As in the previous two seasons three replicated trial sites were laid out. Fungicides were applied on all three sites, and herbicides on two of them. Spray deposits were measured on one site only. Details of the sites and pesticide applications are given in Table 7. A four replicate randomised block design was used at each site.

Table 7. Trial site details, 1991. Plot dimensions 12 m x 18 m.

site name:	Gowkley Moss	Hermiston	SCAE
variety: seed treatment:	Camargue dual purpose	Camargue Ferrax	Natasha Ferrax
herbicides: growth stage, date:	Ally 23, 29/5	-	Ally 23, 28/5
fungicides: growth stage, date:	Corbel+Radar (a) 30, 5/6 (b) 60, 17/7	Corbel+Radar (a) 49, 20/6	Corbel+Radar (a) 30, 5/6 (a) 57, 5/7
harvest date:	6/9	30/8	9/9

dose rates:	Ally	Corbel (a)	 (b)	Radar (a)	 (b)
standard (R200m)	30 g/ha	0.5	1.0	0.25	0.5 *l*/ha
reduced	10 g/ha	0.25	0.5	0.12	0.25 *l*/ha

A key to all the pesticide products used can be found in Appendix VII.

2.4 Assessments.

Crop yields were measured by plot combine at all sites, with the exceptions of Thornton in 1988 (Table 4) and Carberry in 1989 (Table 5). Both these sites were abandoned following inadvertent intervention by local farm staff. Using header widthes of 3.0 m or less allowed two cuts per plot, one on either side of the wheel tracks.

Assessments of weed populations and crop disease levels were made after the effects of the respective treatments had time to develop. Crop samples were collected in 1988, but spoilage made subsequent disease assessment impossible. Thereafter all assessments were carried out in the field.

Crop deposits were measured by tracer recovery. Initially the tracer material was dysprosium, applied in 43% w/w 'Cochlight' solution ($DyCl_36H_2O$) (Dobson et al, 1983). Dried and ground samples of the treated plant material were subjected to neutron bombardment at the Scottish Universities Research and Reactor Centre, East Kilbride. Subsequent radioactivity counts at the dysprosium signature frequencies determined the quantities of dysprosium present. This technique was used successfully in 1988, but a change to a less sensitive detector probe at the SURCC resulted in samples collected in 1989 failing to register a count following excitation.

The tracer was changed to fluorescein in 1990 and 1991. In each application the sprayer traversed two short plots lying at least 6m apart. In each plot, ten main shoots were then cut from four 2m long strips lying parallel to the direction of travel and positioned symmetrically on either side of the centre of the spray swath. Hence a total of 80 main shoots were cut. Each sample of ten plants was subsequently divided into three equal lengths and washed in a weak $NaOH_3$ solution to recover the dye. The plant sections were then oven dried and weighed to permit correction for dry matter variations between samples. Solution samples taken from the spray tank in each case were analysed to scale the crop deposits. Tracer concentration was corrected to give the same rate at either spray volume.

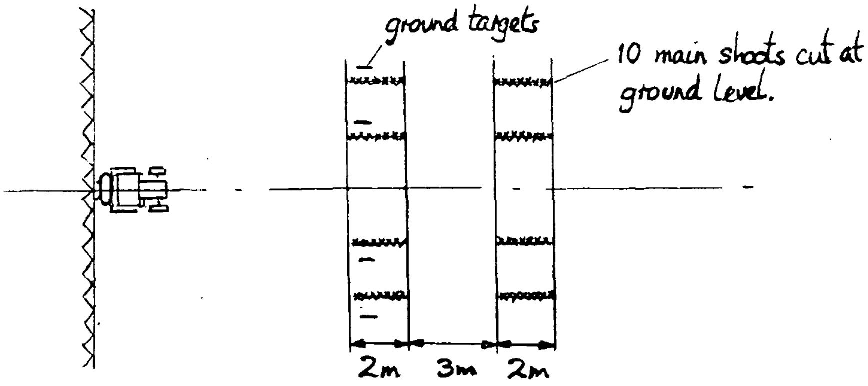

Fig. 2. Layout of deposition tests used in 1990 and 1991

Variance analyses were carried out on all results where appropriate. Least significant differences (LSD's) were calculated at the 5% probability level (Finney, 1972).

3. RESULTS

3.1 Weed control

In 1988 the herbicide used was a mixture of Ally (20% w/w metsulfuron-methyl; Du Pont UK Ltd) and Duplosan New System CMPP (60% w/v mecoprop-P; BASF UK Ltd). The trial site included an untreated area at the upwind end of the treated plots. The range of weeds found and their sizes prior to treatment are shown in Appendix II. No differences in weed control were found between application systems from post treatment assessments at the 6 large plot sites. The same was true of the replicated full rate herbicide trial, but there were differences in the replicated trial when the herbicide rate was reduced. These are shown in Table 8.

In 1989, the herbicide used was the same mixture as that applied in 1988, but at $^1/_3$ rate only. The principal weeds present and their densities prior to spraying are shown in Appendix II. The equivalent data assessed 54 days after spraying are shown in Table 9, and the weed control achieved in terms of numbers and percentage survival of the susceptible species is presented in Table 10.

In 1990 and 1991 the herbicide used was metsulturon methyl alone, applied at reduced dose rates other than in a reference treatment at full dose. Weeds were assessed by percentage ground cover 9 - 10 weeks after treatment, to allow the full herbicidal effects to develop. In 1990 (Table 11) some weeds had died from the effects of drought rather than herbicide.

After treatment in 1991, few of the susceptible species survived in sufficient quantities for sensible assessment. Orache and redshank were found at Gowkley Moss, and fat hen alone at SCAE. The percentage ground cover by these species at the respective trial sites is shown in Tables 12 and 13.

Table 8. Glencorse 1988, $^1/_3$ dose herbicide trial. Percentage ground cover of the principal broadleaf weed species 4 weeks after treatment.

application system	species and mean % ground cover buttercup, field	hempnettle, common	redshank	knotgrass	total
F200m	0.4	-	0.4	1.8	2.6
F100f	0.6	0.1	0.6	1.8	3.1
WRW100m	0.2	-	0.1	0.9	1.2
TF100m	0.8	0.1	0.1	1.8	2.8
TF100f	0.6	0.1	0.8	3.0	4.5
untreated	3.0	0.2	1.0	3.0	10.2
SED = 0.144 LSD 2.97					

Table 9. Glencorse 1989. Weed species and populations per m^2, 8 weeks after spraying. (populations in the treatment area are means of 4 plots).

application system	weed species and number per m^2 Redsh	Orac	BWD	Knot	AMG	Btc	SD	Chw	Gdsl	MW
F200m	0.25	2.3	0.3	7.3	70	0	0	0	0	0
F100f	2.0	4.4	0.5	10.6	78	0.25	0	0	0	0
WRW100m	0.6	2.9	0.75	6.2	61	0.25	0	0	0	0
TF100m	1.5	1.3	0.05	9.5	49	0.05	0	0.05	0	0
TF100f	0.75	4.2	0.1	7.3	56	0	0	1.0	0.45	0
untreated	28.8	22.1	2.4	25.4	63	3.0	2.1	5.5	1.2	3.6

Key to Tables 8 and 9: Redsh = redshank, Orac = orache, Spur = spurrey, BWD = black bindweed, Knot = knotgrass, AMG = annual meadow grass, Btc = buttercup, SD = seedling dock, RMG = rough meadow grass, Chw = chickweed, Gdsl = groundsel, MW = mayweed.

Table 10. Glencorse 1989. Populations of all susceptible weeds 8 weeks after spraying, means of 4 blocks (excludes annual meadowgrass).

	F200m	F100f	WRW100m	TF100m	TF100f	SED	LSD
plants/m^2	14.35	17.70	10.65	12.40	13.75	6.37	NS
% survival	26	27	18	28	19	9.55	NS

Table 11. Glencorse, 1990. Percentage ground cover of the major susceptible weeds surviving 9 weeks after treatment; means of 4 replicates.

application system		Weed species and % ground cover Common chickweed	Other weeds
R200m	(full dose)	0.1	0.1
F200m	(${}^1/_3$ dose)	3.5	0.2
AF200m/VL	" "	0.02	0.1
F100f	" "	0.2	0.2
AF100f/VL	" "	0.3	0.2
SED		1.37	0.09
LSD		2.99	0.20

Table 12. Gowkley Moss, 1991. Percentage ground cover of principal broadleaf weed species before and 11 weeks after treatment (means of 4 blocks).

species:	chickweed	hempnettle	orache	redshank
before treatment:	0.53	0.05	0.34	0.94
SD	0.38	0.03	0.40	0.90
after treatment:application system				
R200m			0.63	0.80
F100f			1.38	0
AF100f/VL			3.75	0.88
AF100f/AL			0.25	0.38
AF100f/VH			0.75	0.38
AF100f/AH			0	0.13
SED			1.23	0.64
LSD			2.66	1.38

Table 13. SCAE, 1991. Percentage ground cover of principal broadleaf weed species before and 10 weeks after treatment (means of 4 blocks).

species:	chickweed	hempnettle	fat hen	redshank
before treatment:	3.83	0.74	0.47	0.07
SD	0.84	0.54	0.40	0.04
after treatment: application system				
R200m			0.50	
F100f			4.00	
AF100f/VL			1.25	
AF100f/AL			3.25	
AF100f/VH			0	
AF100f/AH			4.00	
SED			1.69	
LSD			3.65	

3.1.1 Discussion - weed control

Group 1

There was no clear pattern of response to full chemical rate treatments in 1988. In general, weed control was very good. All broad-leaved weeds were controlled at Hermiston, and most of the weeds at the other sites.

At the replicated sites (Tables 8 and 9), weed control at the full chemical rate was again very good. When the herbicide rate was reduced to $^1/_3$ of the label recommendation, there was a difference in response in 1988. Best control was achieved by system WRW100m, which gave significantly better overall weed control than system TF100f, the least effective system that year. There were no significant differences between systems in 1989, however system WRW100m again gave the best overall control.

There was no evidence of crop scorch from any of the systems tested at any of the sites.

Group 2

In 1990 the minor broad leaved weeds, grouped together as 'other weeds' in Table 13, were best controlled by the standard rate of herbicide. There was no difference in control between the reduced dose treatments. Common chickweed (Stellaria media) was the only broad leaved weed present in sufficient numbers to warrant separate analysis. There were significant differences between control by the $^1/_3$ rate herbicide treatments applied with air assistance compared to those applied without air. The effect was only apparent at the 200 *l*/ha volume, where air assistance brought control by the $^1/_3$ dose up to the same level as the full dose treatment (R200m).

The 1991 results (Tables 12 and 13) show an inconsistency between the two sites. The sprayer setting which gave the best control of orache (Atriplex patula) and fat hen (Chenopodium album) used the higher air outlet speed. However, there was a discrepancy in the effect of boom orientation between the two varieties. The vertical nozzle orientation gave significantly better control of fat hen at SCAE than angled nozzles (high air), while angled nozzles gave significantly better control of orache at Gowkley Moss (low air). Only at SCAE did air assistance give significantly better control of any weed at the 100 *l*/ha volume, $^1/_3$ dose, compared to the same treatment applied without air. Both crops were at the same growth stage (GS23) when the herbicide was applied.

3.2 Disease control and crop yield

Mean yields for each of the Group 1 systems in 1988 are shown in Table 14. Yield data from the individual non-replicated large plot sites and the replicated trials can be found in Appendix III.

Combining the yields from the large plot trials in 1988 reveals a small yield reduction from system TF100m sprays compared to all the others except F200m. In the replicated fungicide trials there were no significant differences at either full or reduced rates.

In 1989 three sites were assessed for fungal infections at a minimum interval of 4 weeks after treatment. The plots were clear of foliar diseases, apart from some mildew (Erysiphe graminis) at Hermiston where the level of infestation was too slight for any meaningful comparisons. Eyespot (Pseudo-cercosporella herpotrichoides) and sharp eyespot (Rhizoctonia cerealis) were found at all three sites. The highest initial level (at 25% of stems infected) was found at Carberry, where a second assessment was conducted later in the season. The analyses were confined to eyespot, as the fungicides applied were not expected to control sharp eyespot. It is likely that drought in late May and June inhibited eyespot development. In all cases the errors exceed any differences between systems. Assessed mean disease levels can be found in Appendix IV.

Mean yields from the three sites where fungicides were applied in 1989 are shown in Table 15. Yield data from the individual sites can be found in Appendix IV.

Yield differences between systems in 1989 in no case exceeded differences between the trial blocks. When the three sets of yield data are combined there are no differences between systems.

In 1990 the only significant diseases found were mildew and septoria (Septoria triticii), which affected all three sites to varying degrees. Hermiston and Glencorse sites were treated with propiconazole (Tilt 250EC, Ciba-Geigy) at GS 39 as a protectant against both diseases. At the same growth stage, the trial at Thornton was treated with propiconazole + tridemorph (Tilt Turbo 375EC, Ciba-Geigy) to give protection against the additional risk of yellow rust (Puccinia striiformis) spreading to the trial from neighbouring fields. Later infections of mildew at all sites were treated with a mixture of fenpropimorph (Corbel, BASF) plus propiconazole (Radar, ICI), both with the standard rate set at half that recommended on the label. This treatment was repeated one month later at Hermiston and Thornton only.

All three wheat sites were assessed at intervals of at least 4 weeks after applying the first of the fenpropimorph plus propiconazole sprays. The only significant difference in mildew control occured at Glencorse, where F200m produced inferior control to both R200m and AF200m. These differences were not consistent at the other sites, and when the site means are combined there were no significant differences. There were no significant differences in control of septoria. Post treatment infection levels can be found in Appendix V.

Mean yields from three sites in 1990 are shown in Table 16. Yields from each of four blocks at the individual sites are shown in Appendix V.

All sites suffered infections of mildew in 1991, but no other diseases were present at more than trace levels. Both SCAE and Gowkley Moss sites were treated with a mixture of morpholine (Corbel, BASF) plus triazole (Radar, ICI) at GS 30, and again at around GS 60 (see Table 2). The 'standard' rate was set at half the recommended label dose, and 'reduced' dose treatments were applied at quarter label dose. These dose rates were doubled in the second treatment at Gowkley Moss, due to higher levels of mildew. The disease assessments shown in Table 17 were made at intervals following both treatments, as shown in Tables 4 and 5.

At Hermiston, a single treatment with the same fungicide mixture was applied at GS 49. A combination of a low incidence of disease and a very uneven crop (probably due to spreading of chicken manure) made meaningful disease assessments impracticable.

There were no significant differences in mildew control between application systems following any of the individual treatments. The composite line in Table 17 was derived by combining the two sets of assessment results from SCAE (analysed as one treatment replicated 8 times). This indicates that control was less effective from the non-air assisted half dose system (F100f) compared with the reference system (R200m). Adding a moderate air flow with the nozzles set to spray vertically down (AF100f/VL) gave equivalent control to the reference.

None of the individual sites in 1991 exhibited any significant yield differences between application systems, nor were there any differences when the three sets of data were combined. Leaving aside the low disease site at Hermiston, and combining the results from SCAE and Gowkley Moss alone (Table 18) reveals a significantly higher yield from the high air speed, vertical nozzle treatment (AF100f/VH) than either of the non-air assisted treatments. Yield data from the individual sites is provided in Appendix VI.

Table 14. Mean grain yields from Group 1 applications in 1988, t/ha at 15% m.c..

	application system						
site	F200m	F100f	WRW100m	TF100m	TF100f	SED	LSD
composite of block trials	6.87	7.04	7.25	6.59	7.12	0.19	0.41
replicated, full rate fungicide	3.09	3.43	3.55	3.26	3.47	0.39	NS
replicated, $^1/_2$ rate fungicide	3.46	3.71	3.79	3.18	3.58	0.39	NS

Table 15. Mean wheat yields from Group 1 applications in 1989, t/ha at 15% m.c..

	application system							
site	F200m	F100f	WRW100m	TF100m	TF100f	CT200m	SED	LSD
Hermiston	6.47	6.58	7.90	7.42	7.10	7.25	0.52	1.12
Trefoil, full rate fungicider	9.58	9.68	8.99	9.58	9.88	9.78	0.39	0.84
Trefoil, reduced rate fungicide	10.08	9.48	9.48	9.68	9.09	9.29	0.46	0.98
composite, corrected to a common mean of 8.5 t/ha	8.34	8.20	8.52	8.57	8.34	8.45	0.30	NS

Table 16. Mean wheat yields from Group 2 applications in 1990, t/ha at 15% m.c..

site	application system R200m	F200m	AF200m /VL	F100f	AF100f /VL	SED	LSD
Hermiston	12.88	13.16	12.76	12.98	12.42	0.31	0.68
Thornton	9.61	8.90	8.95	9.52	9.14	0.42	NS
Glencorse	8.38	8.48	8.30	8.75	9.03	0.37	NS
composite mean	10.29	10.19	10.01	10.42	10.20	0.26	NS

Table 17. Disease control from Group 2a applications in 1991 - percentages of plants infected with mildew (means of 4 blocks).

site and assessment	application system R200m	F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH	SED	LSD
SCAE								
treatment 1 + 13 days	0.10	2.75	0.55	1.58	2.03	2.28	1.38	NS
treatment 2 + 20 days	0.68	1.80	0.10	0.58	0.10	1.80	0.95	NS
composite	0.39	2.28	0.33	1.08	1.06	2.04	0.83	1.70
Gowkley Moss								
treatment 1 + 16 days	0.55	0.10	0.58	0.83	0.33	0.33	0.57	NS
treatment 2 + 8 days	27.5	33.8	22.5	22.5	31.3	18.8	12.4	NS

Table 18. Mean barley yields from Group 2a applications in 1991, t/ha at 15% m.c..

site and assessment	application system R200m	F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH	SED	LSD
SCAE	5.82	6.07	5.87	6.00	6.37	5.76	0.30	0.65
Gowkley Moss	6.84	6.84	7.13	6.98	7.53	7.51	0.34	0.74
Hermiston	7.20	7.26	6.89	7.29	6.91	7.36	0.24	0.52
composite (all sites)	6.62	6.72	6.63	6.75	6.93	6.88	0.18	0.36
composite (SCAE and Gowkley Moss)	6.33	6.45	6.50	6.49	6.95	6.64	0.23	0.46

3.2.1 Discussion - disease control and crop yield

Group 1

In 1988, the large plot trials indicated a reduction in yield from areas treated by the twin fluid medium sprays (TF100m). TF100m consistently under-yielded system TF100f at each large plot site, by around 0.5 t/ha. The TF100m mean yield was significantly less than all the other systems except F200m. Although the replicated fungicide trials that year produced no significant yield differences, consistent with the large plot results TF100m yields were at the bottom of the range in both full and reduced dose trials.

In contrast, the 1989 yield results indicate no advantage to any of the systems tested. The yield reductions attributed to system TF100m in 1988 were not repeated. Yield variations between systems were found at all three trial sites, but these were not consistent. Considering all the fungicide trials together (Table 15) there was no detectable yield effect due to the method of spray application.

The spray qualities produced by the twin fluid system in these trials were both coarser than would normally be recommended for fungicide applications.

Group 2

Stem base diseases never infected the trials in 1990 to any measurable extent. Given that all the fungicides used have systemic activity, as might be expected air assistance had little effect on treatment of the foliar diseases encountered. Correspondingly, no yield effects were found.

The results from 1991 show a variable pattern of disease control due to the effects of boom orientation and air speed. In all the assessments the non-air assisted, reduced dose treatments were less effective than the reference, full dose treatment. At each assessment, the best control by treatment at reduced dose was always achieved by one or other of the air assisted sprays. At one of the two sites assessed, one air speed/boom orientation (F100f/VL) at reduced dose gave significantly better control than the same treatment applied without air. This effect was not found at the other site.

Considering the two sites in 1991 (SCAE and Gowkley Moss) where fungicide treatments were expected to have a yield response, all the air assisted treatments produced yields at least as good as, and in one case significantly more than, the reference treatment. Increased overall deposition could explain this, but not the improvement over the 100 *l*/ha non-air assisted treatment, which gave a similar deposit pattern to the air assisted treatments. The analyses on deposition used here did not assess evenness of distribution on the plants, which could have been having an effect on fungicide take up. It is worth noting that the best results in both disease control and yield were produced by air assisted treatments, though not the same ones.

3.3 Spray deposition

In 1988 the tracer material (dysprosium) was sprayed onto the inter-plot zones of one trial site on 30th June at around GS 60. 2 hours later, plants in a 0.25 m^2 quadrat were pulled from three sites within each treatment area. The plants were divided to estimate spray distribution between the plant lower halves and upper halves; the resulting samples were then dried and ground. Five phials containing 0.2 g were taken from each sample to undergo neutron bombardment. The results are presented in Table 19 as parts per million of dry plant material.

A similar deposition test was conducted on wheat in 1991, on May 31 at around GS39 when the average crop height was 60 - 70 cm. As explained in section 2.3, the tracer material used was fluorescein dye, applied in the same manner as the pesticides. Eight samples of ten plants each were cut into upper, middle and lower sections of roughly similar length and leaf numbers. The results are shown in Table 20.

A further test using the same technique was carried out in 1991. On this occasion the crop had been drilled at broad enough spacing to allow ground targets to be placed and retrieved. The test was conducted at SCAE on 1 Aug (GS 73) when the mean stem height was 80cm. Plant density was estimated at 1150 stems/m^2. Fluorescein dye was applied using all the systems detailed in Table 3, including an application at 200 *l*/ha with air assistance (AF200m/VL). The results are shown in Tables 21 and 22.

To estimate ground deposits, 50 cm x 5 cm strips of chromatography paper were attached to thin timber battens. Four of these were placed between the drills, adjacent to but one drill away from the sample drills in the first plot. Three 5 cm x 5 cm samples were cut from each strip for analysis after the sprayer had passed. The results are shown in Table 23.

Tables 21 and 22 show that adding air assistance to the medium, 200 *l*/ha spray with the nozzles aimed vertically down had the effect of increasing deposition at the bottom of the plants. Overall spray recovery from the plants was also increased.

The effect on the fine, 100 *l*/ha spray, is shown in Table 22. Overall spray recovery was unchanged by any of the air assisted treatments, although small non-signicant increases were recorded on the lower plant sections when the nozzles were set vertical. Angling the nozzles back at the low air speed tended to reduce penetration and increase deposits higher up the plant. Increasing air speed tended to shift deposits from the upper to middle strata, countering the effect of the angled nozzles. Table 23 shows that ground deposits were significantly reduced at both air speeds when the nozzles were angled back.

Table 19. Group 1 spray deposits on barley plants, 1988, means of 5 tests; ppm dm.

deposit	application system						
location	F200m	F100f	WRW100m	TF100m	TF100f	SED	LSD
upper halves	0.82	0.67	0.87	0.67	0.72	0.176	NS
lower halves	0.5	0.36	0.26	0.34	0.29	0.064	0.146
overall	0.66	0.52	0.57	0.51	0.51	0.098	NS

Significant differences are indicated between F200m and WRW100m, F200m and TF100m, and F200m and TF100f on the plant lower halves.

Table 20. Group 2 spray deposits on wheat plants (means of 8 samples), 1990; μl per 10 stem sections.

application	plant section			
system	upper	middle	lower	whole plant
F200m	2.70	0.33	0.26	3.29
AF200m/VL	2.56	0.44	0.39	3.39
SED	-	0.051	0.044	0.229
LSD	NS	0.11	0.10	NS
F100f	2.65	0.38	0.33	3.36
AF100f/VL	2.91	0.45	0.30	3.66
SED	0.220	0.062	-	0.306
LSD	NS	NS	NS	NS

Table 21. Group 2a deposits on barley plants sprayed at 200 *l*/ha (means of 8 samples), 1991; μl per 10 stem segments

location	application system			
	R200m	AF200m /VL	SED	LSD
upper stems	66.0	79.1	6.84	NS
mid stems	14.2	18.4	2.72	NS
lower stems	6.1	11.8	1.56	3.4
total	86.3	109.3	9.84	21.3

Table 22. Group 2a deposits on barley plants sprayed at 100 *l*/ha (means of 8 samples), 1991; µ*l* per 10 stem segments, corrected to the same rate of tracer as sprays at 200 *l*/ha.

location	application system F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH	SED	LSD
upper stems	85.2	82.7	102.0	81.1	83.2	12.56	NS
mid stems	11.6	12.2	10.5	14.9	16.1	3.28	NS
lower stems	6.0	9.7	5.0	7.4	6.1	2.48	NS
total	102.7	104.6	117.5	103.4	105.4	16.16	NS

Table 23. Group 2a spray deposits on ground targets (means of 4 samples), 1991; µ*l* per 100cm^2 corrected to 200 *l*/ha spray volume.

application system R200m	AF200m /VL	F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH
29.2	33.6	43.2	30.4	18,4	28.8	13.0
SED = 4.4						SED = 7.2
LSD NS						LSD 15.0

In Tables 20 - 23 preceding, underlined values indicate a significant change compared to the same spray applied without air.

3.3.1 Discussion - spray deposition

Group 1

The analysis reveals two interesting phenomena. Firstly, the total quantity of spray collected on the plant surfaces was highest from the higher volume (200 *l*/ha) sprays. Calling this 100%, the next highest was the swirl jet which deposited 86%, while the rest were between 75% and 80%. (Note that the amount of tracer applied in each treatment was the same.) Secondly, the distribution of spray collected over the length of the plants was biassed towards the upper half in all treatments. The bias was greatest in the swirl jet treatments, where only 23% of the spray collected was on the lower halves. The equivalent figures averaged around 35% in all the other treatments.

Group 2

Although overall deposition was little changed, penetration to the lower horizons in the crop canopy was improved by air assistance. The only surprise is that the medium quality, 200 *l*/ha sprays were affected more than the fine 100 *l*/ha sprays. The opposite might be expected, as smaller droplets are more influenced by aerodynamic forces.

The improvement in penetration using a 200 *l*/ha, medium spray was again demonstrated in 1991. Attempts to fine tune the air speed and boom orientation with a 100 *l*/ha, fine spray have proved less conclusive. The only significant result was reduced deposition on the ground when the boom was angled to the rear.

3.4 Spray drift from group 2 applications

Concurrently with the deposition test in 1990, an assessment was made of spray drift using the same tracer and recovery method. In an adjacent field of wheat, also at 60-70cm plant height, four masts at 10 m intervals were set in a line at right angles to the nominal wind direction. Each mast supported 9 pairs of horizontally disposed pipe cleaners at 0.5 m intervals from 0.8 m to 4.6 m height above ground.

The sprayer was driven along a path parallel to the masts, such that the near boom end passed 5 m upwind of them. Four passes were made in each test (two in each direction), while a hand held hot wire anemometer with averaging facility monitored windspeed at boom height immediately upwind of the sprayer.

Although the method employed cannot replicate wind conditions exactly between tests, the results show that air assistance reduced drift collection substantially for both spray qualities. The more consistent wind conditions during the test with the fine sprays indicate a drift reduction of 50% due to air assistance.

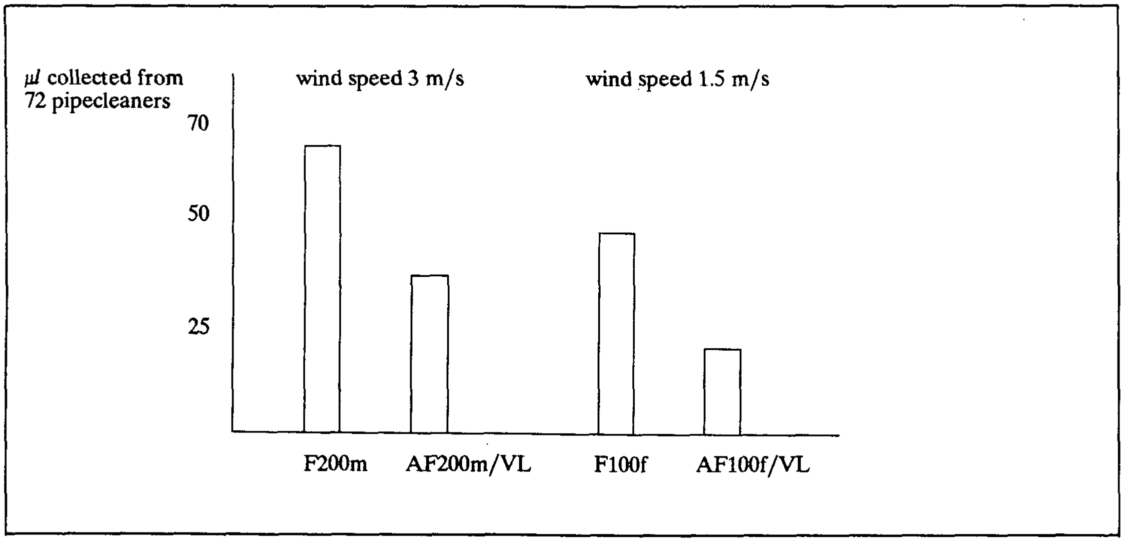

Figure 3. Spray drift over wheat at GS39, measured 5m downwind of boom end.

4. CONCLUSIONS

For any spray application system to work reliably throughout the growing season, good coverage of all parts of the cereal plants and underlying weeds is desirable. This is especially relevant when tank mixing products for differing targets, like herbicides with fungicides. The reference system, flat fan jets applying 200 *l*/ha in a 'medium' spray quality (F200m), demonstrated a robust ability to perform well in all the treatments applied throughout these trials. Comparing deposition patterns with the other systems gives a partial explanation; only the air assisted applications in Group 2 increased deposition at the lower stem levels. Similarly, only the air assisted applications demonstrated any consistent gain in efficacy, particularly in reduced rate herbicide treatments.

Two of the Group 1 systems allow reduced spray volumes simply by changing spray jets on a conventional sprayer. The small flat fan jets (F100f) generally performed as well as the reference system, but create a significantly higher drift hazard (Rutherford et al, 1989). For this reason, a 'fine' spray quality is not often recommended for herbicide treatments. Where differences in spring barley weed control were found at all, the swirl jets (WRW100m) produced the best results in Group 1, despite giving a low rate of deposition at the lower stem levels. Disease control as reflected in yields of spring barley from swirl jet applications was similar to the reference, although the yields tended towards the upper end of the range. However, this trend was not repeated in denser wheat crops. Although producing a 'medium' spray quality, relative to the reference system spray drift from the swirl jets is closer to that from the 'fine' fan jets (Rutherford et al, 1989), due at least in part to the need for a higher boom (Miller, 1988).

Both twin fluid sprays produced slightly less consistent results than the reference system. Where differences in spring barley weed control were found at all, twin fluid 'fine' sprays were the least effective. This is consistent with the deposition pattern, which shows less spray deposit on the lower halves of the crop stems than for the reference system. In spring barley fungicide trials, yields from plots treated by twin fluid 'medium' sprays tended to be at the bottom of the range. As with the swirl jets, this trend was not repeated in trials in winter wheat. Spray drift from the twin fluid nozzles at either setting was generally less than from the reference system. As the spray qualities turned out to be rather coarser than those intended, the twin fluid nozzle manufacturer has since issued revised pressure settings.

The 'Crop Tilter' proved awkward in anything other than very level fields. Any rut in the wheel track, or rise in the ground to either side of the wheelings, caused the low end of the boom to dig in to the extent that the boom end swung back on the break-back protection mechanism. While a more sophisticated boom mounting system could reduce this tendency, the practicality of the 'Crop Tilter' must be questioned on less than even fields or boom widthes greater than 12m.

Air assistance provided by the ducted fan arrangement in Group 2 improved penetration and crop capture of a 200 *l*/ha medium spray. At the same time, spray drift was reduced by around 50%. Although overall deposition was little changed, penetration to the lower horizons in the crop canopy was improved by air assistance. Deposition on the ground from a 100 *l*/ha fine spray was reduced by air assistance with the boom angled to the rear, and distribution in the crop was biassed towards the upper strata. The only surprise is that the medium quality, 200 *l*/ha sprays were affected more than the fine 100 *l*/ha sprays. The opposite might be expected, as the influence of aerodynamic forces relative to gravitational force increases as drop size reduces.

Air assistance using $^1/_3$ rate herbicide improved control of certain weed species. The effect was most noticeable when air assistance was added to the 200 *l*/ha medium spray, consistent with the improvement in crop penetration. Boom orientation had variable effects on weed control with fine sprays, but higher air speeds gave marginally better results.

Air assisted fungicide sprays did increase yields of spring barley where mildew incidence was moderate or higher. A high air speed with the nozzles set vertically gave the best yield results. However, air assistance did not have any consistent affect on the assessed mildew levels, regardless of boom orientation or air speed. No effect attributable to air assistance was found in fungicide treatments on winter wheat.

By effectively controlling spray drift, air assistance in the form tested here has the potential to increase the number of work opportunities. Improved spray timeliness is likely to have a greater benefit than the small efficacy increases recorded. The added parameters of air speed and boom orientation allow some tuning of the spray deposition pattern in the crop. As these trials have shown, it is not always easy to predict the optimum settings. To obtain the best results a high degree of operator skill is required, involving a knowledge of both the nature of the pesticide target and the characteristics of the equipment.

ACKNOWLEDGMENTS

The author acknowledges full financial support from the Home-Grown Cereals Authority. Appreciation is expressed to the farmers who provided trial sites over the period of the investigations.

SAC Edinburgh staff contributing to this work were: Dr D H K Davies, Crop Systems Department, for the weed assessments; Dr S J P Oxley, Plant Protection Department for the disease assesssments; Mr P J M Krause, project technician, for conducting the field operations; and the SCAE field staff for assisting in machinery preparation and harvesting.

The air assisted sprayer was kindly loaned by Hardi Ltd. Special thanks are due to Mr W Taylor of Hardi International A.S., who assisted in carrying out all the fluorimetric deposit and spray drift analyses.

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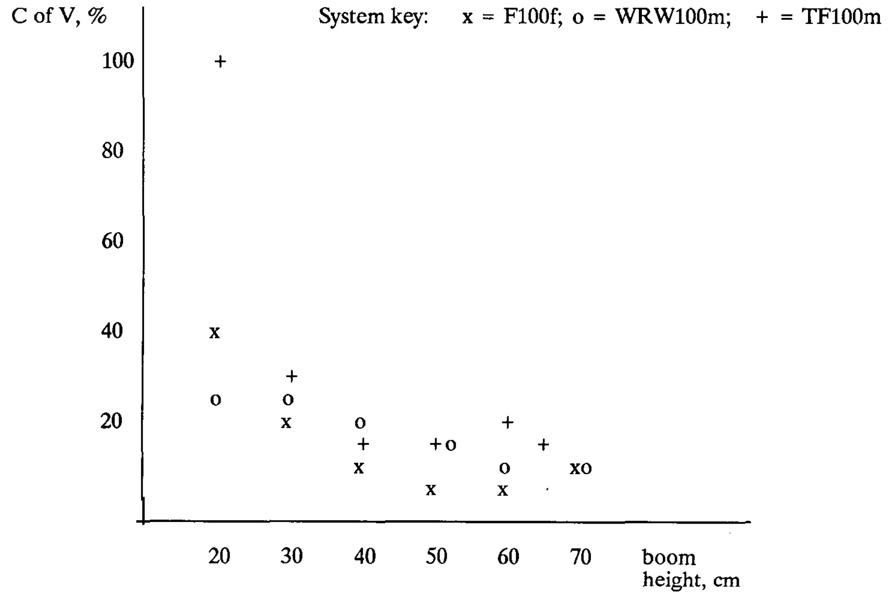
APPENDIX I

Spray patternator tests, Group 1.

Coefficients of variation (%) across spray boom at various heights.

boom	application system		
height (cm)	F100f	WRW100m	TF100m
20	40	23	98
30	18	25	30
40	12	20	17
50	6.5	13	17
60	4.9	12	22
70	7.7	7.7	16



APPENDIX II

Pre-treatment weeds and populations, 1988 and 1989.

Weeds growth stages and sizes at time of spraying, 1988.

	site name						
weed	Carberry	Meadowfield	Halls	Hermiston	Thornton	Section 5	Glencorse
bindweed, black	-	-	-	-	-	-	C
buttercup, field	-	-		-	-	-	3lf
chickweed, common	10-20mm	20-40mm	-	C-2pr	-	C-2pr	3pr
cleavers	-	1-3 whorl	-	C-1 whorl	-	-	-
deadnettle, red	-	-	-	C	-	-	-
groundsel	-	-	-	-	-	C-2pr	-
hempnettle, common	-	-	-	C-1pr	2pr	C-2pr	1pr
knotgrass	2lf	-	-	-	40mm	-	2lf
mayweeds	-	20-40mm	-	1pr	-	C-2pr	2pr
meadowgrass, ann.	4lf	3lf	2lf	2lf	-	C-2lf	2lf
oilseed rape, vol.	-	2-4lf	-	C-1pr	-	-	-
pansy, field	C-1pr	-	-	-	2pr	C-2pr	-
poppy, field	40mm	20-40mm	-	-	-	-	-
redshank	2lf	-	-	-	40mm	C-2lf	2pr
speedwell, ivy-leaved	C-3pr	3pr	-	C-1pr	-	-	-
speedwell, com. field	C-3pr	-	-	-	-	-	-
crop growth stage	13-21	22	13-21	12-13	21-22	13-21	13-21

Key:C = cotyledons; lf = leaves; pr = pairs of leaves.

Glencorse 1989. Weed species and populations per m^2 - pre spray.
(populations in the treatment area are means of 4 plots)

	Weed species and number per m^2											
application system	Redsh	Orac	Spur	BWD	Knot	AMG	Btc	RMG	SD	Chw	Gdsl	MW
F200m	16.6	10.2	1.2	3.0	11.0	51.2	5.0	0.4	0.8	4.2	1.0	9.2
F100f	21.8	26.2	0.6	2.0	16.8	38.6	1.2	0.6	2.0	14.2	2.8	1.4
WRW100m	16.4	26.2	1.8	1.8	11.8	52.8	1.2	0.4	0.8	6.4	0.2	0.6
TF100m	13.5	6.0	0.6	2.4	12.2	63.0	2.4	1.2	0.2	6.0	0.4	0.8
TF100f	18.4	19.6	0	4.0	17.4	63.4	2.6	1.2	0.6	11.6	0.4	0.8
Untreated	23.6	22.1	0.1	4.8	19.0	45.6	2.7	0.4	1.3	5.4	1.2	1.6

Key: Redsh = redshank, Orac = orache, Spur = spurrey, BWD = black bindweed, Knot = knotgrass, AMG = annual meadow grass, Btc = buttercup, SD = seedling dock, RMG = rough meadow gras, Chw = chickweed, Gdsl = groundsel, MW = mayweed.

APPENDIX III

Individual site yields, 1988.

Yields from the large plot trials, t/ha at 15% mc.

site name	application system site F200m	F100f	WRW100m	TF100m	TF100f	mean
Carberry	6.73	7.18	7.73	6.89	7.11	7.27
Meadowfield	8.61	8.67	9.00	7.56	8.83	8.67
Halls	5.49	5.89	6.33	5.40	5.89	5.87
Hermiston	7.47	7.17	7.41	7.16	7.44	7.30
Section 5	6.06	6.32	5.78	5.93	6.32	6.07
mean	6.87	7.04	7.25	6.59	7.12	
SED between systems = 0.19						
LSD	0.41					

Significant differences are indicated between system TF100m and all the others except F200m.

Yields from the full rate replicated fungicide trial, Glencorse, t/ha at 15% mc.

block number	application system site F200m	F100f	WRW100m	TF100m	TF100f	block mean
1	3.04	2.89	3.22	3.37	3.38	3.18
2	3.15	4.81	4.13	3.65	4.43	3.95
3	2.37	3.70	2.72	2.31	3.07	3.12
4	3.80	2.91	4.13	3.70	2.98	3.47
mean	3.09	3.43	3.55	3.26	3.47	3.43
SED between systems = 0.39						
LSD	NS					

No significant differences are indicated between systems or blocks.

Yields from the $^{1}/_{2}$ rate replicated fungicide trial, Glencorse, t/ha at 15% mc.

block number	application system site F200m	F100f	WRW100m	TF100m	TF100f	block mean
1	3.18	3.03	3.56	2.93	3.31	3.21
2	4.02	5.38	4.74	3.17	4.45	4.13
3	2.77	2.96	3.83	3.84	3.32	3.38
4	3.86	3.42	3.05	2.76	3.23	3.16
mean	3.46	3.71	3.79	3.18	3.58	3.47
SED between systems = 0.39						
LSD	NS					

No significant differences are indicated between systems or blocks.

APPENDIX IV

Disease levels and individual site yields, 1989.

Percentages of stems infected with eyespot - means of 4 blocks.

site, date, growth stage	application system					
	F200m	F100f	WRW100m	TF100m	TF100f	SE
Carberry, 25/5, GS45	20.0	10.0	20.0	10.0	17.5	9.22
Carberry, 17/7, GS75	97.5	95.0	92.5	95.0	92.5	6.37
Hermiston, 13/6, GS49	57.5	65.0	65.0	60.0	65.0	12.06
Trefoil A, 26/5, GS37	20.0	35.0	15.0	17.5	32.5)	11.72
Trefoil B, 26/5, GS37	30.0	20.0	30.0	10.0	30.0)	

Trefoil A = full rate fungicide, Trefoil B = $^{1}/_{2}$ rate fungicide. In all cases the errors exceed any differences between systems.

Wheat yields from fungicide trial, Hermiston; t/ha at 15% m.c.

block number	application system						
	F200m	F100f	WRW100m	TF100m	TF100f	CT200m	block mean
1	6.04	6.39	6.70	6.69	5.79	6.45	6.34
2	6.96	5.99	8.21	8.30	7.26	6.89	7.27
3	6.10	7.61	7.88	7.05	6.15	7.49	7.05
4	6.80	6.32	8.79	7.65	9.20	8.18	7.82
mean	6.47	6.58	7.90	7.42	7.10	7.25	7.12

SED between systems = 0.52
LSD 1.12

Significant differences are indicated between systems WRW100m and F200m, and betweeen WRW100m and F100f; also between blocks 1 and 2, and 1 and 4. Variations between systems are less than variations between blocks.

Wheat yields from full rate fungicide trial, Trefoil A; t/ha at 15% m.c.

block number	application system F200m	F100f	WRW100m	TF100m	TF100f	CT200m	block mean
1	9.72	9.77	9.08	10.53	9.49	10.81	9.88
2	9.10	8.90	8.86	9.34	8.91	9.16	9.09
3	10.53	10.90	9.46	9.51	10.34	10.14	10.18
4	9.17	9.15	8.55	8.88	10.57	8.99	9.19
mean	9.58	9.68	8.99	9.58	9.88	9.78	9.58

SED between systems = 0.39
LSD 0.84

A significant difference is indicated between systems TF100f and WRW100m; and between blocks 1 and 2, 1 and 4, 3 and 2, and 3 and 4. Variations between systems are no greater than variations between blocks.

Wheat yields from half rate fungicide trial, Trefoil B; t/ha at 15% m.c.

block number	application system F200m	F100f	WRW100m	TF100m	TF100f	CT200m	block mean
1	10.19	9.52	8.98	9.34	10.33	10.00	9.68
2	9.31	8.46	9.14	9.06	8.73	8.80	8.89
3	10.81	10.51	10.39	11.05	8.39	8.97	9.98
4	10.11	9.33	9.24	9.25	8.85	9.42	9.39
mean	10.08	9.48	9.48	9.68	9.09	9.29	9.58

SED between systems = 0.46
LSD 0.98

Significant differences are indicated between F200m and TF100f; and between blocks 3 and 2. Variations between systems are no greater than variations between blocks.

APPENDIX V

Disease levels and individual site yields, 1990.

Percentages of plants infected with mildew - means of 4 blocks.

site, date, growth stage	application system R200m	F200m	AF200m	F100f	AF100f	SED	LSD
Hermiston, 25/7, GS75	0.5	0.5	2.0	0.5	0.75	1.01	NS
Thornton, 25/7, GS75	0.8	3.28	3.03	1.8	3.8	2.75	NS
Glencorse, 22/7, GS71	0	2.0	0	0.5	0.78	0.80	1.76
combined mean	0.43	1.9	1.60	0.9	1.78	0.67	NS

Significant differences are indicated between F200m and R200m, and F200m and AF200m at Glencorse.

Percentages of plants infected with septoria - means of 4 blocks

site, date, growth stage	application system R200m	F200m	AF200m	F100f	AF100f	SED	LSD
Hermiston, 25/7, GS75	2.25	1.25	2.0	1.78	1.5	1.30	NS
Thornton, 25/7, GS75	5.25	8.75	4.75	5.5	8.75	1.94	NS
combined mean	3.75	5.0	3.38	3.64	5.12	1.48	NS

Wheat yields from the trial site at Hermiston, t/ha at 15% m.c.

block number	application system R200m	F200m	AF200m	F100f	AF100f	block mean
1	12.85	12.39	13.06	12.57	12.24	12.63
2	13.23	13.45	12.19	13.07	12.33	12.85
3	13.31	13.21	12.65	13.14	12.63	12.98
4	12.13	13.58	13.15	13.14	12.48	12.89
mean	12.88	13.16	12.76	12.98	12.42	12.84
SED between systems = 0.31 LSD 0.68						

A significant difference is indicated between systems F200m and AF100f.

Wheat yields from the trial site at Thornton, t/ha at 15% m.c.

block number	application system R200m	F200m	AF200m	F100f	AF100f	block mean
1	8.99	8.43	8.12	8.99	8.46	8.60
2	10.64	10.12	10.58	9.07	9.87	10.06
3	8.24	7.80	8.39	10.12	8.62	8.64
4	10.56	9.26	8.71	9.90	9.65	9.61
mean	9.61	8.90	8.95	9.52	9.14	9.23

SED between systems = 0.42
LSD NS

Wheat yields from the trial site at Glencorse, t/ha at 15% m.c..

block number	application system R200m	F200m	AF200m	F100f	AF100f	block mean
1	7.55	8.19	7.68	8.90	8.73	8.21
2	9.25	8.97	8.98	8.80	8.87	8.97
3	8.74	8.28	7.81	7.92	9.52	8.46
4	7.96	8.45	8.72	9.39	8.98	8.70
mean	8.38	8.48	8.30	8.75	9.03	8.59

SED between systems = 0.37
LSD NS

APPENDIX VI

Individual site yields, 1991.

Barley yields from SCAE, t/ha at 15% m.c.

block	application system						block
number	R200m	F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH	mean
1	5.32	6.12	6.19	6.01	6.05	5.99	5.95
2	5.81	6.49	5.77	6.30	6.58	5.21	6.03
3	5.91	5.26	6.26	5.80	6.49	5.96	5.95
4	6.25	6.39	5.25	5.87	6.35	5.88	6.00
mean	5.82	6.07	5.87	6.00	6.37	5.76	5.98

SED between systems = 0.30
LSD NS

Barley yields from Gowkley Moss, t/ha at 15% m.c.

block	application system						block
number	R200m	F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH	mean
1	5.48	6.83	7.37	7.04	7.50	7.65	6.98
2	6.61	6.89	6.50	6.98	7.44	7.31	6.95
3	7.61	6.75	7.52	6.55	7.49	7.69	7.27
4	7.65	6.89	7.12	7.33	7.68	7.42	7.35
mean	6.84	6.84	7.13	6.98	7.53	7.51	7.14

SED between systems = 0.34
LSD NS

Barley yields from Hermiston, t/ha at 15% m.c.

block	application system						block
number	R200m	F100f	AF100f /VL	AF100f /AL	AF100f /VH	AF100f /AH	mean
1	7.51	6.81	7.00	7.45	6.69	7.41	7.14
2	6.97	7.39	6.14	7.02	7.19	7.40	7.02
3	7.38	7.48	6.96	7.31	6.53	7.09	7.12
4	6.95	7.35	7.48	7.40	7.23	7.55	7.33
Mean	7.20	7.26	6.89	7.29	6.91	7.36	7.15

SED between systems = 0.24
LSD NS

APPENDIX VII

Equipment suppliers

Flat fan jets used in 1988 and 1989, and the 'Crop Tilter': Lurmark Ltd, Longstanton, Cambridge CB4 5DS

Swirl jets (Superjets'): Country Workshop Ltd, Swannybrook Developments, Swannybrook Farm, Kingston Bagpuize, Abingdon, Oxon OX13 5NE

Twin fluid ('Airtec') system: Cleanacres Machinery Ltd, Hazleton, Cheltenham, Gloucestershire GL54 4DX

Ducted boom air assisted sprayer ('Hardi Twin System'): Hardi Ltd, Watling Close, Sketchley Meadows Business Park, Hinckley, Leicestershire LE10 3EX

Key to pesticide products (from The UK Pesticide Guide 1991).

'Ally' - 20% w/w metsulfuron methyl (DuPont (UK) Ltd);

'Bravo 500' - 500 g/*l* chlorothalonil (BASF plc);

'Corbel' - 750 g/*l* fenpropimorph (BASF plc);

'Duplosan New System CMPP'- 60% w/v mecoprop-P (BASF plc);

'Radar' - 250 g/*l* propiconazole (ICI Agrochemicals);

'Sportak Alpha' - 100:266 g/*l* carbendazim + prochloraz (Schering Agriculture);

'Tilt 250EC' - 250 g/*l* propiconazole (Ciba-Geigy Agrochemicals);

'Tilt Turbo 375EC' - 125 g/*l* propiconazole + 350 g/*l* tridemorph (Ciba-Geigy Agrochemicals).

'Airtec' twin fluid system

'Superjet' swirl jets

'Crop Tilter' deflector

'Hardi Twin' spraying with air assistance