3.
Air-Assisted Spraying in Field Crops

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EARLY STUDIES ON SPRAY DRIFT, DEPOSIT MANIPULATION AND WEED CONTROL IN SUGAR BEET WITH TWO AIR-ASSISTED BOOM SPRAYERS

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ABSTRACT

The effects of air-assisted spraying on drift, spray deposition and weed control in sugar beet were examined. Two air-assisted sprayers were used, the Hardi Twin Spray System and the Ferrag Degania, each calibrated to apply 90 volume l/ha but with contrasting drop sizes. The use of air assistance reduced drift by approximately 50%. Spray deposition on the under-side of leaves and on targets under sugar beet plants that were covering 30% of the ground could be improved by the use of air assistance, but the studies suggested that drop size may play a large role in the distribution of such sprays. Air assistance appeared to improve the reliability of a low volume, low dose application of phenmedipham applied to large weeds (two to four leaves) but, again, selection of an optimum drop size and air speed combination may be needed.

INTRODUCTION

The majority of the UK sugar beet-crop is now sprayed with a low volume, low dose technique (Smith, 1983) for weed control. Most fields require at least two post-emergence applications for broad-leaved weed control. Timeliness of treatment is essential if good weed control is to be obtained and, with the low spray volumes utilised (generally 80 to 100 l/ha), wind can often delay application. It would be helpful to sugar-beet growers if drift could be reduced and therefore allow an increased number of spray days during the season. When weed control is delayed, sugar beet can become large and shelter small weeds under its foliage. Better coverage under the leaves would help weed control in these situations. In addition, a major pest of sugar beet in the last two seasons has been aphids, and improved leaf cover may help in their control. Again air assistance may help.

The preliminary trials described in this paper looked at three aspects of using air-assisted spraying in sugar beet: the possibility of reducing drift, the amount of spray deposited on the upper and/or lower surfaces of beet leaves or targets placed under beet plants and the biological effectiveness of air-assistance in late weed control sprays.

MATERIALS AND METHODS

Two air-assisted 12 m boom sprayers were tested: a Hardi Twin Spray System (Taylor *et al.*, 1989) mounted on a John Deere 2150 tractor and a Ferrag Degania (Cooke *et al.*, 1990) on a Ford 6610. All the studies were at Morley, Norfolk and throughout the Hardi used Hardi 4110-12 fine spray flat fan nozzles at 3.5 bar pressure and 0.5 m spacing on the boom and the Degania used Albuz brown hollow cone nozzles at 1.5 bar pressure at 0.33 m spacing on the boom. Both machines applied a spray volume of 90 l/ha at 8 km/h forward speed, but drop size differed. The VMD (measured by a Malvern Instrument model 2600 using an 800 mm lens) for the nozzles as used in the studies was 129µ for the 4110-12 and 163µ for the Albuz (Bruin, pers. comm.). Boom height of the Hardi was 0.5 m above the crop and the Degania 0.55 m above the crop. Various boom and air settings were used in the studies (Table 1). The rearward setting of the Hardi boom was 50° for the nozzles, 30° for the air and the air was 30° forward when the nozzles were vertical. This vertical nozzle setting was used so a direct comparison of a conventional nozzle setting with and without air could be made. The speed of the air coming from the machines was measured with a hot-wire anemometer (Airflow Instrumentation Model TA 6000) 100 mm below the air exit.

Drift assessment

Drift studies were undertaken on two separate days, 13 May (Hardi Twin Spray System only) and 12 June (both machines). On both dates the machines sprayed fluorescein-sodium dye plus 0.1% non-ionic surfactant (Agral) and made four 100 m passes parallel to, but 5 m upwind (as measured from the boom end) of, a total series of four (13 May) or three (12 June) 4.5 m high masts each 10 m apart. Each mast had two 150 mm long pipe cleaners attached either side of the mast at 0.5 m intervals (starting 0.5 m above the soil surface). The cleaners (each of plan area 620 mm^2) were set parallel to the direction of travel of the sprayer. The cleaners were removed immediately after the finish of each four runs and placed in small glass jars. They were kept in the dark and then the fluorescence measured against known standards in a filter fluorimeter (Perkin Elmer LS2) on 14 May (13 May study) and 14 June (12 June study).

TABLE 1: Treatment details of drift studies.

Boom and nozzle settings	13 May Air speed at outlet m/s	Wind speed m/s at 2 m	12 June Air speed at outlet m/s	Wind speed m/s at 2 m
Hardi vertical	0	6.5	0	4
" "	20	6.5	12	4.5
" "	28	6	23	5
Hardi rearward	0	3	0	3
" "	20	6.5	12	3.5
" "	28	5	23	3
Degania	-	-	0	4
"	-	-	27	4
"	-	-	56	4

The two drift studies were in separate fields on the cv. Rex (13 May) and cv. Hilma (12 June). On 13 May the beet were in the four to early six leaf stage and on 12 June there was 25% ground cover. On both days the weather was cloudy and cool (11°C on 13 May and 12°C on 12 June) with a NNW wind and some drizzle earlier in the day.

Spray deposition

This study was carried out on 12 June in cv. Rex at 30% ground cover.

The treatments were the same as those used for the drift study carried out earlier the same day and used the same dye concentrations. Thirty pieces of chromatography paper each 40 mm wide and 120 mm long were folded in half and clipped with a stapler over the end of leaf eight so that half of the paper was on the top and the rest was underneath. At the same time, 30 pieces of five-ply wood (each 100 mm by 250 mm) with a 45 mm diameter round filter disc 30 mm from each end mounted 50 mm high on 75 mm nails were placed with one filter paper in the middle of the sugar-beet interrow (i.e. not sheltered by the leaves) and the other immediately under the beet. Both the boards and the paper clipped to the leaves were placed down the rows in the centre of one outside boom section in the direction of spraying. After spraying, the paper was removed from the leaves, cut and fluorescein deposits on the top and the bottom sections determined, as were deposits from the discs.

Weed control

There was one study on weed control using the Degania sprayer only. This was carried out on 17 May on cv. Hilma, which was at the six to eight leaf stage. The main weeds present were *Sinapis arvensis* in the cotyledon to early two leaf and the four leaf stage, *Fallopia convolvulus* and *Veronica persica* in the two to four leaf stage and *Galium aparine* with one whorl approximately 10 mm above the cotyledons. The herbicide treatments were 0.2 and 0.4 kg a.i./ha phenmedipham (as Betanal E). Weed counts and weed and beet vigour scores were done on 23 May. The scores used a 0 to 10 linear scale, where 0 = dead plants and 10 = normal healthy ones.

RESULTS

Drift studies

TABLE 2: Results of 13 May drift study with the Hardi Twin Spray System, µl fluorescein / pipe cleaner (mean of replicates).

	Boom vertical			Boom rearward		
Air speed at outlet: Mast height	0 m/s	20 m/s	28 m/s	0 m/s	20 m/s	28 m/s
SE			±0.33			
0.5 m	3.8	3.3	1.4	4.9	6.9	3.4
1.0 m	3.2	2.8	1.4	4.5	5.5	1.9
1.5 m	2.7	2.1	1.0	3.1	4.3	1.4
2.0 m	1.9	1.7	0.9	2.4	3.7	1.1
2.5 m	1.5	1.1	0.6	1.8	2.3	0.7
3.0 m	1.2	0.8	0.5	1.3	1.4	0.5
3.5 m	0.8	0.4	0.3	0.7	0.7	0.3
4.0 m	0.5	0.3	0.2	0.4	0.4	0.2
4.5 m	0.3	0.1	0.1	0.2	0.2	0.1
SE			±1.26			
Total	15.9	12.6	6.4	19.3	25.4	9.6

The drift assessment on 13 May with the Hardi Twin Spray System showed that spray drift was reduced by the use of full or reduced air when the nozzles were in the vertical position compared to the same positions without air. Angling the nozzles 30° rearward actually increased the amount of spray drift that was detected.

TABLE 3: Results of 12 June drift study with the Hardi Twin Spray System, µl fluorescein / pipe cleaner (mean of replicates).

	Boom vertical			Boom rearward		
Air speed at outlet:	0 m/s	12 m/s	23 m/s	0 m/s	12 m/s	23 m/s
Mast height						
SE			±0.21			
1.0 m	1.1	0.7	0.5	1.6	1.2	0.5
1.5 m	1.3	0.7	0.5	1.6	1.5	0.4
2.0 m	1.0	0.6	0.5	1.6	1.1	0.4
2.5 m	0.8	0.5	0.4	1.5	0.9	0.3
3.0 m	0.6	0.3	0.2	1.1	0.6	0.3
3.5 m	0.4	0.2	0.2	0.8	0.5	0.2
4.0 m	0.3	0.2	0.2	0.5	0.3	0.1
4.5 m	0.2	0.1	0.2	0.4	0.2	0.1
SE			±1.87			
Total	5.7	3.3	2.7	9.1	6.3	2.3

On 12 June the drift recorded from the Hardi Twin Spray System was of a lower magnitude than that recorded at the earlier assessment, however, the pattern of results was similar.

TABLE 4: Results of 12 June drift study with the Degania (boom vertical), µl fluorescein / pipe cleaner (mean of replicates).

Air speed at outlet:	0 m/s	27 m/s	56 m/s
Mast height			
SE		±0.08	
1.0 m	1.8	0.6	0.2
1.5 m	1.2	0.6	0.2
2.0 m	1.4	0.6	0.2
2.5 m	1.0	0.3	0.1
3.0 m	0.5	0.2	0.1
3.5 m	0.3	0.2	0.1
4.0 m	0.1	0.1	0.1
4.5 m	0	0.1	0
SE		±2.13	
Total	6.3	2.7	1.0

The drift assessment on the Degania on 12 June also showed 50% less drift when sprays were applied with full or half air speeds compared to without air.

Spray deposition studies

TABLE 5: Spray deposition under plants and between rows by the Hardi Twin Spray System, µl fluorescein / 45 mm diameter disc.

Nozzle positioning	Air speed at outlet m/s	Between beet rows (SE)		Under beet rows (SE)	
Vertical	0	8.4	(±2.38)	1.6	(±1.56)
"	12	9.7	(±4.49)	1.6	(±1.45)
"	23	12.7	(±5.90)	2.6	(±1.91)
Rearward	0	9.6	(±4.67)	1.2	(±1.21)
"	12	9.6	(±3.54)	1.8	(±1.45)
"	23	11.5	(±5.40)	1.4	(±1.05)

The use of full (23 m/s) air assistance with the nozzles mounted vertically or facing rearward resulted in increased deposition on the targets visible between the rows. However, it was only with the nozzles mounted vertically that the same effect occurred with the deposition under the crop plants, no difference between air speed treatments being recorded when the nozzles were directed rearwards. The spray volume of 90 l/ha should give 14.3 µl of fluorescein per 45 mm diameter disc.

TABLE 6: Spray deposition under plants and between rows by the Degania, µl fluorescein / 45 mm diameter disc.

Air speed at outlet m/s	Between beet rows (SE)		Under beet rows (SE)	
0	6.2	(±2.81)	0.7	(±0.75)
27	6.2	(±4.01)	1.0	(±0.82)
56	9.7	(±5.82)	1.5	(±1.61)

The use of full (56 m/s) air assistance with the Degania increased deposition on the discs placed between the beet rows and air assistance (either 27 or 56 m/s) appeared to increase deposition on targets under the beet (table 6).

The use of reduced (12 m/s) air assistance with the Hardi made no difference to the deposition of the dye on the top or bottom of the leaves (table 7). However, when full air was used (23 m/s) the deposit on the upper surfaces of the leaves was reduced. With full air assistance and nozzles in the vertical position there was an increase in the amount of dye detected underneath the leaves although total deposition on the leaves had not changed. There was no increase in deposits under the leaf when the nozzles were angled rearward. A spray volume of 90 l/ha should give 21.5 µl fluorescein per target (top plus bottom).

TABLE 7: Spray deposition on top and under leaves by the Hardi Twin System Sprayer, µl fluorescein / 2400 mm².

Nozzle positioning	Air speed at outlet m/s	On top of leaf	(SE)	Underneath leaf	(SE)
Vertical	0	20.4	(±5.99)	1.3	(±0.89)
"	12	20.6	(±7.32)	1.5	(±1.14)
"	23	16.1	(±8.18)	4.5	(±5.08)
Rearward	0	21.9	(±5.28)	1.1	(±0.63)
"	12	21.1	(±6.29)	1.3	(±1.35)
"	23	17.4	(±6.40)	1.6	(±1.27)

TABLE 8: Spray deposition on top and under leaves by the Degania, µl fluorescein / 2400 mm².

Air speed at outlet m/s	On top of leaf	(SE)	Underneath leaf	(SE)
0	8.5	(±6.48)	2.7	(±3.96)
27	11.7	(±6.26)	2.0	(±6.78)
56	13.4	(±5.83)	1.7	(±3.40)

The use of air assistance with the Degania increased the deposits detected on the upper surface of the leaves, but there was some reduction in the amount detected on the under-side (table 8).

Weed control

TABLE 9: Crop and weed assessments for the Degania on 23 May.

Sprayer setting	Phenmedipham dose (kg a.i./ha)	Weeds/m² *S. arv.* (<4 true leaves)	*F. conv.*	*V. pers*	Total weeds	Vigour scores Weeds	Beet
SE		±0.30	±0.20	±0.15	±1.94	±1.54	±0.17
No air	0.2	1.2	0.8	0.4	9.4	6.3	10.0
27 m/s air	0.2	0.7	0.6	0.5	6.3	4.0	10.0
56 m/s air	0.2	0.9	0.8	0.3	8.9	5.8	10.0
No air	0.4	0.4	0.4	0.2	5.5	4.0	10.0
27 m/s air	0.4	0.4	0.3	0.4	3.7	1.8	9.5
56 m/s air	0.4	0.3	0.3	0.4	3.2	1.8	10.0
Untreated		1.4	1.3	0.8	11.0	9.3	10.0

There was no significant difference between treatments on the large weeds with more than four true leaves or on *Galium aparine*. The three 0.4 kg a.i./ha doses of phenmedipham and the 0.2 kg a.i./ha dose applied with reduced (27 m/s) air reduced numbers of small (less than four true leaves at treatment), *S. arvensis* and total weeds when compared with the untreated. The three 0.4 kg a.i./ha doses of phenmedipham also gave significantly better control of this weed than the 0.2 kg a.i./ha doses. All herbicide treatments reduced numbers of *F. convolvulus* compared to the untreated and the 0.4 kg a.i./ha doses with air assistance (27 or 56 m/s) gave significantly better control of this weed compared to 0.2 kg a.i./ha applied without air or with full air (56 m/s). All herbicide treatments reduced numbers of *V. persica* compared to the untreated, but there was no significant difference between them.

All six herbicide treatments reduced weed vigour compared to the untreated. The 0.2 kg a.i./ha phenmedipham treatments without air and with full (56 m/s) air gave a smaller reduction in weed vigour compared to the 0.4 kg a.i./ha dose with either full or reduced air assistance.

The 0.4 kg a.i./ha dose of phenmedipham with reduced (27 m/s) air assistance reduced beet vigour compared to all the other treatments.

CONCLUSIONS

With both machines the use of air assistance reduced spray drift by approximately 50% compared with an equivalent application applied without air, and full air volume was desirable for maximum drift reduction. The lower wind speed on 12 June compared to 13 May probably accounts for the lower drift figures recorded at the later date by the Hardi. The higher amount of drift on 13 May when the nozzles were angled rearward (but not lowered) compared to when they were vertical, agrees with earlier findings (Taylor *et al.*, 1989). Their findings would suggest that angling of the nozzles forward might have further reduced drift compared to use of the vertical position. The low figures recorded by the Degania (even without air) are most likely due to the larger drop size produced by this machine in these studies.

The use of air assistance improved the deposition of sprays on targets between the rows of beet that were covering 30% of the ground. Air assistance and vertical nozzles also appeared to increase the deposition under the crop plants. It was interesting to note that the fine spray from the Hardi nozzles used with full air and the nozzles vertical or angled rearward, resulted in virtually complete retention of dye by the targets. The use of the coarser drop size by the Degania probably explains the lower figures for this machine, although full air assistance still increased deposits on targets compared to no air.

The virtually complete retention by the targets on the leaves of the 90 l/ha sprayed by the Hardi Twin Spray System was probably a result of the fine nozzles used. The use of full air assistance with the Hardi increased the amount of dye detected on the under-side of the leaves whilst at the same time reducing the amount on the upper surface (but total deposition was still virtually 100%). This effect appeared to be due to physical twisting and movement of the leaves caused by the air; it was not detected with the nozzles facing rearward. During spraying, the use of air with the Degania or with vertical nozzles on the Hardi appeared to move crop leaves more than air used with rearward facing ones. The Degania appeared to deposit more on the top of the leaf but less under the leaf as air assistance was introduced. This effect may be due to the coarser drop size used with this sprayer compared to the Hardi.

Because the two machines used different nozzle types and sizes and therefore produced different drop spectra, comparisons between the machines should not be drawn. However, this work does suggest that selection of drop size and possibly air speed may be of great importance when setting up machines for different purposes.

The weed control results suggest that air assistance can improve the weed control activity of a chemical like phenmedipham. On the weed numbers, reduced air assistance (27 m/s) tended to give better weed control with 0.2 kg a.i./ha phenmedipham than the same dose applied without air or with full (56 m/s) air. This is probably a reflection of the amount of movement and possible redistribution of sprays caused by the use of high air speeds. As the treatments were being applied, the full air volume appeared to have a great physical effect on the beet plants and flatten and batter them. The 0.4 kg a.i./ha phenmedipham with reduced air was the only treatment to reduce crop vigour and this also adds to the argument for selecting a lower air speed for such weed control tasks. The results suggest that air assistance might lead to more consistent weed control, but was not able to compensate for a halving of chemical applied. However, these treatments were applied to weeds that were larger than recommended for such applications and results might be different at the recommended cotyledon stage.

This study has indicated that air-assisted spraying may well prove useful to growers because of the reduced drift that can be achieved. This is likely to give more spray days during the sugar-beet weed control season. The results of the deposition studies and the single weed control trial suggest that air assistance may well have a role to play in improving the consistency of herbicide, insecticide or fungicide activity in sugar beet, but more work is needed on the possible interactions between drop size and air volume.

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THE PERFORMANCE CHARACTERISTICS OF A TWIN-FLUID NOZZLE SPRAYER

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ABSTRACT

This paper reports results from field studies measuring the spray drift from a twin-fluid boom mounted nozzle arrangement operating above a grass/stubble surface with measurements made over three separate spraying seasons. Results from this work are related to comparable drift measurements made in wind tunnel environments and measurements of the physical characteristics of the spray formed.

The results indicated that the measured drift from the twin-fluid nozzle operating at a nominal volume application rate of 100 l/ha was no greater than the drift from conventional flat fan pressure nozzles operating at a nominal 200 l/ha and significantly less than from nozzles operating at 100 l/ha. Results from previously published work have shown that the larger droplets (>100 μm) produced by the twin-fluid nozzle contain "air-inclusions" and measurements of the droplet size/velocity characteristics in the spray produced by this nozzle confirm that this is the case.

The possible reasons for lower drift from the twin-fluid nozzle are examined together with the likely consequences for droplet retention on leaf surfaces under field conditions.

INTRODUCTION

The nozzle design used in the work reported in this paper uses both air and liquid under pressure to form the spray. Both fluids are fed into a chamber within the nozzle body via metering orifices and the liquid/air stream is then emitted through a form of impact nozzle (flood jet) to create a fan-shaped spray. Liquid flow rates through the nozzle are a function of the pressures of the two fluids and it is possible with this design to produce sprays with different physical characteristics but the same liquid flow rate from the nozzle (Western, et al., 1989; Young, 1990).

Studies of the droplet structure produced by this nozzle design when spraying solutions of surfactant have shown the presence of "air-inclusions" within individual droplets (Rutherford et al 1989). This droplet structure has been shown to influence the behaviour of such droplets in flight when compared with the expected behaviour of entirely liquid droplets (Miller, et al., 1990). The complex droplet structure has also made for difficulties when classifying the spray quality produced by this nozzle with different operating pressures since many laser-based sizing instruments are unable to analyse the spray produced with surfactant solution and obtain droplet size/cumulative volume curves that can be compared directly with those from the reference BCPC nozzles. Work in wind tunnel environments is beginning to show how such problems may be resolved (Western et al., 1989; Young, 1990). An initial classification for this nozzle design at different operating pressures has been produced based on measurements with a Malvern analyser and relating the results to the standard nozzle. (Doble et al, 1985).

Results from field and wind tunnel studies of spray drift have shown that the twin-fluid nozzle operating at the appropriate pressures is capable of applying volume rates in the order of 70-100 l/ha while giving significantly lower drift than would be obtained from flat fan nozzles operating at comparable volume rates (Rutherford, et al., 1989; Miller et al., 1990; Western et al., 1989).

The purpose of the work reported in this paper is to:

(i) Examine the results from comparative drift measurements made under field conditions over three separate seasons and to compare these results with previously published data;

(ii) Consider the droplet size/velocity characteristics produced by the nozzle and to examine the extent to which calculations of droplet velocities at a given point in the spray can be used to deduce information about droplet structure and hence aid spray quality classification;

and

(iii) Review published data from field trials with the system and to relate these results to the physical characteristics and drift performance of the nozzle.

SPRAY DRIFT MEASUREMENTS

Experimental methods

The spray drift measurements were made using the experimental techniques described by Gilbert and Bell (1988). A 12 m sprayer boom mounted on a lightweight vehicle was arranged so that different tracer dyes could be sprayed simultaneously from conventional and twin-fluid nozzles mounted along the boom on either side of the vehicle. The spraying vehicle (a petrol engined "Frasier Agri-buggy") was not equipped with a p.t.o. shaft and so two separate petrol engines were used to drive a diaphragm pump and rotary vane compressor to provide liquid and air under pressure for the twin-fluid nozzle system. The spraying circuit was arranged to mimic that used on a full-size sprayer with a re-circulating liquid flow used to minimise the risk of sedimentation behind the nozzles and give good tank agitation. The flat fan nozzles were fed from two pressurised containers which were plumbed to minimise the pressure drop between the containers and the nozzle. This system was calibrated for each of the two nozzle sizes used by measuring both flow rate and pressure (as a check) on the boom and adjusting the container pressure to give the required values. The twin-fluid nozzle settings and comparative flat fan nozzles are given in Table 1.

TABLE 1. Nozzle Parameters

Twin-fluid nozzle				Hydraulic flat fan nozzle	
Nominal BCPC spray quality*	Setting	Pressures KPa	Flow rate l/min	Nozzle & pressure KPa	Flow rate, l/min
Medium	A	Liquid 200 Air 70	0.57	F110/1.6/3.0 at 300	1.61
Fine	B	Liquid 300 Air 140	0.64	F110/0.8/3.0 at 300	0.80

*Nominal description of twin fluid spray based on original data provided by Cleanacres Machinery Ltd.

Spray drift was collected on 2 mm polythene tubing supported from masts 11 m tall at distances of 8, 20 and 50 m downwind from the end of the boom. Drifting spray was quantified by spectrophotometry (Gilbert and Bell, 1988). Only data from the 8 m collectors is used in this paper but a further analysis of the full results is to be presented elsewhere (Miller et al, 1991). Meteorological conditions at the time of spraying were monitored using a 10 m mast supporting cup anemometers at 0.6, 1.5, 2.8, 5.0 and 10.0 m above ground level; temperature difference sensors between 2.0 and 6.0 m, 2.0 and 1.0 m and 2.0 and 3.4 m; a wind vane at 7.0 m; and a wet and dry bulb psychrometer at 2.0 m. Data from these sensors was logged at 10 s intervals onto magnetic tape for subsequent computer analysis to give wind velocity and temperature profiles above the surface and hence a measure of atmospheric stability (Richardson Number).

All experiments over the three seasons were conducted over a cereal or grass stubble on which re-growth had been stimulated to give a reasonably dense "crop" canopy some 150 mm tall. The spraying speed was in the range 8.2 - 11.5 km/h and was monitored for all runs to provide data relating to the applied volume rate. The boom height was 500 mm for all experiments (above the top of the crop). Each experiment involved six passes (out and back) in front of the array of collectors so as to build up adequate drift deposits and average over the weather conditions pertaining at the time of the test.

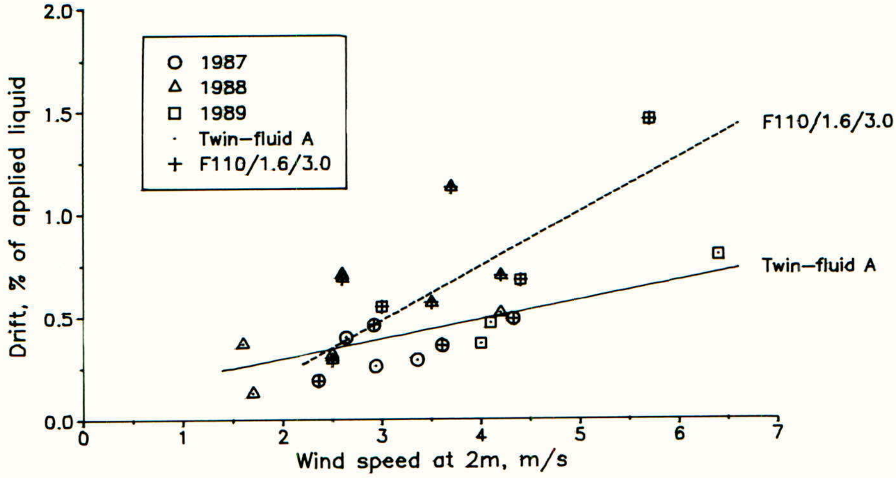

Fig. 1–*Measured spray drift from medium spray quality nozzles at 8m down wind of the end of a 12m boom.*

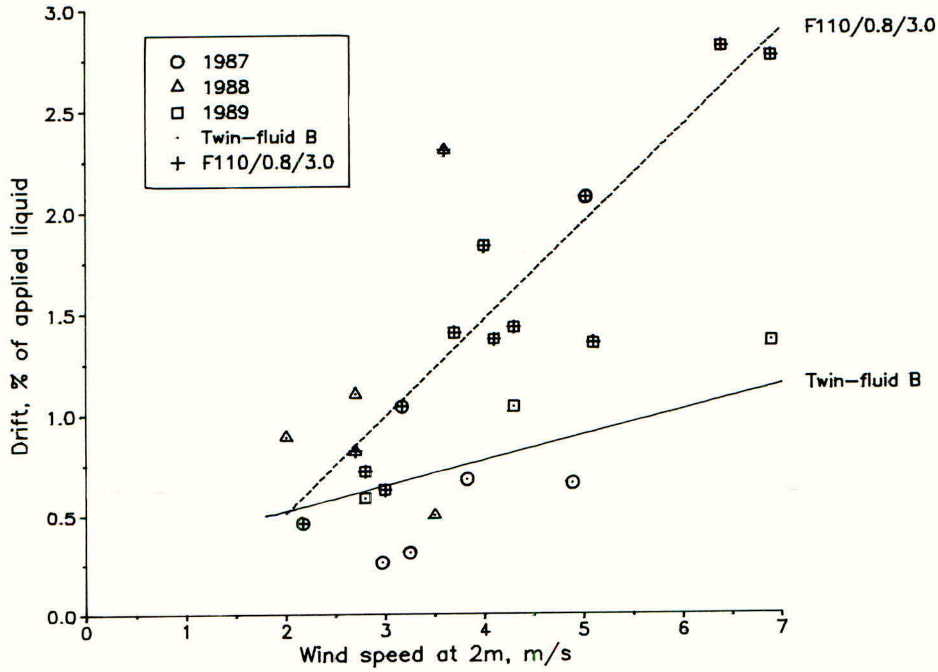

Fig. 2–*Measured spray drift from fine spray quality nozzles at 8m down wind of the end of a 12m boom.*

Results from drift experiments

The results from the field drift measurements are plotted in Figs. 1 and 2. Drift values are expressed as a percentage of the boom output from a single 12 m sprayed swath that was captured 8 m downwind from the end of the boom. It should be noted that no allowance has been made for the effects of upwind swathes of the sprayer as discussed by Gilbert and Bell (1988). Data points for each year of the experiment are plotted separately with a single linear regression line fitted to all of the values for a particular nozzle over the three seasons.

The drift from the twin-fluid nozzle was less as a percentage of applied liquid than that from the comparative flat fan nozzle in both cases with the differences for the fine nozzles being statistically significant (P=0.001). As expected, levels of drift from the fine hydraulic nozzle were significantly higher than for the fan nozzle producing a medium spray quality. The form of the relationship of drift against wind speed was consistent with that recorded elsewhere, both under field conditions (Rutherford et al., 1989, Miller et al., 1990) and in laboratory wind tunnels (Western et al., 1989). Although the scatter of experimental data points is greater than noted in many wind tunnel experiments, the relationship between drift and wind speed was well described by the linear relationship for both nozzles (r = 0.87 and 0.73 for fine and medium flat fan nozzles respectively with equivalent figures of 0.49 and 0.66 for the twin-fluid design). The intercept of the regression lines does not pass through the origin. For the flat fan nozzles the regression lines intercept the x axis at between 1 and 2 m/s and this is also in agreement with laboratory measurements made by Western et al (1989).

The agreement between the relative magnitudes of spray drift recorded in this work for the different nozzles and those from previous laboratory studies is particularly encouraging when considering the use of laboratory test protocols as the basis of future work to clarify spray quality.

DROPLET SIZE/VELOCITY CHARACTERISTICS

Measurements of the droplet size/velocity characteristics in the spray from a reference flat fan nozzle and the twin-fluid nozzle were made using a Particle Measuring System's analyser with a two-dimensional imaging probe (Type 2D-GA1) positioned at 450 and 700 mm below the nozzle. Measurements were made by moving the nozzle backwards and forwards over the sampling probe in a direction at right angles to that of the spray fan and at a speed of 50 mm/s so that data was obtained for four points (two at each height) in the spray from each nozzle setting. All measurements were made in a sampling chamber ventilated to prevent recirculation of small spray droplets. The spray solution was water + 0.1% of a non-ionic surfactant in all cases.

Results from the measurements made in the centre line below each nozzle are shown in Figs.3 and 4 with similar results being obtained at positions between the centre line and edge of the spray sheet. As expected the velocities measured closer to the nozzle were the higher in each case and the shape of the droplet size/velocity characteristic

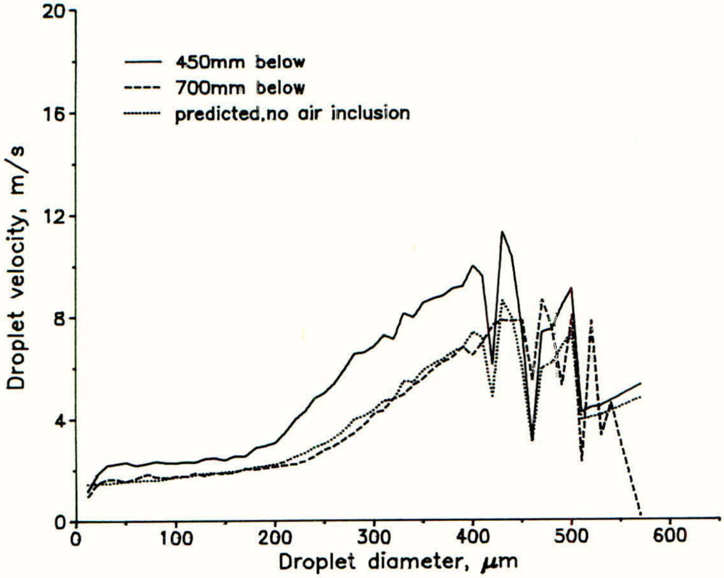

Fig. 3—*Comparison of velocity profiles for a F110/1.6/3.0 nozzle at 2.5bar at two heights.*

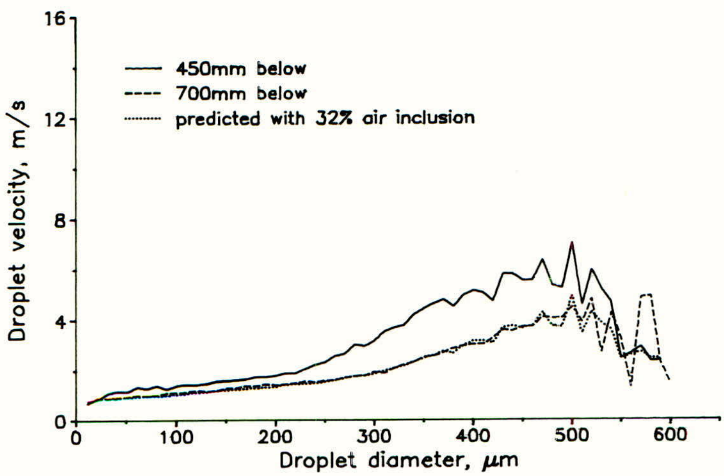

Fig. 4—*Comparison of velocity profiles for a Twin–Fluid nozzle,(setting A) at two heights.*

agreed with previous results (Miller and Hadfield, 1989). Velocities of droplets above approximately 400 μm diameter from the flat fan nozzle, and 500 μm diameter from the twin-fluid nozzle, show relatively wide variations and this is due to the small numbers of droplets measured in these size ranges as indicated from Fig.5.

Data recorded at the higher of the two measurement levels and closer to the spray nozzle was used as input to a mathematical model (Miller and Hadfield, 1989) to predict the velocity profile measured at the lower level and the results are plotted in Figs. 3 and 4. To obtain model inputs relating to the entrained air conditions between the two measuring heights, the recorded velocities of droplets in the 50 μm size class at the lower height was taken as the entrained air velocity. This was an approximation which should have resulted in velocities being under-predicted but it can be seen in Fig.3 that for the conventional nozzle, the agreement between measured and predicted velocities was reasonable. Further work is currently in progress to improve the prediction of entrained air conditions in a Linked Research project involving the AFRC Institute of Engineering Research and the Department of Applied Mathematics and Theoretical Physics at Cambridge University.

For the twin-fluid nozzle, the effects of air inclusion was calculated by arranging for the computer model to vary particle density to obtain the best fit between measured and predicted velocities and the results are shown in Fig.4. For setting A of the twin-fluid nozzle it was estimated that air inclusions reduced the mean droplet density by an average of 32%. Photographic studies reported by Rutherford et al., (1989) suggested that the percentage of air inclusions increases with droplet size and at sizes of less than approximately 100 μm there were no air inclusions in the droplets.

The air input to the twin-fluid nozzle may be expected to increase entrained air velocities in the spray produced by this type of nozzle. Measurements made by Porskamp (1986) of the air flow 700 mm beneath a nozzle when only air was input at a pressure of 1.6 bar suggested that output air in an oval envelope some 500 mm by 250 mm had velocities up to 2.5 m/s and had velocities above 1.5 m/s in the central two thirds of the envelope. These data show some agreement with those in Fig.4 although direct comparisons are not possible because the presence of liquid will influence air flow through the nozzle and entrained air flows will be enhanced by the action of droplets leaving the nozzle.

A comparison of the results shown in Figs. 3 and 4 indicates that the mean droplet velocities from the twin-fluid nozzle at the settings used were less than for the conventional nozzle and at 450 mm below the nozzle entrained air velocities were higher for the conventional nozzle than for the twin-fluid design. The reductions in spray drift may therefore be due to:

(i) the reduced percentage of spray volume in droplets less than 100 μm in diameter as shown in Fig.5;

and/or(ii) higher velocities close to the nozzle with the twin-fluid design due to the compressed

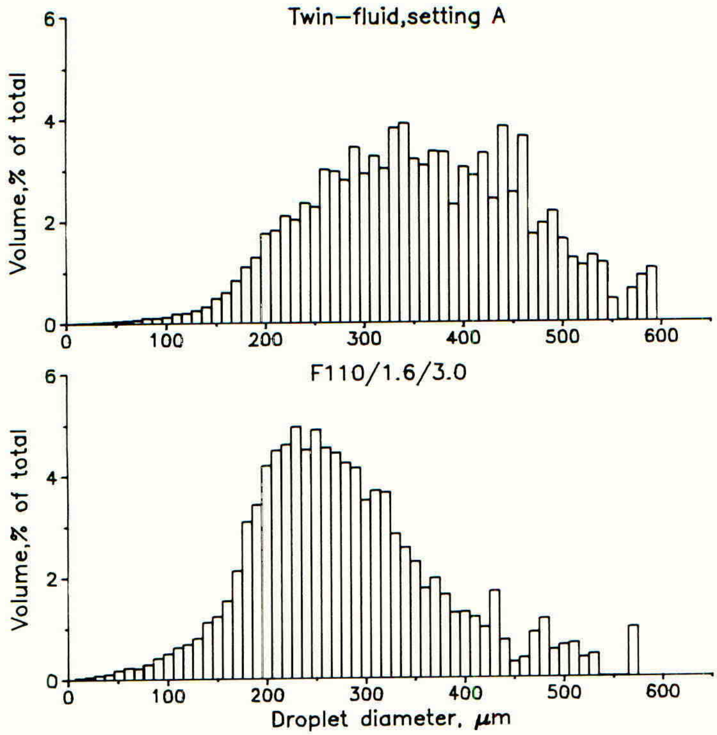

Fig. 5—*Distributions for medium spray quality nozzles 450mm below nozzle.*

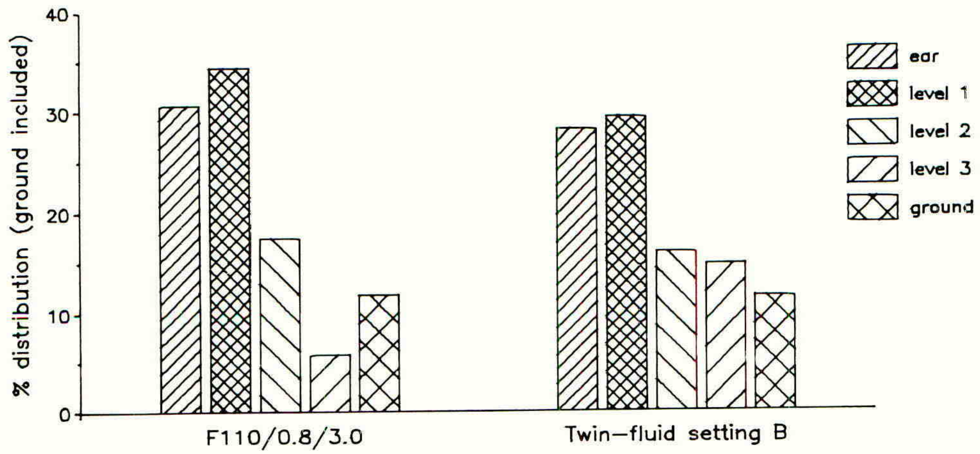

Fig. 6—*Distribution of spray deposit within the crop canopy for two different fine quality spray application methods (variety:Mission winter wheat)*

air input. This effect is difficult to measure and hence no data is currently available to show this velocity increase.

IMPLICATIONS FOR FIELD PERFORMANCE

Previous work concerned with droplet retention (Lake and Marchant, 1983) has indicated that large droplets (>400 μm) are less likely to be retained on plant leaf surfaces. From the data shown in Fig.5, it may therefore be expected that spray retention when using the twin-fluid nozzle would be inferior to that of sprays from conventional nozzles. Evidence exists to show that this is not so. A limited laboratory experiment in which sprays were applied to pot grown species of crops and weeds showed that the retention of sprays from the twin-fluid nozzle at settings close to those used in this report was at least equal to that from a fine hydraulic nozzle over the range of plant types examined (Miller, et al., 1990) both with and without surfactant added to the liquid.

Measurements of the spray deposits were made on weeds in field cereal crops and compared the performance of a number of spraying systems including the twin-fluid nozzle at two pressure settings and a conventional flat fan nozzle producing a fine spray at 100 l/ha, and found no significant differences between the twin-fluid nozzles at either setting and conventional flat fan nozzles operating at comparable volume rates. Work by Cooke and Hislop (1987) showed that fungicide deposits on winter barley from two settings of the twin-fluid nozzle were somewhat higher than from conventional nozzles operating at 200 l/ha and that disease control from the two systems gave no differences.

Work by Robinson (1990) has also examined both spray deposits and biological performance of sprays applied with the twin-fluid and conventional flat fan nozzles and found no significant differences when operating at comparable volume rates. Fig.6 shows typical results from the work by Robinson applying sprays to winter wheat and sampling at different positions within the crop canopy.

CONCLUSIONS

It is concluded that:

(i) The twin-fluid nozzle produces an agricultural spray that is physically different from that produced by conventional pressure nozzles. Effective spray quality is a function of liquid and air input pressures and can be changed independently of liquid flow rate.

(ii) The system enables applications to be made at spray volume rates in the region of 100 l/ha with significantly lower potential drift than would be expected from conventional pressure nozzles but with no reduction in spray retention or biological performance.

(iii) Spray drift measurements in field conditions show good agreement with those made in a range of wind tunnel environments and this has important implications for future work concerned with nozzle classification and performance assessment.

ACKNOWLEDGEMENTS

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The original work concerning the spray structure from this nozzle design was commissioned by Cleanacres Machinery Ltd. and thanks are due to Mr. C.B. Christian for his help in collecting some of the data used in this paper.

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FIELD EXPERIENCES WITH AN 'AIRTEC' TWIN FLUID SPRAYING SYSTEM

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ABSTRACT

The role of a Twin Fluid Nozzle sprayer in intensive cereal farms is discussed. Special consideration is given to the implications of COPR, COSHH and product liability. Application of a range of agrochemicals used in cereal crop production is considered.

INTRODUCTION

1984 and 1985 were productive years for arable farmers growing combinable crops. In 1986 and 1987 yields were lower and market prices less stable. Careful financial reflection by many progressive farmers recognised that serious attention was required on both the fixed and variable cost sectors of their farming enterprises if they wished to continue to make a reasonable return on their investment.

On several farms attention was directed to the "Airtec" Sprayer as one possible opportunity for streamlining fixed costs with some potential also to reduce spray inputs.

This paper reviews some experiences gained making agrochemical recommendations for Twin Fluid Sprayers on 2000 hectares of cereal crops since the autumn of 1987.

TWIN NOZZLE VERSUS CONVENTIONAL: CONSIDERATIONS BEFORE MAKING AN AGROCHEMICAL RECOMMENDATION

Most agrochemicals are currently applied by boom mounted hydraulic nozzles applying water volumes of 100-220 l/ha. The Twin Fluid nozzle provides for pesticides to be applied in water volumes as low as 50 l/ha. However, most agrochemicals have no label recommendation for application at such reduced water volumes. Consequently consideration must be given to the following:

Control of Pesticide Regulations (COPR) 1986 (SI 1510)[EWS]

All agrochemicals now have label hazard ratings as required by COPR. COPR does allow for the use of reduced volume application systems as long as the guidelines in the Code of Practice are followed. These guidelines however do not permit the application of agrochemicals with a hazard rating of corrosive, very toxic or toxic at water volumes below that recommended on the label. For example, 'Gramoxone' has a Toxic hazard rating and must not therefore be applied in water volumes below the 200 l/ha specified on their label. Hence where the restrictors in a Twin Fluid Sprayer system do not permit applications at these water volumes, application of either of these products is not legally acceptable under COPR.

Control of Substances Hazardous to Health Regulations (COSHH) 1988 (SI 1657) [EWS]

The COSHH Regulations require that when agrochemicals are applied at water volumes below that recommended on the label, a specific assessment must be made to assess the risk of exposure to the operator and others.

Product Liability

Where agrochemical applications are made at water volumes below that recommended on the product label the position of product liability is unclear. In practise this may result in advisers making more cautious recommendations for products and possible tank mixes.

HERBICIDE APPLICATIONS

Thought must be given to whether the herbicide is to be applied pre or post-emergence of the crop, whether it is residual or contact, and if residual what it's mobility through the soil is. These factors will affect choice of water volume, spray droplet spectrum and chemical dose rate.

Many Glyphosate formulations are particularly suitable to low volume spraying systems because water is a known antagonist of Glyphosate. There are also many label recommendations for water volumes as low as 80 l/ha although one notable exception is in the dessication of Oilseed Rape. The product manufacturers also recommend any approved additive to be used as a concentration of the water volume and not as a rate /ha.

The substituted urea group of herbicides are also very successful when applied by twin fluid systems. Applied pre-emergence, a coarse droplet spray can be selected, but when applied post emergence where target weeds have emerged a medium droplet spectrum can be chosen.

Pendimethalin has been successfully applied by twin fluid systems but if applied alone great care is needed for consistent results. It has been found necessary to keep the water volume as high as possible and to spray with a fine to medium-fine spray providing weather will permit. Pendimethalin is not mobile in the soil and good ground coverage is essential although if there is sufficient moisture at spraying there may be some redistribution of the chemical to provide a complete chemical barrier.

Hydroxybenzoic acids have not always given satisfactory results particularly when conditions are adverse as in a late cool spring. In these situations water volumes need to be increased and label recommended dose rates applied for consistent results.

Diclofop-methyl is very successful when applied through the twin fluid nozzle and is an effective wild oat herbicide once the wild oats (Avena spp) have one leaf and up until tillering.

Imazamethabenz-methyl has also been successful when applied by the twin fluid nozzle but there is a need to rethink the wetter rates needed for consistent wild oat and onion couch control.

Difenzoquat has good label instructions for water volumes as low as 80 l/ha. It has been used safely on barley and approved wheat varieties but sometimes wild oat control has been indifferent. This may be because it is a contact only herbicide and the balance between droplet spectrum and droplet number has not been such as to ensure all target plants are covered.

Flamprop-M-isopropyl without approved adjuvant has given outstanding results when applied at 80 l/ha water by the twin fluid nozzle.

Metsulfuron methyl has successfully been used through the twin fluid system at low dosages in both Winter Wheat and Spring Barley. However, a full dose application on Winter Barley under adverse climatic conditions and when the crop is under stress, may cause some undesirable crop effects.

One years experience with fenoxaprop-ethyl has initially revealed there is more to be learnt with this product. In 1990 wild oat control was more variable applied by twin fluid systems than by conventional nozzles. In addition some unexplained scorch was apparent after application at full recommended rate in 90 l/ha water with a medium spray droplet at GS 37.

INSECTICIDE APPLICATIONS

Barley Yellow Dwarf Virus in cereals

The application of pyrethroid insecticide in the autumn has proved successful at 85% of recommended rate when sprayed at the correct time at volumes as low as 70 l/hectare of water. Care is needed in tank mixture with herbicides applied when the first frosts of the autumn may be imminent as the combination of factors can cause scorching of any soft growth.

Chlorpyrifos applications post grass leys

This is always a difficult chemical to use in situations of minimising pest damage after grass. Success rate has only been about 60% with twin fluid nozzles at low volume. To minimise the risk of variable results, application should be at high water volumes and preferably on days with high relative humidity.

Summer Aphids in all arable crops

Once again treatment has been very successful both with approved pyrethroids and with pirimicarb.

FUNGICIDE APPLICATIONS

Here thought must be given to the disease present and its severity. Equally important is consideration of the mode of action of the fungicide to be used. In cases of severe infections of brown or yellow rust, chemical dose rates should not be reduced and water volumes maintained at 90 l/ha and above.

Where mildew has been very active in both wheat and barley, applications of morpholines have been very successful. It would be unusual that more than half the recommended application rate was needed to eradicate a moderate infection of mildew.

Where a Fungicide Systems Programme is applied the twin fluid nozzle has proved an ideal vehicle, as it very conveniently allows the use of low dose low volume applications at regular intervals. It is however much harder to keep track of total a.i. applied. This is especially important because COPR requires that specified maximum residue levels must not be exceeded.

TRACE ELEMENT APPLICATIONS

Trace elements have always been easy to apply through the twin fluid nozzle even manganese sulphate although a dose rate of 4.0 kg/ha has not needed to be exceeded..

GROWTH REGULATOR APPLICATIONS

Chlormequat plus the adjuvant Li 700 is used as a regular tank mixture, although the full recommended dose of Chlormequat is only used on Winter Oats.

Ethephon based growth regulators have been applied at no more than 50% of the label recommended rates. This in sequence with Chlormequat has been quite sufficient to prevent lodging in high risk situations, and no adverse crop effects have been observed.

TANK MIXTURES

Of the approved tank mixtures applied there have not been any problems except with diflufenican and diclofop methyl. Herbicidal efficacy appeared impaired and there was some crop scorching.

Complex tank mixes have never been necessary with twin fluid systems because the improved timeliness of applications has allowed a more systematic approach to agrochemical programmes.

ADJUVANTS AND ADDITIVES

Many of these are recommended as a concentration of the water volume used and so may be dependent on the accuracy and efficiency of the field dilution.

Additives and adjuvants that have been used with success have been Li 700, Bond, Agral and Ethokem.

DISCUSSION

Disadvantages

These are mainly associated with liability. Firstly the requirements of the twin fluid system and secondly that of the chemical manufacturers. Where applications are not made within label constraints anyone making a recommendation or applying agrochemical is unlikely to find himself well positioned in the eventuality that something goes wrong.

In addition under COPR it may not be possible to select the ideal agrochemical for the problem at hand without the help of a contractor.

Advantages of the Twin Fluid System

The major advantage has undoubtedly been timeliness and the improvement in the logistics of spraying. The ability to travel over large acreages at reasonable speeds, and minimum down time for refill makes the whole spraying system more professional. On one large estate the Sprayer has in addition a liquid fertiliser line and the unit is mounted on an MB trac. Spraying at 24 metre centres, all the agrochemical applications, all the compound and Nitrogen applications over 1100 hectares of arable crops are applied and only rarely do applications get behind in their timing.

The second advantage is that the majority of operators become more interested in the applications they are making.

The third advantage is that applications can be made on days where the wind may be unsuitable for a conventional hydraulic spray system. For example wind speeds above 6 mph are unsuitable for conventional spraying, but twin fluid applications have been satisfactory at wind speeds up to 8 mph. Should wind speed change during spray application in a given field, it is much simpler with twin fluid systems to adjust spray droplet spectrum to accomodate the changing conditions.

The final advantage is that twin fluid users in general apply only 85% of the agrochemical a conventional system uses in a given year. On a 200 hectare arable farm, the agrochemical bill would total around £20,000 in a year. A twin fluid user would probably spend only £17,000 and so there is scope for saving £3,000. On a 1000 hectare farm a potential saving of £15,000 would be made each year.

CONCLUSIONS

Low chemical dose low water volume systems have been used on farms for many years, pioneered originally for the Sugar Beet Crop. The difficulties of making such applications are:

a) the lack of trials data to support them.
b) the lack of agrochemical manufacturer support in most instances.
c) the anxiety about COPR implications.
d) the requirements of COSHH for a specific risk assessment to be made where there is no label recommendation for the water volume to be used.

Essentially a farmer and his agronomist are on their own, with the legislation demanding comprehensive documentation on applications.

However low dose low volume systems through the twin fluid systems have produced consistent results over the last four years. For those farmers using the system considerable financial savings have been made, and there have been the opportunities to streamline overhead costs. Low dose systems in the long term are also environmentally friendly and therefore advantageous to the public at large.

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"Airtec" is a trademark of Cleanacres Machinery Ltd.

"Gramoxone" and "Agral" are trademarks of Imperial Chemical Industries PLC.

"Li 700" and "Bond" are trademarks of Newbrook Agricultural Products Ltd.

"Ethokem" is a trademark of Midkem Ltd.

THE EFFECT OF AIR ASSISTANCE AND SPRAY QUALITY (DROP SIZE) ON THE AVAILABILITY, UNIFORMITY AND DEPOSITION OF SPRAY ON CONTRASTING TARGETS.

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ABSTRACT

Small horizontal and vertical targets were sprayed with hydraulic nozzles applying four BCPC 'Spray Qualities' conventionally, or with air assistance. Applications were made under still air, low and high wind speeds to establish the effect of air assistance on deposit levels and their variability. Smaller, conventionally applied drop spectra were more effectively deposited on vertical targets, than the larger (Coarse) spray. In still air and in the low wind, air assistance generally enhanced deposits, in particular on vertical surfaces and with small drop use, Deposit variability was not affected or even reduced with air assistance. In the stronger wind, no clear conclusions could be made.

INTRODUCTION

Deposits from pesticide spraying are inevitably not uniform and may therefore restrict some opportunity for dose reduction - an issue actively addressed in Denmark (Thonke, 1988). The source of variability may have many origins, being derived from factors concerned with the target geometry, the method of application and/or the conditions under which spraying took place. Our efforts have concentrated on the deposit variability on small, concealed targets, as improvements of performance on this scale are crucial for the scope of dose reduction of foliar products.

Many new developments claim improved distribution but there are few useful figures. Currently, it is air assistance that is attracting much attention for possibilities of drift reduction (Cooke and Hislop, 1987; Jensen et al., 1989; Taylor et al., 1989) and improving crop canopy penetration (Jagatheeswaran, 1978; Bode, 1988; Quanquin et al., 1989) but little effort has quantified whether such a use could change deposit levels, variability, or perform differently under currently marginal wind speeds. The preliminary work described in this paper represents our first attempts at technique development and seeks reference values on which our future research in this area will be based.

MATERIALS AND METHODS

A Hardi Twin Spray System with 12m boom was used, the sets of 24 nozzles spaced at 0.5m intervals, spraying 0.5m above the target surface. The range of nozzles used were selected to apply the BCPC Spray Qualities - Very Fine, Fine, Medium and Coarse (Table 1). The same machine and nozzles were used to spray conventionally or with air assistance (30 m/sec at the outlet and with air curtain angled back). The spray liquid was water with a non-ionic surfactant (Agral) at 0.1% v/v and a fluorescent dye (Sodium salt of fluorescein) at 25g/600 l to facilitate deposit measurements.

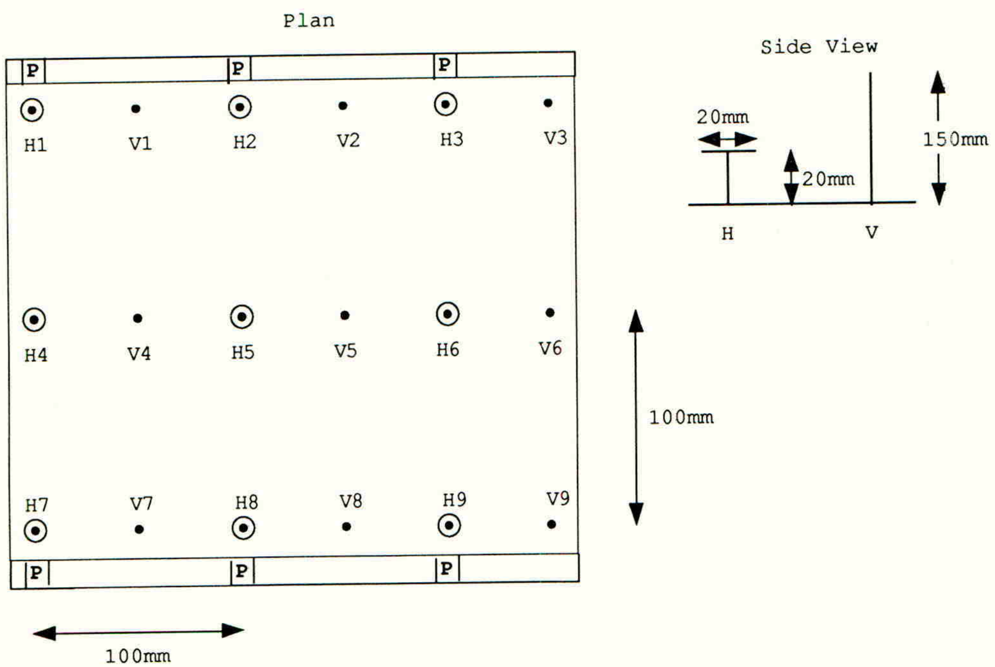
Table 1: The application parameters used

Spray quality	Nozzle	Pressure; bar	Drop size; VMD	Speed; km/h	Spray volume rate; l/ha
Very Fine	411010	4.0	200µm	9.5	68
Fine	411014	2.0	320µm	9.5	93
Medium	411020	1.7	400 µm	7.8	185
Coarse	411030	1.5	520µm	7.8	320

Wind speeds were chosen to give three contrasting regimes; zero, c. 1 to 2 and c. 3 to 7 m/sec; being referred within the text as Wind Level 0, 1 and 2 respectively. Whilst these speeds were measured at a normal reference height of 2.0m, it must be noted that many other measurements were made (such as wind speeds at other heights, wind angle, temperature) and are only summarized in this paper.

Artificial targets that represented a cotyledenous broad-leaf plant, a single leafed Gramminacæ and the bare ground were positioned on boards (Figure 1) and positioned under

Figure1 : Single board with horizontal and vertical targets



V = Vertical pipe cleaner with surface areas of 22.4cm^2 (Wind Level 0 and 1) and 17.8cm^2 (Wind Level 2)

H = Horizontal raised discs with surface plan area of 3.1cm^2

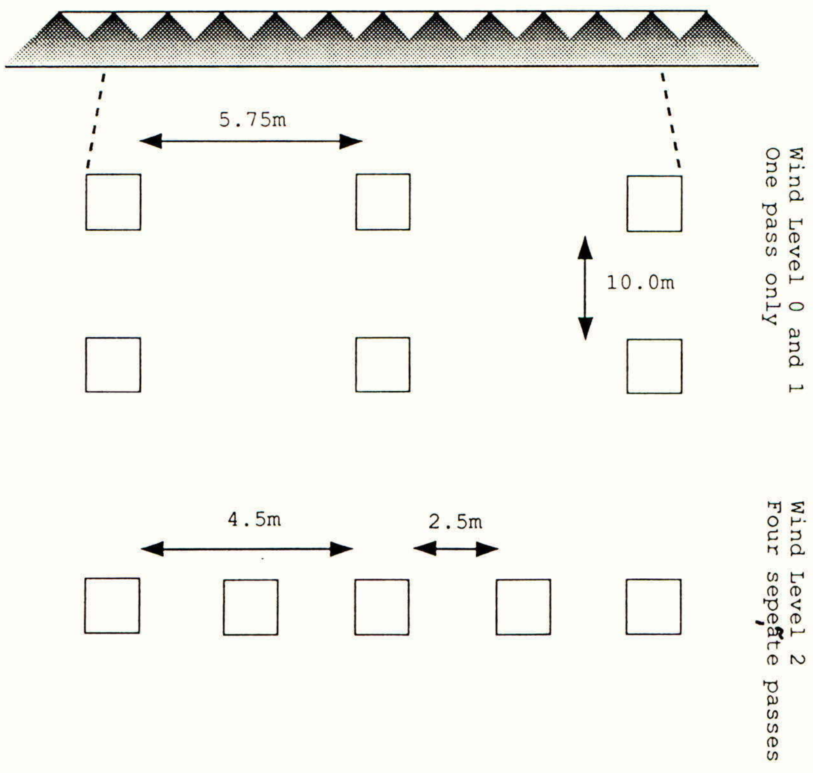
P = Areas (5cm by 5cm) were cut from paper strips (5cm wide) before and after each sample area (Wind Level 0 and 1 only).

the spraying swath, in fixed arrays (Figure 2). The areas used for the application were:

- Wind Level 0, a 60m by 40m soil tillage shed, where the surface was bare ground and the swath was 50m long.
- Wind Level 1 and 2, a cut grass flat field with a swath 100m long.

The outside tracks were orientated such that wind was predominately across the swath, the same tracks being used for all applications within each 'Wind Level'.

Figure 2: Layout of boards under swath



RESULTS

The experimental parameters could not allow true separation of spray quality from spray volume rate - and so, to ease comparisons, all values for the deposits, have been normalised. Statistical tests (at the 5% level) were carried out for the three Wind Levels independently.

WIND LEVEL 0 AND 1

Statistical difference between these values, albeit derived on two separate occasions, were not significant, and all values were compounded. On one occasion, a comparison between conventional vertical spraying was made with the nozzle angled back (but still without air assistance). There was no significant difference in deposit on the targets.

Air assistance enhanced mean deposits on the discs and pipe cleaners, but not the paper strips (Table 2).

Table 2: Mean deposits of all values for conventional and air assisted spraying

	Discs	Pipe Cleaners	Paper
Conventional	79	20	82
Air assisted	84	24	84
Increase; %	6	16	n.s.

Air assistance especially enhances deposits on discs with Very Fine Sprays, whereas on the vertical pipecleaner both Very Fine and Coarse sprays showed increased depots (Table 3). There was no significant interaction between air assistance and spray quality on deposits on the ground paper strips.

Table 3: Increase of mean deposit from air assistance with changes in spray quality; % over conventional

Spray quality	Coarse	Medium	Fine	Very Fine
Discs	0	7	4	17
Pipe cleaners	21	11	22	32

Efficiency of spray transfer, as judged by target plan areas and nozzle emission, shows that Coarse sprays on the discs were poorer than other spray qualities. (Table 4). The trend with the pipe cleaner target was most noticeable, a significant increase with every change to finer sprays. The ground deposits followed no such clear trend.

Table 4: Efficiency of spray transfer to contrasting targets from differing spray qualities; %

Target;	Discs	Pipe Cleaners	Paper
Spray quality;			
Coarse	74a	16a	82 b
Medium	84 b	20 b	93 c
Fine	82 b	25 c	84 b
Very Fine	82 b	32 d	72a

Figures followed by the same letter within vertical column are not significantly different.

Deposit variability within and between boards indicates whether variability is on a micro or macro scale. The Coefficient of Variation for all discs from all boards varied between treatments from 61 to 15 (mean 24) %. Pipe cleaners ranged from 137 to 16 (mean 37) % whereas the respective figures for the paper strips were 38 to 9 (22) %. The effect of air assistance was to decrease variability on the pipe cleaners (Table 5).

Table 5: Deposit variability on contrasting targets with air assistance; % CV

Target;	Discs	Pipe cleaners	Paper
Conventional	21	46	18
Air assisted	27	28	26

The variability of deposit on these targets is almost as great from within each board (Micro-variability) as it is from all boards (Macro variability), as cited above. (Table 6).

Table 6: Variability of deposit over large and small segments of the spraying swath; % CV

Target;	Discs	Pipe cleaners	Paper
Macrovariability	24	37	22
Microvariability	20	21	19

The frequency of deposit reaching threshold levels is an important measure of spraying efficiency, for it is this factor that will probably most contribute to biological response. The use of air assistance increases the efficiency of spray transfer onto the discs such that 36% of them by number retain more than 90% of the applied deposits, whereas from conventional practice it was 19%. (Table 7). At the same threshold level of 90%, paper strips showed that air assistance increased numbers exceeding this value from 30 to 39%. With the pipe cleaners at the lower threshold level of 25%, air assistance increased numbers from 22 to 41%.

Table 7: Frequency arbitrary threshold levels of spray deposit are exceeded on contrasting targets from conventional and air assisted applications; % based on mean of all spray qualities

Target:	Discs		Pipe cleaners		Paper	
Application:	Con.	Air.	Con.	Air.	Con.	Air.
Threshold level*						
>110	4	13			5	12
>90	19	36			30	39
>50	98	93	1	3	96	91
>25	100	100	22	41	100	100
>12			83	97		
>6			100	100		

* Mean emission on 100%

Spray quality markedly affects the pipe cleaner deposits: the finer the spray quality, the higher the frequency of targets achieving the higher threshold levels (Table 8). Coarse spray failed to reach the higher threshold levels on discs at the same frequency as other spray qualities. The paper strips, at ground level were also at the lowest frequency with Coarse spray, but were at the highest with Medium.

Table 8: Frequency arbitrary threshold levels of spray deposit on contrasting targets from differing spray qualities; %

Target;	Discs				Pipe cleaners				Paper			
Spray quality:	C	M	F	VF	C	M	F	VF	C	M	F	VF
Threshold levels												
>110	2	7	10	13					3	14	9	7
>90	11	34	30	30					21	49	34	26
>50	98	97	93	94			2	6	100		100	100
>25	100	100	100	100	1	10	42	68				
>12					77	91	92	98				
>6					100	100	100	100				

WIND LEVEL 2

Wind speed was measured at 3 heights viz 0.5, 1.0 and 2.0m every second and averaged for a period of 6 seconds from the moment of spraying the line of boards. It will be seen that wind speeds (quoted at 0.5 m height) were not uniform between the four applications and it is with care we have made comparisons. Knowledge of the exact relation between windspeed and deposition unfortunately cannot be obtained with this design. Assuming the relationship to be linear, the effects of spray quality and of air assistance were estimated by the method of "least square means". Stated values are relative to the mean deposits for discs and pipe cleaners when sprayed conventionally with a Very Fine drop spectra at a wind speed of 2m/sec.

Table 9: Mean deposits on discs from four consecutive applications, with differing spray qualities and at a range of wind speeds

Wind speed; m/sec	2	3	4	5	6	7
Spray quality:	*Application*					
Very Fine						
Conventional	100	69/209	61			
Air Assisted	134/99		56	144		
Fine						
Conventional	65	115/127		153		
Air assisted			66/99	85/116		
Medium						
Conventional		91/94	43	37		
Air assisted		56/76		35	32	
Coarse						
Conventional		33	34	26/47		
Air assisted			20	21/39		35

Table 10: Mean deposits on pipe cleaners from four consecutive applications, with differing spray qualities and at a range of wind speeds

Wind speed	2	3	4	5	6	7
Spray quality:	*Application*					
Very Fine						
Conventional	100	103/124	113			
Air assisted	106/122		116	127		
Fine						
Conventional	67	54/71		55		
Air assisted			58/66	102/108		
Medium						
Conventional		37/47	54	53		
Air assisted		46/48		60	60	
Coarse						
Conventional		25	34	32/41		
Air assisted			49	40/51		34

Mean deposits on the discs (Table 9) and pipe cleaners (Table 10) for each of the four 'replicated' treatments are shown against their corresponding recorded wind speeds. The effect of air assistance was to reduce deposits on the discs by an estimated 21%, but to enhance deposits on pipe cleaners by an estimated 15% (Table 11). However, there is a major effect of wind speed with deposits reducing on both types of targets as wind speed increased (Table 12).

Table 11: Mean deposits on discs and pipe cleaners

Targets; Application	Discs	Pipe cleaners
Conventional	64	73
Air assisted	80	63

Table 12: Effect of wind speed on spray deposits on discs and pipe cleaners

Target Wind speed; m/sec	Discs	Pipe cleaners
2	100a	99a
3	97a	61 c
4	55 b	70 b
5	71 b	67 b
6	32 c	60 c
7	35 c	34 d

Values with same letter are not significantly different

Spray quality also had a major effect on spray deposits on both discs and pipe cleaner, efficiency increasing with smaller drops (Table 13). The interaction between air assistance and spray quality is significant, but the trend is not clear (Table 14).

Table 13: Deposits on discs and pipe cleaners with changes in spray quality

Target: Spray quality:	Discs	Pipe cleaners
Coarse	32	38
Medium	60	49
Fine	102	71
Very Fine	93	114

Table 14: Changes in deposit level from the conventional when air assistance is used

Spray quality; Target:	Coarse	Medium	Fine	Very Fine
Disc	-24	-22	-41	+11
Pipe cleaners	+23	+11	+24	+11

The effect of position of sample boards under the spraying boom on subsequent deposits, was statistically tested - and differences were slightly significant, the patterns being different for discs and pipe cleaners. There was no indication of displacement from windward to leeward side, and the reason for this, has not yet been pursued.

The deposit variability in each application was 67% CV for discs and 27% CV for pipe cleaners. Without forgetting the limitations of the unbalanced design, these mean CVs can be separated into those for conventional and air assisted spraying to show a slight decrease in variability with the latter application despite being achieved at slightly higher wind speeds. (Table 15).

Table 15: Mean variability in deposit on different targets with changes in application; CV%

Target;	Disc	Pipe cleaners
Conventional	72	27
Air assisted	62	26

DISCUSSION

A great number of studies on spray drift have shown that increasing wind speed increases the proportion of spray liquid to be found on objects on the ground and on masts offswath (Nordby and Skuterud ,1974; Lagerfelt, 1988; Maybank and Grover, 1988; Western et al., 1989). Conversely, one would intuitively believe deposition within the swath on small targets near the ground to decrease, at least on objects horizontally orientated.

From this series of experiments, unbalanced as they were, we were not able to deduct a true relationship between deposition and wind speed. Nevertheless, statistical testing of the groups of four runs with the same spraying configuration showed wind speed to have a significant effect, with high wind speeds generally restricting deposition compared to lower wind speeds. With the purely arbitrary assumption of a linear relationship, the effect of wind was 'withdrawn' from the data from the 3rd set, and new estimated means produced for the effects of experimental factors.

The evidence that air assistance enhances deposition on pipe cleaners in all cases and on discs with the light wind can most probably be explained in terms of the extra kinetic energy given to the drops, enabling more of them to reach the targets and also not to follow micro-air currents around it. Supporting this view, air assistance especially enhances deposition on vertical objects, where droplets are caught by inertia only. Furthermore, in the light-wind there is a clear tendency that the smaller drop spectra configurations benefit more from air assistance than do the larger. It is at this stage not clear why, in the case of strong wind, air assistance led to a decline in deposit, on discs, at least as our estimated values indicate.

This shift in deposit patterns from horizontal towards vertical objects using air assistance might have useful implications in pesticide use. For example, Merritt (1980) mentions the importance of deposits of difenzoquat on the more sensitive vertical leaves of wild oats.

The increase in deposit efficiency on raised objects with the configurations producing smaller drop sizes is quite interesting. Smaller drops per se, a higher pressure and a higher driving speed are the same configuration that normally give rise to a higher degree of drift. Also there was a tendency, that less deposit was found on the ground paper strips with the smaller drop size configurations.

So far, explanations can only be speculative: for vertical objects, the smaller the drop size, the greater will be any wind produced, horizontal component of drop trajectories both in absolute terms and relative to the vertical component. This means, that at the same time, velocity for impaction is increased with the vertical pipe cleaner intercepting the trajectory of a moving drop. At the other hand, the velocity requirement is greater for the smaller drop to impact, leaving quite a complex process to be explained. Finally, the similar results derived during strong wind of a greater deposit efficiency with smaller drop sizes for the horizontally raised discs, complicates explanations further.

In addition to the better deposit on individual targets with the smaller drop sizes, it is well known from other experiments and theory, that smaller drops also cover the exposed surfaces more effectively.

The comparison of deposition in the conventional configuration with nozzles pointing vertical versus 25° rearwards showing no significant difference was in line with findings of Combellack and Richardson (1985). Whilst they found a significant increase in mean deposits by pointing nozzles 95° rearwards, there was no difference between vertical use and nozzles pointing 45° rearwards.

The deposit 'grand total' average from the light wind conditions were in the ration 1:1.7 for pipe cleaners:disc. In the strong wind this ration was reduced to 1:1.3. This tendency is well in accordance with the average shift in drop trajectory towards the horizontal.

Whilst the average CV for all objects of a type within a run in the light wind was somewhat similar for discs and pipe cleaner, in strong wind the average CV-value was 2.5 times bigger for discs than for pipes. The process of vertical sedimentation seems to have become more erratic with the higher wind speed than has the process of lateral impaction.

Considering the mean variability within a single board, this is seen to comprise the major part of the total variability within a run: 83% for discs, 57% for pipe cleaners and 86% for paper-strips. With the tractor repeatedly driving along the same trail and boards located at the same spot, variability is supposedly less than it would be in a full field. Especially boom movement beyond the repeated 'frozen picture' obtained in this experiment would give rise to more of the 'macro'-variability from one end to the other of the boom (Nation, 1980). Still, our results show, that despite reducing variability by careful calibration, the operator is left with quite a variability on this small size of target.

The use of air assistance reduced deposit variability for discs under windy conditions and for pipe cleaners under light wind conditions. Hagenvall (1981) showed the importance of reducing this deposit variability to obtain a proper effect of both a contact and systemic herbicide.

Cumulative frequencies of objects having received (per unit area) a certain fraction of the nozzle output, combined with averages and variability gives a good illustration of application efficiency. Whilst with conventional spraying one quarter of the discs received a full dose and nearly all at least a half dose, with air assistance half received, a full dose and again nearly all at least a half dose. With pipe cleaners, one quarter received a quarter of full dose and all received one 16th thereof with conventional sprayer, whereas with air assistance nearly half received a quarter and nearly all objects one 8th thereof.

The relationship between dose per target surface area and a biological effect is not always obvious. For example, Western and Woodley (1987) found the correlation between total leaf-deposit and herbicidal effect to be poor, and suggested, that possibly the deposition pattern over the plant surface may be as equally critical as the total deposit. Hence our results will need much pesticide work relating changes in deposit patterns to subsequent biological effect.

CONCLUSION

Air assistance enhances deposits with all configurations at low wind speeds, the improvement being greatest on vertical objects and with the smaller drop size spectra. With stronger winds, air assistance also enhances deposit on vertical objects, but reduces deposit on horizontal discs. However spraying with configurations that produce the smaller drop sizes enhances deposition efficiency on both types of object. Variability on the scale of these small individual objects is equal to or less than that with conventional spraying.

Wind speed has a significant, yet undetermined effect of deposition on both types of objects. Increasing wind speed seems to reduce deposits, but, as with the air assistance, also tends to shift deposits from horizontal towards vertical surfaces.

The relative position of targets to the ground, and their orientation, interacts strongly with experimental factors such as drop size, and wind speed. The use of raised objects of different orientations in deposit experiments therefore seems imperative, when different plant geometries are to be imitated.

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ENHANCING CONVENTIONAL HYDRAULIC NOZZLE USE WITH THE TWIN SPRAY SYSTEM

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ABSTRACT
The air curtain of the Twin Spray System is shown to entrain sprayed drops, increasing their velocities and the quanity available at typical target distances from the boom. These velocity changes reduce spray drift both under laboratory and field conditions with all spray qualities but increasingly so as drop size reduces. The entrainment of spray maintains uniformity of patterns under varying conditions - and so offers equal security at reduced volumes and Fine sprays, with that of conventional practice. Changing air curtain angle and speed can be used to increase deposits on vertical surfaces and lower that on horizontal - either when such targets are exposed or concealed at the base of winter wheat. Increases in vertical deposits are associated with a lowering of quantities reaching the ground. Spray retention on winter wheat was increased with air assistance - the top of the plant retaining more from Fine sprays but the lower parts more from Medium quality. In potatoes, air speed had an effect on canopy penetration and quantities available to both top and bottom leaf surfaces. In essence, spray conventionally retained at the top of the plant was applied further within. Measurements on sugar beet leaves showed similar effects of being able to increase under surface deposits. In addition, the quantity of spray under and between the crop rows show that herbicide deposits may again be enhanced with air assistance. In all plant retention studies, it was noted that efficiency of spray transfer was very high and may only be further bettered by swath containment of the 'driftable' drops or modifications to their trajectories.

INTRODUCTION
Pesticide performance arising from careful hydraulic nozzle selection and use remains - so far - unsurpassed by other more novel application systems (Rutherford *et al* 1989). However, whilst wishing to retain this proven, reproducible performance, the spray machine operator and the environmentalist seek still more economic, easier and safer use of pesticides. Hence independent application research and commercial developments have had common objectives, that are embodied in this new air assisted boom sprayer, and include the desire to spray low water volume rates, when labels so permit, lessen spray drift and optimisation of foliar deposits. Accepting that conventional hydraulic nozzles are likely to remain the dominant means of drop formation for field crop sprayers, our engineers have sought ways of enhancing their performance but with due consideration to the following,

Field performance of sprayers has been measured (Nation, 1978), the database being further extended, modified and made available as a computer program (Drouin, 1990). Application variables, that include spray volume rates, interact to affect workrates in the field. Clearly, halving volume rates - where possible - from 200l/ha saves considerable amounts of water, energy, haulage and refilling time. Reducing water volumes still more yields few additional advantages, for factors such as spray tank and field size then dominate in spraying logistics under European conditions. Hence there are few practical advantages from reducing volumes much below 100 l/ha.

The target, and subsequent 'zone of influence' for pesticide deposits vary widely. Where targets are relatively large, exposed and the active ingredients undergo further redistribution, then opportunities for very low volumes and even large drops should increase (Table 1). In reality, whilst many products will tolerate applications at 100 l/ha (Bailey 1978, Skuterud 1988), efficacy is sub-optimal as volumes are reduced still further, sometimes for reasons associated with spray liquid concentration (Merritt and Taylor, 1977) as well as cover. At the lower end of these current volume rate recommendations, spray quality may strongly interact with biological effect. Whilst those products that can tolerate application as Coarse sprays at 100 l/ha could be sprayed with equal biological effect as Fine sprays, the reverse may not be true.

Table 1: Theoretical numbers of drops of two sizes, from three volume rates on two sizes of horizontal target.

Target size; mm^2		100		10	
Drop diameter; µm		150	350	150	350
Volume rate; l/ha	200	1130	88	113	9
	100	565	44	57	4
	50	283	22	28	2

Manipulating foliar deposits through changes in volume rate or spray quality offers little scope (Table 2). Retention of conventionally applied sprays are very effective and ground deposits through 'run off' are minimal when using adaquate formulations. Such sources of ground contamination are more governed by the plant growth stage and its subsequent ground cover. Comparing spray retention on cereals when surfactants are not used is dangerously misleading. Foliar applied products almost always substantially reduce the surface tension of the spray liquid, and retention always

Table 2: Spray retention (µl 100 l/ha) at two winter wheat growth stages, and ground deposit (as % of that applied)

Application; Spray		100 l/ha 'Fine'		300 l/ha 'Coarse'	
		- retained	- on ground	- retained	- on ground
Growth stage	Plant section				
Zadoks 14,22	-Total	1.4	(96)	1.0	(93)
45	-Top	17.2	(9)	15.0	(6)
	- Bottom	0.2		0.6	

marginally increases with lowering volume rates - irrespective of application mode.

Spray drift is closely associated with drop size (spray quality) and attempts to apply smaller drops at lower volumes increases this hazard (Table 3) and restricts available spraying days (Adams 1978) if conventional nozzles are used unmodified. Those products that demand use of Fine sprays are therefore more difficult to 'time' their application in the field, than those that tolerate Coarse. However, in the near future, it is likely that foliar applied products - rather than soil-applied 'residuals' - will be more environmentally acceptable, and these products, coupled to their application in repeat low-dose programmes to small targets, may force an increasing need for both low volumes and Fine sprays - without more drift than existing practice.

Table 3: Spray drift, spray quality and wind speed; µl/mast 100 l/ha

Volume rate;		l/ha	VMD; µm	Wind speed; m/sec 3.0	3.5 to 5.0
Spray quality:	Very fine	90	200	5.25	12.21
	Fine	125	320	2.13	3.29

The engineers directive was to therefore retain conventional hydraulic nozzles but to enhance and extend their use - particularly at volume rates of c.100 l/ha and apply the more driftable Fine sprays with at least equal accuracy and security to that accepted today at higher volumes and larger drop sizes. A further core requirement was to offer more control and option in choice of drop trajectory - even at distances of over 1.0m from the nozzle, and in the presence of interceptory leaf surfaces so that foliar pesticides may be redirected, as and when necessary, to preferred sites. It was also made quite clear that improved penetration of dense leaf canopies was not to be matched against losses through poor retention or increased ground contamination.

A REVIEW OF SOME KEY AREAS OF RESEARCH

Measurements on the effect of air entrained drops:

- On speeds, number and volume applied.

In conventional practice hydraulic nozzles produce, small drops, which, with their low momenta, slow down quickly to be readily winnowed out by the forward motion of the sprayer and/or wind. Vortices trail, rise up, and accumulate to form the subsequent diffusing spray drift cloud. The air curtain, at a typical target distance of 0.5m from the nozzle, increases small drop speed (Fig 1), containing number (Fig 2) and hence volume of this spray that would form the 'driftable' spray fraction. Wind tunnel predictions on driftability of sprays over a large range of nozzle sizes and pressures - show that drift may be reduced and applied deposits increased, to an extent dependant on spray quality - or drop size. (Fig 3) (Young 1990, Young 1991).

Figure 1: Velocities for 4110-14 at 2.0 bar. 40cm below nozzle.

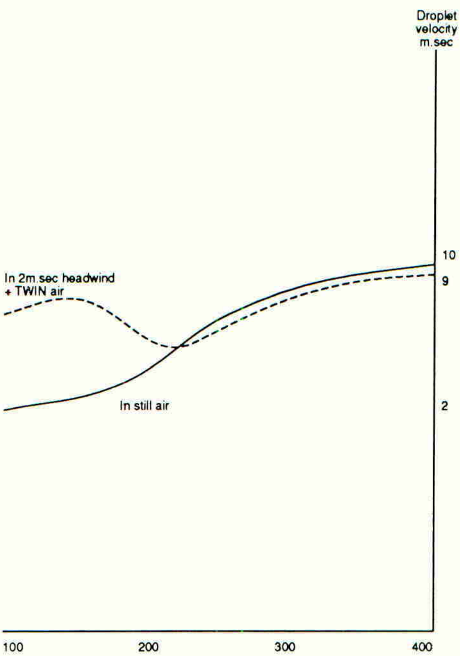


Figure 2: Numbers and size of drops 40cm below nozzle with the effect of 'wind' and air assistance

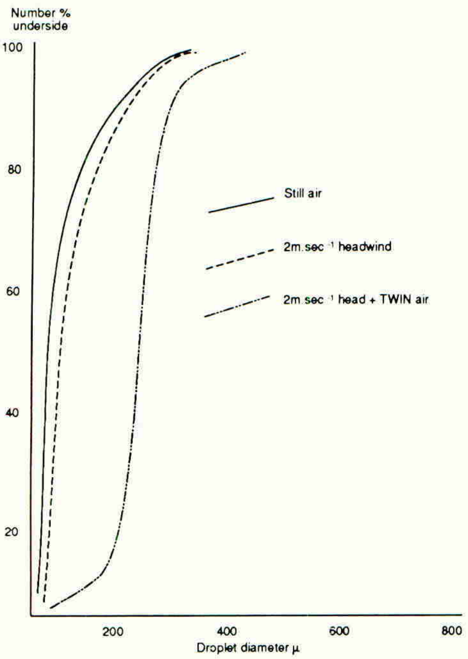
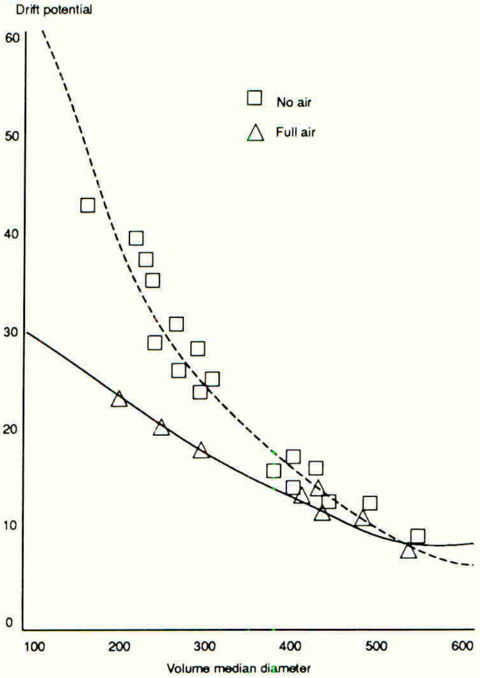


Figure 3: Relationship between median diameter and drift potential for Hardi 4110 series nozzles



- On reducing spray drift in the field. The urgency from within Europe to reduce drift dominated the earlier field research - measurements being made under a wide range of climatic, cropping and application conditions. Particularly relevant to the UK is the demonstratable ability to use volume of 90 to 125 l/ha as Fine sprays, with at least equal security to that associated with conventional 200l/ha applications using Medium quality sprays (Table 4). This magnitude of drift control should permit spraying at higher wind speeds (Table 5) to 'widen' the spraying window and improve

Table 4: Comparing the Twin System using a Fine spray with traditional practice; µl/mast 100 l/ha

	Safe wind	Marginal wind
Medium spray quality	1.79	2.71
Fine spray quality with air assistance	1.52	1.38

Table 5: Effect of air assistance and wind speed on spray lost as drift; % of the emitted spray

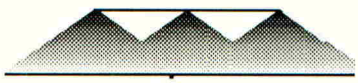
Wind speed at 2m height; m/.sec		1.5	3.0	4.5	8.5
Air assistance	off	1.9	1.8	3.2	4.7
	on	0.8	0.8	1.1	1.8

Nozzles 4110 12 at 2.5bar (Very Fine) and spraying speed of 7.7km/h applying 100l/ha.

pesticide application timing. Drift measurements were made using downwind masts with collectors that non-intrusively sample the passing spray cloud. Equal concern by other European countries is directed at the quantity of spray that sediments out downwind to contaminate non-target areas - especially environmentally sensitive zones such as ponds and hedgerows. Reductions in spray drift equates to that which sediments out using Fine, Medium or Coarse spray qualities (Table 6) (Taylor, Andersen and Cooper 1989, Taylor, Cooper and Quanquin (1990).

Table 6: Effect of conventional spraying and air assistance on swath deposits, swath edge and downwind displacement of sedimenting drops; $\mu l/25cm^2$ (mean of 3 replicates)

Swath - sprayed - edge - downwind



Wind speed; 1 to 1.5m/sec

Air assistance

- Without	18.6	18.3	16.7	18.6	16.1	16.2	18.4	15.6	11.7	10.9	4.7	3.8	4.6	3.8	3.2	2.5	2.0	1.6	1.0	1.2
- With	18.8	21.7	24.3	21.0	25.4	22.8	20.0	14.8	13.7	9.4	0.7	0.9	0.4	0.5	0.6	0.5	0.5	0.4	0.2	0.2

4.0m

- On spray distribution by contrasting targets. The frequency target surfaces retain more than the threshold dose level to give acceptable levels of control is fundamental to predicting field performance. Increasing mean deposits applied and reducing their variability would encourage some reduction in dose and/or an increase in reliability of effect - a problem urgently being addressed in Denmark. Hence the advantages gained with drift reduction, must not be off-set with a poorer spray distribution - irrespective of target type, be they large or small, flat or vertical. Air entrainment can increase applied deposit levels (Table 7), maintain uniformity of cover over a range of wind speeds and when needed, direct sprays from horizontal to vertical surfaces (Fig 4) (Nordbo 1991).

Figure 4: Effect of air assistance and spray quality on spray retention by vertical surface; µl.target

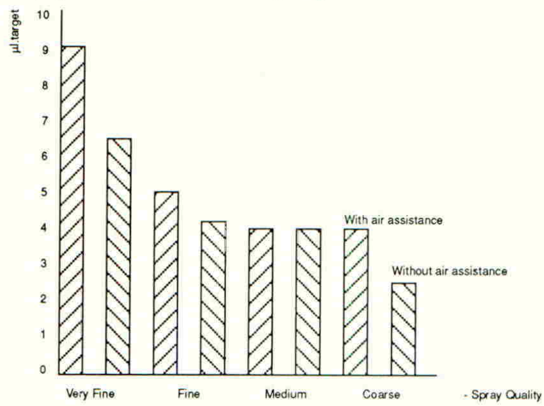


Table 7: Effect of air assistance on increasing spray deposits with changes in spray quality; %

Spray quality:	Very Fine	Fine	Medium	Coarse
Raised, horizontal paper discs	18	6	2	2
Vertical pipe cleaners	32	6	8	33

Table 8: Compounded effects of spray deposits on artificial targets from a) air speed, b) air curtain angle – to identify major contributory causes; µl/target

a) air speed		No air	Air at 15m.sec	-28m.sec
Target	Horizontal	2.32	1.90	1.75
	Vertical	2.18	2.85	3.44
	Ground	13.65	11.40	7.93

b) air curtain angle		Forward	Vertical	Backward
Target	Horizontal	2.15	1.45	1.86
	Vertical	3.74	3.11	2.59
	Ground	9.75	8.25	11.00

Manipulating spray deposits -

- at the cereal canopy base. Few application systems consider the contrasting needs met when, for example, one herbicide is directed at broad leaf weeds and another to the vertical surfaces of the wild oat. Almost identical application systems are used for these two extremes of target. In Germany, current legislation already attempts to restrict spray drift by limiting volume rates to those at 200l/ha or more, and limiting speed to less than 8.0km/h. Hence, attention is refocussed on ground contamination and potential waste of pesticide within the treatment zone.

Artificial targets that present both horizontal and vertical surfaces were placed within a winter wheat canopy (Zadoks 32-37) to show how drop laden air curtains can be used to increase deposits on vertical surfaces when needed (Table 8). This increased lateral movement of sprays contributes to reduced ground contamination. Deposit values whilst higher - are of an equivalent uniformity to that associated to conventional spraying; a measure of efficiency not matched by other air entrainment systems that rely on random air and drop mixing. (Ringel, Taylor and Andersen 1991).

Table 9: Spray retention and distribution on winter wheat (Zadoks 39) with and without air assistance; µl/plant – or section thereof.

Spray volume rate; l/ha	Air assistance	TOTAL DEPOSIT	LOCAL Top	LOCAL Middle	LOCAL Bottom
100	without	13.4	10.6	1.5	1.3
	with	14.6	11.6	1.8	1.3
	% change	+9	+9	+20	-8
200	without	13.2	10.8	1.3	1.1
	with	13.6	10.2	1.8	1.6
	% change	+3	-6	+38	+45

- on winter wheat. Much speculation surrounds the efficiency of conventional spraying practice, the influence of spray volume rates and any potential advantage that could be gained from air assistance. Spray deposits were measured on winter wheat (Zadoks 39) to derive total values for retention and its local distribution. Deposits from lower volumes of Fine sprays may be increased with air assistance more than the comparable increase derived from

Table 10: Efficiency of spray transfer onto winter wheat, with and without air assistance; %

Spray volume rate; l/ha	Air assistance	%
100	Without	91
	With	99
200	Without	90
	With	92

Note: Field broadcast sown to produce 680 stems.m^2. At 100l/ha, deposits from a uniform application when totaly retained by the plant would be 14.7µl/stem. Wind speed was low – c.1.5 to 2.0m.sec. Spray liquid was water and surfactant at 0.1%.

conventional volumes and Medium sprays (Table 9). This modest increase is likely to be that due to the containment - rather than loss - of the driftable spray.

Efficiency of conventional spraying practice - even with a spray solution of only 0.1% surfactant - is very high with spray always being predominantly retained at the top of the plant (Table 10). Local increases in deposit with air assistance applying Fine spray may be from more being available where as with Medium sprays, the use of its larger drops capable of following an angled trajectory. (Jeffrey and Taylor, 1991).

Table 11: Changes in spray deposits on upper and lower 'leaf' surface of potatoes, relative to the conventional practce of 200 l/ha and Medium Quality; %

Leaf surface	Upper				Lower			
Air emission speed; m.sec	0	15	22	28	0	15	22	28
Plant Top	100	94	44	44	100	133	410	247
Middle	100	121	135	123	100	94	147	141
Bottom	100	143	188	143	100	100	150	200

- *on potatoes.* The canopy shape, distances between leaves and the areas they present to sprays pose problems if the pesticide to be applied should preferentially be deposited on the inner leaves, and/or the underside. Using folded filter paper strips stapled around leaves at the top, middle and bottom of plants an attempt has been made to predict likely changes in deposition patterns with the use of air assistance. Tentative results suggest that whilst deposits on the undersurface of leaves and those within the canopy, could be increased, they are dependant on air outlet speeds. (Table 11). (Jeffrey and Taylor, 1991).

Table 12: Spray retention on upper and lower leaf surfaces (sample size 40 x 60mm) of sugar beet; l/ha

Leaf surface		-upper	-lower
Air assistance	-without	85	5
	-with	67	19

Air assistance was vertical (23m.sec at outlet) and the emitted volume rate of Fine spray was 90 l/ha

Table 13: Spray deposition on raised circular (45mmD) targets between and under rows of sugar beet; l/ha

Spray deposited		-between	-under row
Air assistance	-without	53	10
	-with	80	16

Air assistance was vertical (23m.sec at outlet) and the emitted volume rate of Fine sprays was 90 l/ha.

- *On sugar beet.* Low volumes of Fine sprays are frequently used in this crop for both aphid and weed control. Measurements of deposits on both the leaf upper and lower surfaces (Table 12), and those areas below and between the crop rows (Table 13) show that air assistance will change the final location of the sprayed deposit (May, 1991). Again, it must be worthy of note that the efficiency of transfer cannot be improved when low volumes of Fine sprays are applied, and that air assistance reallocates the deposit to areas not attainable with conventional machines.

DISCUSSION

The basis behind many attempts to improve pesticide performance, beyond that possible with conventional hydraulic nozzles (used when following agrochemical label recommendations) is often ill-founded. In particular, it is often quoted, that drops are inefficiently retained by foliage, the resultant 'run-off' being a considerable part of the applied dose and that subsequent improvements can be readily gained through simple application-related changes. The evidence from this and earlier work demonstrates that even spraying aqueous surfactant solutions (0.1%v.v.) onto wheat plants, efficiency of transfer can be very high (>90% of that emitted from the nozzle). Losses with foliar sprays are more closely associated with 'drift' and leaf ground cover - rather than retention. The magnitude of both sources of loss are very variable but now may be better controlled with this system over a greater range of conditions. The extensive evidence available shows improvements in spray transfer are possible in two ways. The first direct benefit is to contain the spray to the swath and hence make available that fraction which is normally lost as drift and/or is displaced. This advantage would be common to all products. The second group of benefits are relevant to foliar applied products and arise from opportunities to redirect the spray, using air assistance to maintain angled drop trajectories and/or ruffle leaves that would otherwise intercept spray. This is a more complex phenomenon and from which, generalised predictions on behaviour are only now becoming clearer. The observed effect of an air curtain passing over two contrasting crops - such as wheat and potatoes - are markedly different, and so not surprisingly, affects spray behaviour too. However, with both extremes, useful changes in deposit location are gained. The manipulation of spray deposits from horizontal to vertical surfaces, even at the base of cereal crops, or by directing more deposits onto under leaf surfaces at the centre of a potato crop should open up exciting possibilities for still more careful matching of application to target. This improvement is gained without altering any of the physical characteristics of the spray and its subsequent deposit, nor in any losses of uniformity of spray cover.

Increases in available spray - and where applicable - subsequent leaf retention - are most noticable with air assistance as traditional conditions for losses worsen. Hence, low volumes of Fine sprays applied at high wind speeds would show the greatest advantage with air assistance, whilst high volumes of Coarse drops at low wind speeds, the least benefit over traditional practice. The ability to link drift reduction with increases in target deposition have been most reassuring.

It is clear, that our efforts have deliberately concentrated on the lower volume rate use of Fine sprays. This is for two reasons. Firstly, to responsibly promote the more extensive use of such application methods demands reliable proof that its consequence would not pose more hazard than that accepted today - and hopefully - better it. This we have demonstrated. In addition, it is generally accepted future environmental pressures will encourage greater emphasis on foliar - rather than soil - applied pesticides. The most successful and judicious use of such products, stems from repeat low dose programmes controlling pests at early stages in their development. Experience from the past has shown that low volumes (for high field work rates) and Fine sprays (for adequate cover) were then a necessity and in the future, will be the norm. The Twin Spray System was thus engineered to meet the agronomists specifications for effective, efficient and safe pesticide use - a challenge that this paper readily shows, is more than matched.

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REVIEW OF THE USE OF A TWIN-FLUID SPRAY SYSTEM ON A BERKSHIRE FARM FROM 1987 TO 1990

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ABSTRACT

The use of a twin-fluid sprayer over three seasons on this cereal farm has shown that compared with conventional spraying, considerable savings have been made in spraying time and application rates, which have more than covered the initial extra capital cost.

INTRODUCTION

Fishers Farm is a holding of 235 hectares situated in West Berkshire. The soil is mostly flinty clay cap over chalk classified as Batcombe Association. A flock of 1000 ewes is maintained on about 50 hectares of rotational grass leys, and the rest of the farm carries autumn sown crops of wheat, barley and herbage seed. Over the past three seasons wheat has yielded on average 8t/ha, and barley 7.1t/ha. Hybrid Italian Ryegrass yields have varied between 0.7 and 1.8t/ha.

THE CHOICE OF SPRAYER

Until three years ago all spraying had been done with a 1500 litre trailed sprayer with an 18 metre boom fitted with conventional nozzles. Herbicides were mostly applied in 240l/ha of water, whereas with fungicides the rate was reduced to 180l/ha. These rates allowed between 6 and 8ha of spraying for each full tank.

In June 1987 this sprayer urgently needed replacement, and various factors influenced the choice of replacement machine. These were price, the need to increase workrate because of farm staff reductions, the need to improve timeliness and accuracy of applications, and if possible to minimise wheeling damage to crops and soil.

The final choice was between a 2000 litre trailed machine fitted with an 18 metre conventional nozzle boom, and with wheel tracking to follow accurately the tractor wheels , or a mounted 800 litre sprayer fitted with twin fluid (air/liquid) nozzles, the Cleanacres Airtec System. At today's prices the Airtec machine is about £2000 more expensive than the conventional sprayer.

Despite this addional cost the Airtec was chosen because of the other criteria and also offered the possibility of reducing chemical rates. Reassurances were sought from the manufacturers and from the relevant authorities as to the implications of the forthcoming FEPA legislation on this category of equipment.

ON-FARM PERFORMANCE

Disadvantages

Few problems have been encountered which can be associated with the extra complexity of this twin fluid machine, and in three seasons maintenance costs have been only slightly higher than those of a conventiional sprayer.

Nozzle blockages have been experienced, but at low application volumes of typically 80l/ha they have been no more frequent than would be anticipated with conventional hydraulic nozzles spraying at 200l/ha.

There have been some occasional restrictions in choice of product because of the lower application volumes used with the Airtec, either for fear of poor efficacy, or because of legal limitations. These have been of little practical significance, and the secondary conventional sprayline has rarely been fitted.

Advantages

Increased workrate

Most applications have been carried out at 70 to 80 l/ha, but fungicides have been applied at 60l/ha, and some herbicides have required 100l/ha. Typically the total cycle including filling, travel and spraying takes 60 to 70 minutes. This has allowed large areas to be covered per day with a relatively small tractor-mounted machine.

Improved timeliness

The ability to spray at low volumes without producing a high proportion of fine droplets, and the facility of adjusting droplet size on the move without changing the spraying rate to suit the prevailing conditions considerably increases the oppurtunity for spraying. Suitably adjusted this machine can continue working safely without drift problems when a conventional sprayer could not be used. This considerably improves the chances of applying agrochemicals at the optimum time, at minimum rates before the target problem increases, and at maximum efficacy.

Agrochemical savings

In practice it has been found that considerable savings can be made in agrochemical costs, especially fungicides. Table 1 shows the costs of spray chemicals actually applied to a 46 hectare crop of winter wheat cultivar Riband, compared with the costs which would have been incurred had a conventional sprayer been used.

This subjective assessment shows a saving of about £21.50 over conventional applications, largely achieved through lower fingicide rates. From this a saving of agrochemical costs, and savings of this order have been achieved with no detriment to cereal yields or quality. Although no claims were made by the sprayer manufacturer of the potential for chemical savings, it was found, within the first year, that such savings more than repaid the extra cost involved in the initial purchase of this machine.

TABLE 1. Table showing actual costs of pesticides per hectare on a winter wheat crop using a twin-fluid sprayer as compared to equivalent costs using a conventional hydraulic sprayer.

Pesticide used	Actual Costs Twin-fluid system £/hectare	Equivalent Costs Conventional hydraulic £/hectare
Trace elements	0.76	1.90
Growth regulators	2.24	3.10
Insecticides	2.13	2.50
Herbicides	28.82	29.60
Fungicides	46.75	67.80
TOTAL	£80.70	£102.20

CONCLUSIONS

The operational, ecological and financial advantages experienced on this farm using a twin fluid air/liquid sprayer indicate that it is likely that this type of machine will become increasingly popular with farmers, and sales figures apparently confirm this trend. It is extremely frustrating and confusing to the user that with few exceptions, product label recommendations are rarely given for these sprayers. Agrochemical manufacturers should revise their product labels.