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PROJECT REPORT No. 96

A COMPARISON OF METHODS OF APPLYING PESTICIDES TO CEREAL GRAINS BEFORE STORAGE

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A COMPARISON OF METHODS OF APPLYING PESTICIDES TO CEREAL GRAINS BEFORE STORAGE

by

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Summary

The project examined methods of improving the application of pesticide to grain streams and so minimise the dose required for effective pest control. An initial hypothesis was that coarser sprays with a small percentage of the spray volume in small droplets (< 100 μm), would give better impaction and retention on a moving grain stream but a less uniform coverage of the treated grain. Experiments were therefore conducted to assess the retention when using coarse sprays compared with conventional nozzles, and the biological performance of liquid pesticides applied as such coarse sprays or as liquid streams.

A shrouded spinning disc and dribble bar arrangement were used to apply both tracer dyes and a liquid pesticide formulation to a moving grain stream at flow rates of nominally 5 tonne h^{-1}. Comparative experiments were conducted with a range of nozzle types, including a twin-fluid design and a conventional cone nozzle commonly used in grain spraying equipment. Measurements showed that the spray from the spinning disc system was coarser than that from the conventional cone nozzle, having a volume median diameter of 252 μm with 0.3% of the spray volume in droplets < 100 μm in diameter compared with 195 μm and 6.1% for the conventional cone nozzle respectively.

An effective technique was established based on the use of tracer dyes to determine the comparative retention of liquids applied to moving grain streams with different application systems.

The main results from the work were:

- Spray recoveries from treated grain were between 60 and 85% with tracer dyes, but were less than 60% with the active pesticide formulation. The lower recoveries with the active pesticide may be related to the method of analysis or the condition of the grain. There was some evidence that a proportion of the 15-40% of spray lost from the grain was absorbed by dust and debris.

- Differences in spray recoveries when using the different application systems were small but there was a trend towards higher recoveries with the coarser sprays from the disc and dribble bar systems. This trend was evident in both tracer dye and pesticide experiments.

- Insect response related directly to pesticide capture by the grain and was consistent with the results from laboratory tests. This means that systems such as the dribble bar or spinning disc that could increase retention would give improved biological control at a given application rate or the same level of control at a lower rate in comparison with conventional nozzle systems.

It was concluded that both the spinning disc and dribble bar arrangement are application systems suitable for further development. They have the potential advantages of increased pesticide retention on the grain for a given nozzle output and improved uniformity in the case of the spinning disc. It would be possible with both systems to match pesticide application rate to grain flow rate without affecting the physical parameters of the pesticide liquid. If realised, these advantages could represent significant savings in pesticide use.

Contents

1. Introduction

The current situation relating to the UK production of cereal grains often involves extended periods of storage and demands for higher quality standards. Grain in which live pests can be found is not acceptable to the major markets. A cost-effective method currently available for keeping grain free from pests is to admix with a contact pesticide. Trials have shown that grain can be protected for a season by a single application of pesticide (Wilkin and Hurlock, 1986) and that the low cost (circa 50p/tonne) and high level of effectiveness has led to the widespread adoption of the admixture of pesticides, particularly in commercial grain stores. A survey of commercial grain storage sites in England and Wales in 1988/89 showed that, at 67% of sites, some or all of the grain had been treated with contact insecticides at some time in the 12 months prior to sampling (Prickett and Muggleton, 1991). There is some evidence that the sales of grain protectant chemicals have continued to increase during the past decade (Garthwaite et al. 1987; Olney and Garthwaite, 1994).

Effective grain protectants have to be relatively persistent and some of the chemicals used show little breakdown after nine months' storage. Residues in the grain are readily passed into the human food chain, particularly in bread (Wilkin and Fishwick, 1981). Post-harvest treatments of grain are now likely to represent an important source of pesticide in the human diet. Over the next five to ten years it seems unlikely that the UK cereals industry will be able to reduce its dependence on pesticide admixture. The continuing possibility of surpluses and extended storage periods may well lead to a further increase in their use. If this is not to result in a rise in the level of pesticide residues in the human diet, efforts must be made to restrict the quantity of pesticide used without losing essential biological control.

Results from work at the Central Science Laboratory, Slough, have indicated that treatment rates of about half those currently recommended, applied in a controlled manner, can give satisfactory protection. If this could be achieved commercially then considerable savings in pesticide usage would be achieved.

The work at Slough also analysed the quantity of pesticide on individual grains of cereal in 25 g samples taken from the flow from a conveyor after conventional spraying (Rowlands and Edwards, 1986). Results from this work showed that most of the grains in the sample had received some pesticide although the dose rates varied from 0.1 mg/kg to 424 mg/kg. Some work has also examined the effects of the distribution of pesticides on treated grain by using a few highly toxic grains to carry most of the pesticide dose in the grain bulk. Results from these studies have indicated that such treatments may be more effective than a uniformly applied dose (Rowlands, 1975). However, any advantages are likely to be short-lived since there is evidence to show that the pesticide will be re-distributed through the grain mass during a month or so of storage (Rowlands and Edwards, 1986). Part of the work reported here aimed to define more precisely the effect of application on the biological performance of grain protectant chemicals and the interactions between uniformity and the applied dose rate.

Relatively little previous research has investigated the deposition of pesticide sprays applied to moving grain streams and it is likely that the parameters currently used have been arrived at by limited experimentation based on available application systems. In the USA, Endsley et al. (1989) examined the uniformity of fungicide applied to maize by spraying the grain at the intake to an auger. Spray coverage on the treated grain was determined using a fluorescent dye and image analysis techniques. The results showed that better coverage was obtained using cone nozzles producing a finer spray than with the coarser spray from flat fan nozzles.

The physical characteristics of a spray, such as droplet size and velocity distributions, are known to influence retention (May and Clifford, 1967; Starr, 1967) and in some cases, the biological performance of sprays applied to agricultural targets (Hislop, 1987). Small droplets tend to follow air streams whereas large droplets may bounce or shatter on impact with a target surface. In the case of a grain flow in an open conveyor, there is likely to be an entrained air flow above the grain surface. Changes in the physical spray characteristics are likely to alter the total quantity of spray on the grain and the penetration of the spray into the moving surfaces of the grain mass. In the case of an open conveyor therefore there is a potential conflict between the need to use fine sprays (large numbers of small droplets) to give uniform coverage of the grain and the need to use larger droplets to impact on the grain hence maximising target deposition and minimising pesticide losses. It should be noted that the work of Endsley et al. (1989) used a closed auger conveyor and no assessments of the total deposition of pesticide on the grain were made.

The results from the previous work at Slough suggest that the need for high levels of uniformity on the treated grain can be relaxed due to a combination of re-distribution mechanisms, insect mobility and chemical vapour action. This project therefore set out to examine methods by which grain protectant chemicals could be applied to moving grain streams to give high levels of transfer of the pesticide dose and uniformity levels that did not impair biological control.

2. Experimental materials and methods

2.1 Pesticide application systems studied

Most systems for treating grain, particularly in commercial stores, are designed for operation in conjunction with conveyors operating at grain flow rates in excess of 10 tonne h^{-1}. The exception to this is in some on-farm installations where grain flow rates may be as low as 4 tonnes h^{-1}. Conventional grain protectant pesticide formulations are applied to grain at volume rates in the range 0.75 to 1.5 l $tonne^{-1}$. Experiments as part of this project work used relatively low grain flow rates (nominally 5.0 tonnes h^{-1}, see also Section 2.3) because:

(a) the problems of spray retention and distribution are likely to be most pronounced when using low grain and nozzle flow rates; and

(b) it was more cost-effective to conduct experiments using tracer dyes with smaller grain flow rates since grain treated in such experiments could not be sold or used commercially.

Experimental pesticide application systems were therefore identified for operation at total flow rates in the range 0.06 to 0.15 $1\ min^{-1}$.

In selecting the spraying systems to be studied, the following criteria were used:

(i) the requirement to be able to create relatively coarse sprays at low volume throughputs;

(ii) the ability to operate over a range of flow rates either by changes to fixed parameters such as nozzle orifice size (so as to match the system to the scale of the grain handling plant) or operating parameters such as nozzle pressure (which would be particularly important when considering the real time control of pesticide application systems to match variations in grain flow rate);

(iii) the ability to control the spray volume distribution pattern such that a "uniform" or controlled application could be made over the surface of grain flowing in a duct with a minimum of wetted surface away from the grain stream;

(iv) the ability to operate in dusty conditions and inaccessible locations where the continuous monitoring of output or re-calibration of the unit are difficult.

A review of possible pesticide application methods was conducted and a summary of the results is given in Appendix I. The work described in this report used the application systems described in Table 1.

Table 1 : Spraying systems used experimentally

Type	Detailed description	Operating conditions
Cone nozzle	Delavan Watson Type WA208. Typical nozzle used in farm-scale grain treatment equipment	Pressure 2.0 - 3.0 bar. Flow rate 0.085 - 0.105 l/min.
Cone nozzle	Spraying Systems Type TX2	Pressure 1.5 - 2.0 bar. Flow rate 0.11 - 0.125 l/min.
Flat-fan nozzle	Spraying Systems Type 110005	Pressure 1.25 bar. Flow rate 0.125 l/min.
Twin-fluid nozzle	Lechler Type 1932581624.	Pressures 1.0 bar air, 1.0 liquid. Flow rates 0.125 l/min.
Spinning disc (shrouded)	Micron Herbiflex. Available with colour coded injector nozzles to control flow rate at a given feed pressure.	Used brown injector. Flow rates between 0.055 and 0.075 l/min. Fed with peristaltic pump. Operated with 6 volt D.C. supply for all experiments.

The pressure nozzle systems were supplied with spray liquid from a controlled pressurised container system and the operating pressure monitored on a gauge positioned close to the nozzle.

In addition to these commercial nozzle systems, a dribble bar arrangement was designed and constructed for operation at flow rates in the range 0.05 to 0.15 l min^{-1} and is shown in Figure 1. The size of the liquid outlet holes in the bar was chosen to be as small as practically feasible considering constraints relating to the accurate construction and the potential for blockage during operation. The dribble bar unit was supplied from an electrically driven peristaltic pump (Watson Marlow Type 502S) via a diaphragm check valve and metering orifice. The diaphragm check valve ensured that the flow from the dribble bar cut off sharply when the pump was switched off and the metering orifice provided some additional back pressure (circa 0.3 bar at the mean flow rate) to stabilise the delivery conditions.

The use of a peristaltic pump to feed both the dribble bar and spinning disc pesticide delivery systems would enable the output of these systems to be controlled to match grain flow rate on a conveyor without major changes in the physical form of the pesticide presented to the grain stream. This would then enable an improved control of the dose applied to the grain to be achieved.

2.2 Physical characteristics of the pesticide delivery from each of the application system

2.2.1 System flow rates

The measured pressure/flow rate characteristics for the cone and flat fan pressure nozzles and for the twin-fluid nozzle are plotted in Figure 2. The plotted data show the ability of the twin-fluid nozzle system to give a wide range of flow rates for relatively small changes in operating pressure when compared with the characteristics of the hydraulic pressure nozzles. These data were used to set the operational parameters in the grain treatment experiments.

The flow rates for the spinning disc and for the dribble bar arrangement were set by calibrating the peristaltic pump operating with the injector nozzle from the disc and directly connected to the dribble bar.

2.2.2 Measurement of droplet size and velocity distributions

Measurements of spray droplet size and velocity distributions were made using the two laser-based instruments available at Silsoe Research Institute. These were:

(a) **A Particle Measuring Systems** analyser which uses the shadowgraph principle to generate images of individual droplets that are then analysed by computer to produce droplet size and velocity distributions. When sampling the spray from the hydraulic pressure nozzles, the nozzles were mounted spraying vertically downwards from a computer controlled x-y transporter and moved at speeds of up to 50 mm/s so as to sample the complete spray pattern 100 mm below the nozzle. Measurements with the spinning disc unit were made by mounting the measuring probe horizontally and moving the disc along a line at right angles to the probe and 100 mm from the sampling laser beam. The experimental arrangement when sampling the spray from the spinning disc is shown in Figure 3.

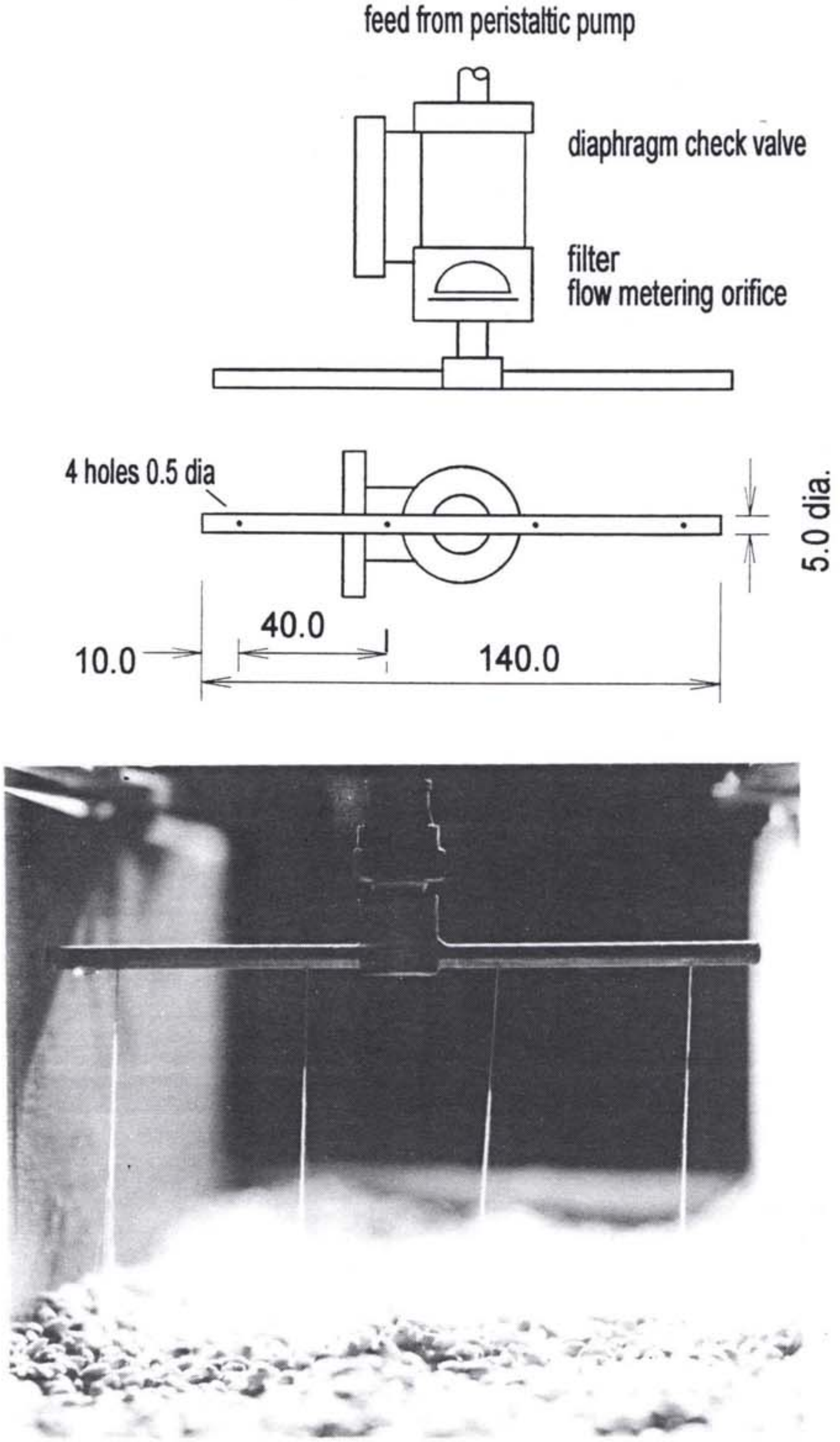
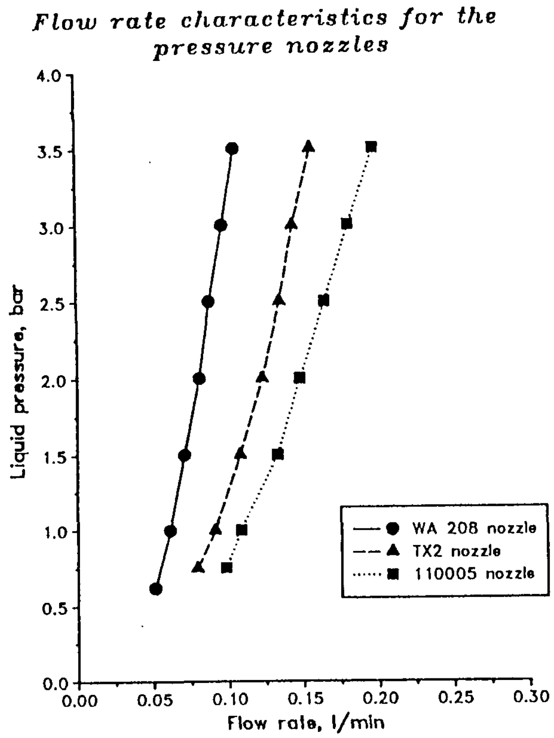


Figure 1 : Dribble bar unit for applying pesticide to grain flowing in a duct
(a) Top: Diagram of the construction of the unit (dimensions in mm)
(b) Bottom: Photograph of the unit in operation over an open duct containing static grain



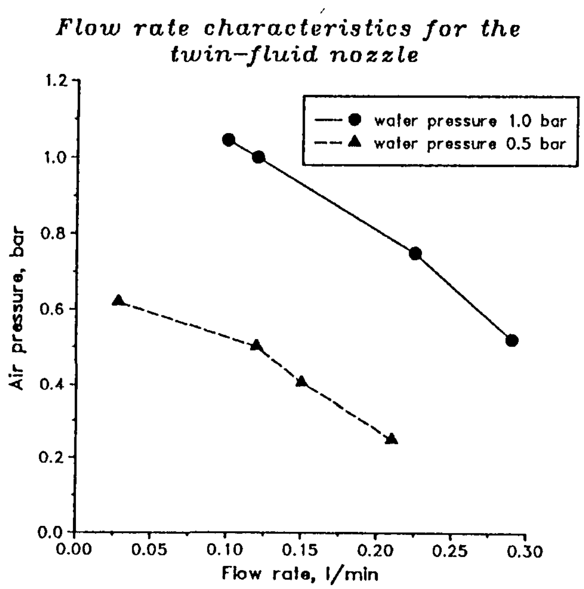


Figure 2 : Flow rate characteristics of the application systems studied
(a) Top: for the hydraulic pressure nozzles
(b) Bottom: for the twin-fluid nozzle

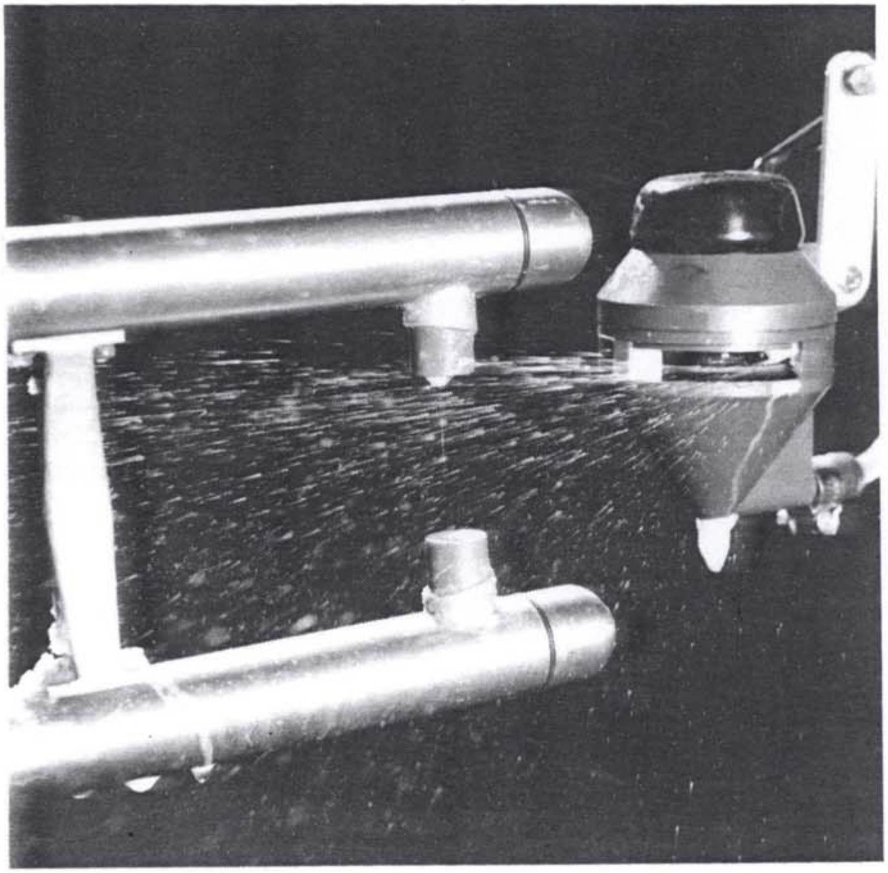


Figure 3 : Droplet size and velocity measurement from the spinning discs using the Particle Measuring Systems analyser

(b) **A Phase Doppler** analyser (Dantec Ltd) which uses the intersection of two laser beams to produce a sampling area defined by an optical interference fringe pattern. Droplets pass through the sampling region and scatter light at a frequency which is proportional to their velocity. This scattered light is detected by three photo-detectors positioned close together and at an appropriate angle to detect the maximum amount of forward scattered light. Computer analysis of the outputs from the photo-detectors determines droplet velocities from the frequency components of the scattered light and droplet size from the phase relationship between the detectors positioned close together. Because the sampling volume of the instrument is small (typically less than 1 mm^3), measurements were again made 100 mm below the nozzle by moving the nozzle in an appropriate sampling pattern on the x-y nozzle transporter to obtain data relating to the whole of the spray pattern produced.

Sampling conditions for measuring droplet size and velocity distributions with both instruments were selected as appropriate to a grain spraying operation. All measurements were made spraying a 0.1% solution of a non-ionic surfactant in a chamber with a very low velocity purge air flow to prevent small droplets recirculating in the sampling zones.

Measurements were not made with both systems for all of the application systems because of the absence of suitable protocols particularly for characterising the spray from a spinning disc with the Phase Doppler analyser. It was also recognised that the two measuring systems would give different results for the systems measured with both instruments. No measurements were made with the dribble bar since the droplets, if formed, would be too large for either measurement system.

2.2.3 Measurement of spray volume distribution patterns

Measurements of the spray volume distribution pattern were made using a standard patternator (BS 6356 Pt 1, 1983) with 25 mm sampling channels. Tube heights on the patternator were recorded manually.

2.3 Grain flow and sampling arrangements

For all the experimental work described in this report, the pesticide application systems were mounted in an inclined 150 mm square section duct down which grain flowed under gravity. Grain was delivered to the experimental arrangement from a conventional galvanised steel hopper-bottomed bin using chain and flight conveyors and bucket elevators. The grain flow rate was controlled by adjustable slides fitted in both the hopper and duct arrangement.

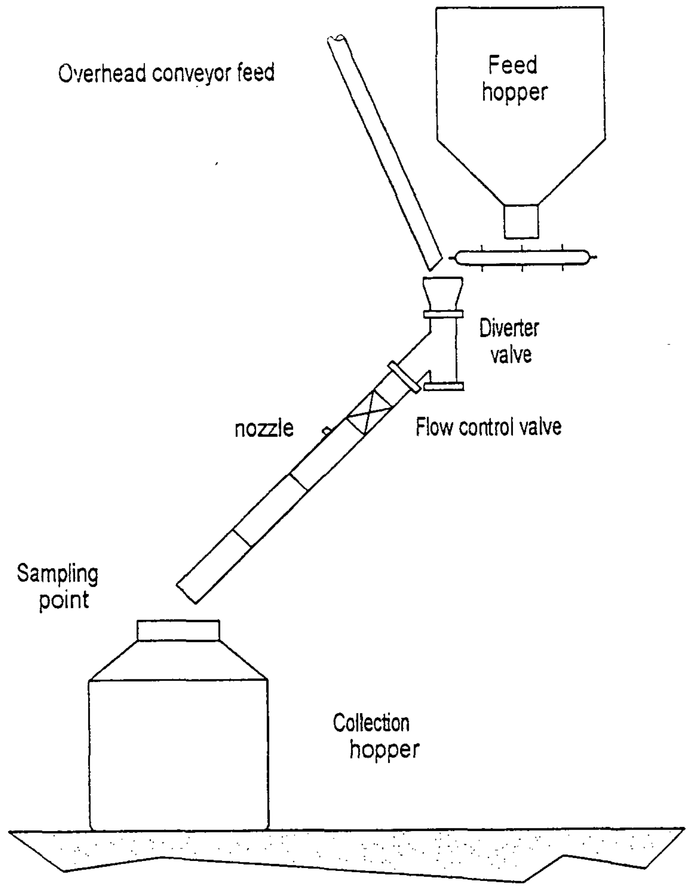
Initial runs with the spinning disc system applying tracer dyes showed that grain bouncing down the duct, rather than sliding in a continuous stream on the lower surface, could contact the disc assembly and cause it to jam. A deflecting baffle was therefore added in the duct immediately upstream of the pesticide application system. The grain duct extended for 2.0 m beyond the pesticide application point to allow some mixing and absorption of pesticide before the treated grain was sampled. The arrangement of the grain feed and sampling points is shown in Figure 4.

All experiments used wheat with a mean moisture content of 14.9% and 1000 grain weight (at 15% moisture content) of 48.4 g. The cleanliness of samples varied depending on grain source over the two seasons of analytical measurement and the position within the supply bin. For experiments in the second year of the work, damaged grain was measured at 3.3% of the sample.

The mounting of the spinning disc and cone nozzle spraying systems in the treatment duct is shown in Figure 5.

2.3.1 Sampling to assess the retention of tracer on the grain

After a stable and calibrated grain flow had been established in the treatment duct, samples were collected at two positions across the grain stream leaving the duct at 45 s intervals after an initial 30 s period to ensure that steady state conditions had been reached. In addition to the above sampling scheme, a plate covered with chromatography paper was used to deflect the grain issuing from the duct through 70° to 90° for a time period of 15 s. Free tracer dye not absorbed by the grain was absorbed by the paper and quantified by spectrophotometric techniques - see Section 2.4.1.



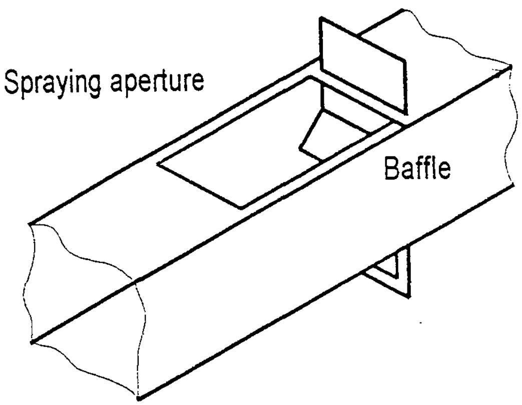


Figure 4 : Experimental arrangement for grain spraying experiments
(a) Left: General layout of treatment duct showing application and sampling positions
(b) Right: Detail of the duct section in which pesticide applications were made

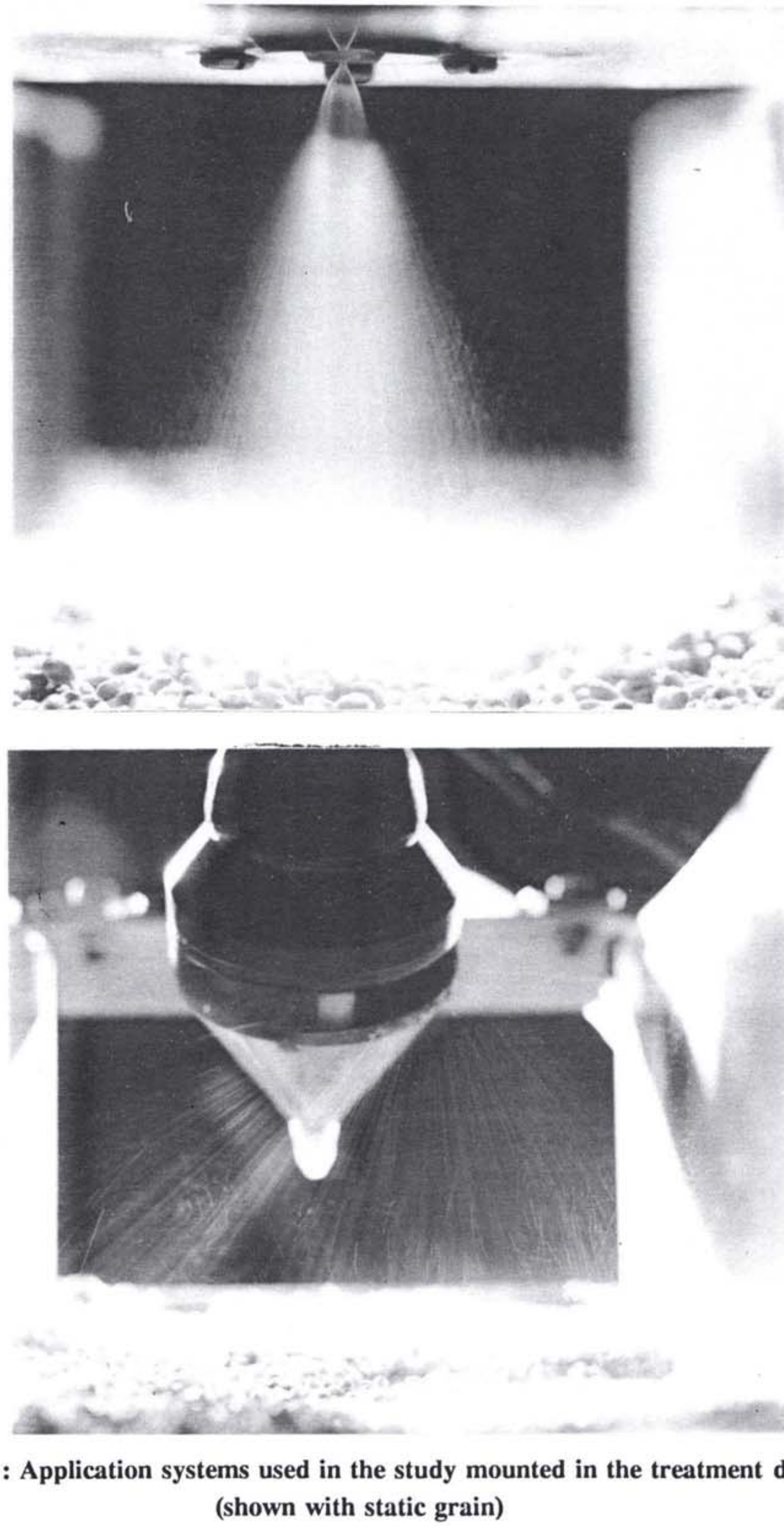


Figure 5 : Application systems used in the study mounted in the treatment duct (shown with static grain)
(a) Top: conventional cone nozzle
(b) Bottom: shrouded spinning disc

2.3.2 Samples for bio-assay and pesticide recovery

Samples from the treatment duct were taken as described in 2.3.1 above. The grain treated with pesticide was collected in a 500 kg hopper and this was sampled at four positions with a gravity spear immediately after spraying and again after 7 days. For one experiment, samples were taken at 7, 14 and 28 days after treatment. The positions where the gravity spear samples were taken were marked so that subsequent samples were taken from the same place so reducing any variability in the results due to different pesticide concentrations occurring at different positions in the hopper.

2.4 Application recovery techniques

2.4.1 Using tracer dyes

Initial experiments were conducted to evaluate the use of both fluorimetry (Sharp, 1974) and spectrophotometry (Gilbert and Bell, 1988) with the appropriate tracer dyes to examine the retention of sprays on a treated grain stream. Comparable results were obtained with both methods and it was therefore decided to use spectrophotometry techniques since these were less likely to be influenced by degradation in ambient light. A laboratory technique was developed for quantifying dye on a sprayed green sample which involved:

(i) accurately weighing a 50 g sample of grain (25 g samples were used in the first series of measurements and in validation experiments);

(ii) the addition of 40 ml of de-ionised water, shaking for 30 s allowing to stand overnight and then filtering;

(iii) centrifuging the samples for 20 min at 10,000 g in order to remove suspended debris in the sample:

(iv) reading samples on a spectrophotometer at a set wavelength for the dye and having previously calibrated the instrument with dye solutions of accurately known concentrations.

The work used two water soluble tracer dyes, Lissamine Green (BDH Ltd) and Dalfcol Green (Butterfield Laboratories Ltd) with the latter being used for most of the full-scale experimental work.

The tracer dye techniques were validated by two experimental methods, outlined below.

1. Treatment of individual seeds with a measured quantity of dye in which 0.035 μl doses of the two tracer dyes were pipetted onto replicated samples of 100 grains individually (see Figure 6). The same pipetting technique was used to apply 100 metered doses to water and filter paper surfaces which were then recovered and quantified using the methods outlined above. Results from this experiment are shown in Table 2.

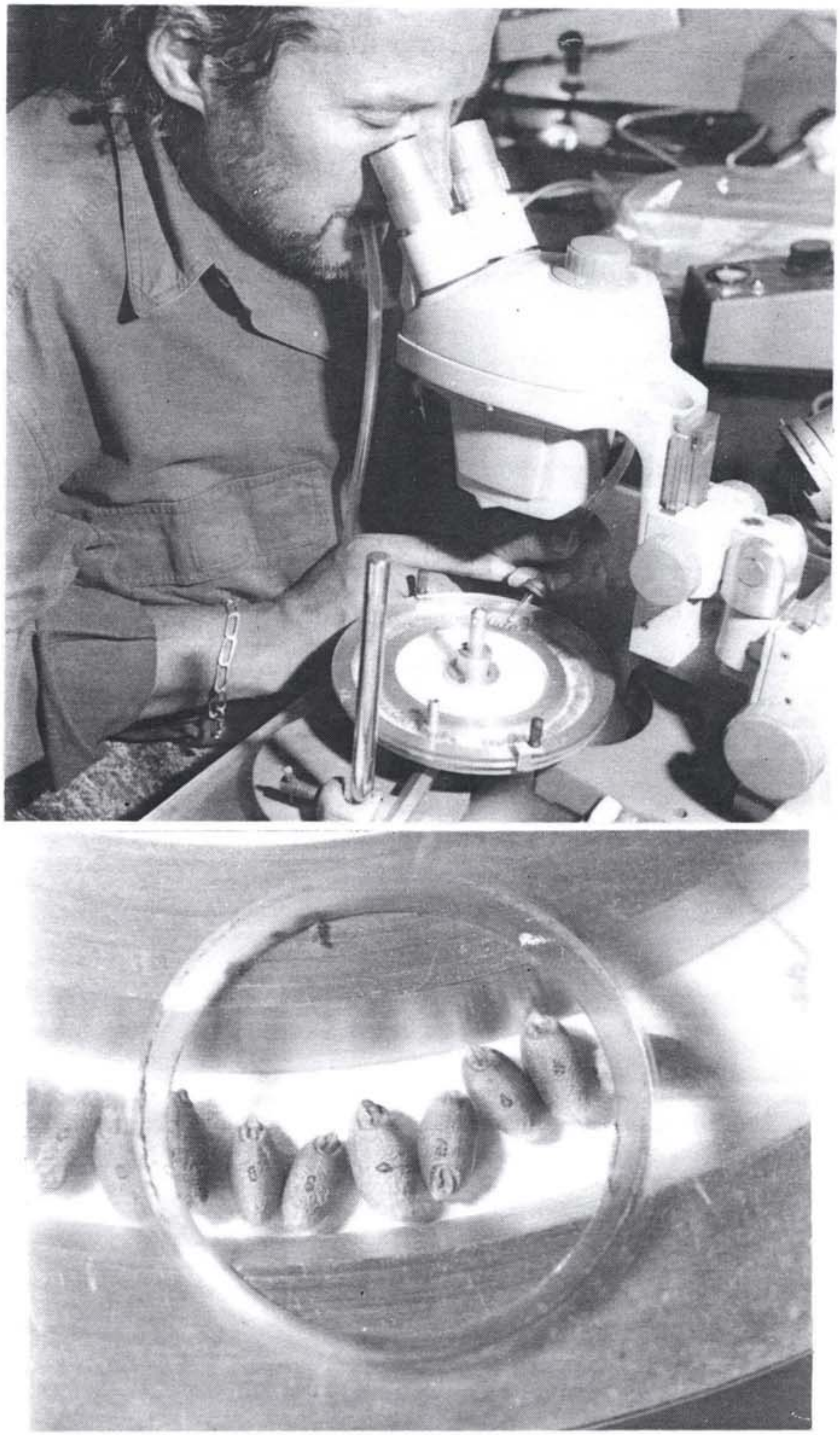


Figure 6 : Photographs of the micro-pipette application of dye to individual grains
Top: Applications being made to grain on a turntable
Bottom: Close-up of treated grains

Table 2 : Measured recoveries, μl of original dye solution applied by Micro-Pipette Treatment of a surface with 100 measured doses of 0.035 μl

Dye	Replicate	Surface		
		10 ml de-ionized water	90 mm filter paper	100 grains
Lissamine green	1	4.02	2.96	4.50
"	2	4.07	2.95	4.51
"	3	4.03	3.01	4.52
MEANS (S.D.)		4.04	2.97	4.51
"		(0.022)	(0.026)	(0.008)
Dalfcol green	1	3.68	2.82	4.09
"	2	3.773.75	2.892.79	4.164.15
"	3	3.75	2.79	4.15
MEANS (S.D.)		3.73	2.83	4.13
"		(0.039)	(0.042)	(0.031)

2. Using a sprayed application from a WA208 nozzle operating at a pressure of 2.0 bar with a measured flow rate of 0.085 l min^{-1} which was moved across sample petri dishes containing grain (25 g), water (20 ml) and filter paper. The nozzle was mounted at a height of 150 mm above the surface and moved at a constant speed of 0.75 m s^{-1}. Results from this experiment are shown in Table 3.

The results from the validation experiments (with the micro-pipette application) show:

(a) that the recoveries from the applications directly into the solvent (de-ionised water) were in very good agreement with the applied dose in the case of the Dalfcol Green dye but rather high in the case of the Lissamine Green;

(b) recoveries when using Lissamine Green were consistently higher than with the Dalfcol Green: this may have been due to different volumes being delivered by the metering capillary tube due to different liquid properties;

(c) agreement between replicates of samples treated with the micro-pipette was excellent with standard errors of less than 2%, of the mean;

Table 3 : Quantities of Dalfcol green dye recovered from petri dish samples sprayed from a moving nozzle

Replicate	Spray liquid recovered, µl		
	20 mls of de-ionised water	90 mm filter paper	25 g wheat
1	16.3	13.6	19.4
2	19.4	20.1	21.6
3	20.9	20.6	25.9
4	31.4	24.4	29.5
5	23.7	19.8	27.4
6	14.1	12.3	15.0
7	21.7	18.1	29.1
8	26.8	26.1	23.0
Mean	20.4	19.4	23.9
s.d.	6.2	4.4	4.7

(d) recoveries from the filter papers were in the order of 75% of dye measured in the directly treated solvent dishes whereas the recoveries from grain averaged above 111%. Background levels for both these materials were subsequently checked and found to be less than 0.03 µl/sample and therefore not directly responsible for all of the observed differences. However, the importance of background levels was noted and measured in all full-scale experiments.

The recoveries of dye from the sprayed surfaces in Table 3 are in good agreement with the micro-pipetted treatments. Recoveries from filter papers were 95% of those from the water surface whereas the recoveries from grain were 117% of those from water. Some of the variability in the sprayed experiment comes from the variation in the dose applied by the nozzle and this is reflected in the higher standard deviations in this case compared with those in Table 2.

The results from these validation experiments showed that the tracer dye techniques would provide an accurate and robust technique for comparing the retention of liquids applied to grain streams by different methods. Absolute measures of recovery were likely to be over-estimated by as much as 18% but the use of measured background values should enable accuracies of better than 10% to be achieved.

2.4.2 <u>Analysis of pesticide residues and spray recoveries</u>

For each test run with pesticide, at least 200 g of grain was retained from each sampled point and sent to the MAFF Central Science Laboratory at Slough for the analysis of pesticide residues. The method used was that developed by the Committee for Analytical Methods (Anon, 1980).

2.5 Bio-assay techniques

The pesticide used in the study was a commercial emulsifiable concentrate formulation of primiphos-methyl (Actellic) containing 250 g l^{-1} of the active ingredient. This was to be applied to the grain to give a nominal dose rate of active chemical of 0.25 mg kg^{-1}. The insects used in the study were resistant strains of *Tribolium castaneum* (CTC-12) and *Oryzaephilus surinamensis* (484 Diamond). Laboratory tests conducted by the MAFF Central Science Laboratory at Slough indicated that the dose of 0.25 mg kg^{-1} on the grain would produce between 5 and 15% knock-down with the former and 90 to 95% knock-down with the latter strain.

2.5.1 Exposure of insects to the grain

Each sample of grain taken from the treated bulk and four of those from the outlet duct for each treatment were divided to give six 50 g aliquots which were then placed in 125 ml wide-necked jars. Three replicate jars from each sample were set up with each of the insect species. The inner lip of the jars to be used in the tests with O. *surinamensis* were coated with fluon to prevent the insects from climbing out. Twenty five 3 to 5 week old adult insects were added to each jar which was then sealed and placed in constant temperature and relative humidity of nominally 25°C and 70% r.h. for a period of 48 hours.

2.5.2 Assessment of treatment response

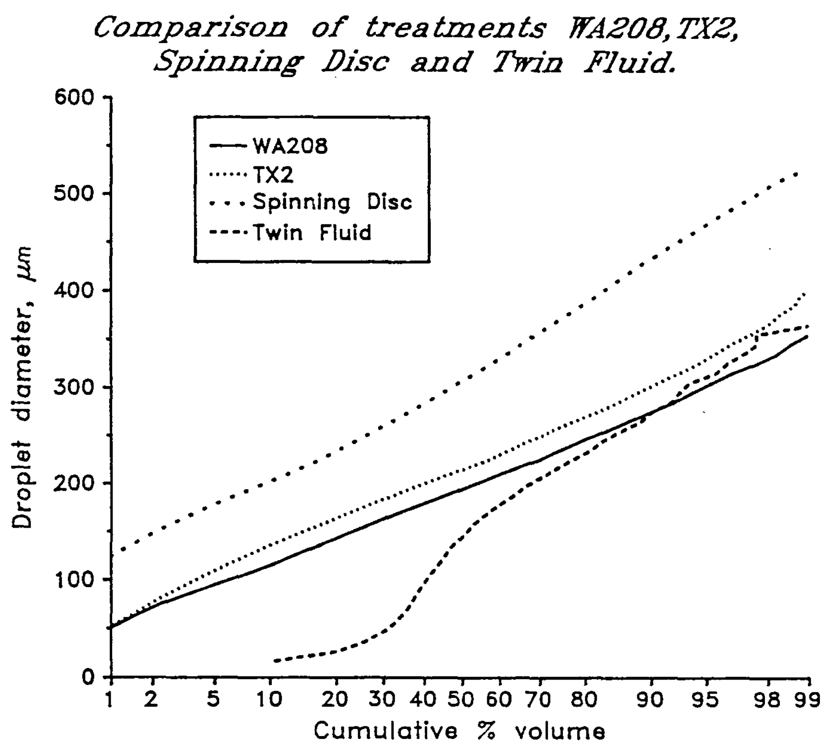
After the 48 hour period had elapsed the contents of each replicate jar were tipped onto an enamelled tray and the number of insects that were knocked-down and dead was recorded. An insect was considered to be knocked-down if it was on its back and unable to right itself, even when aided by a soft brush. It was considered to be dead when no movement was observed even after prodding with a seeker.

3. Results

3.1 Physical characteristics of the liquid delivery systems

3.1.1 Droplet size and velocity distributions

Results from the PMS analyser (Figure 7) showed that the spray produced by the shrouded spinning disc was substantially coarser than that from the narrow cone angled nozzle WA 208. The volume median diameter (VMD) from the disc was 252 μm compared with 195 μm for the WA 208 cone nozzle. The proportion of spray volume in droplets less than 100 μm in diameter (ie. those sizes most likely to be deflected by air streams above the grain surface) was also lower for the spinning disc unit at 0.3% compared with 6.1% for the WA 208 cone. The form of the droplet size distribution for the spinning disc is shown in Figure 8 together with the measured droplet velocity profile. Droplet velocities for the disc were lower than for the WA 208 cone nozzle (Figure 7) but approximately equal to those from the TX2 cone nozzle. The spray from the TX2 nozzle was slightly coarser than that from the WA 208 cone (VMD for TX2 = 214 μm) and reflects the effect of a larger



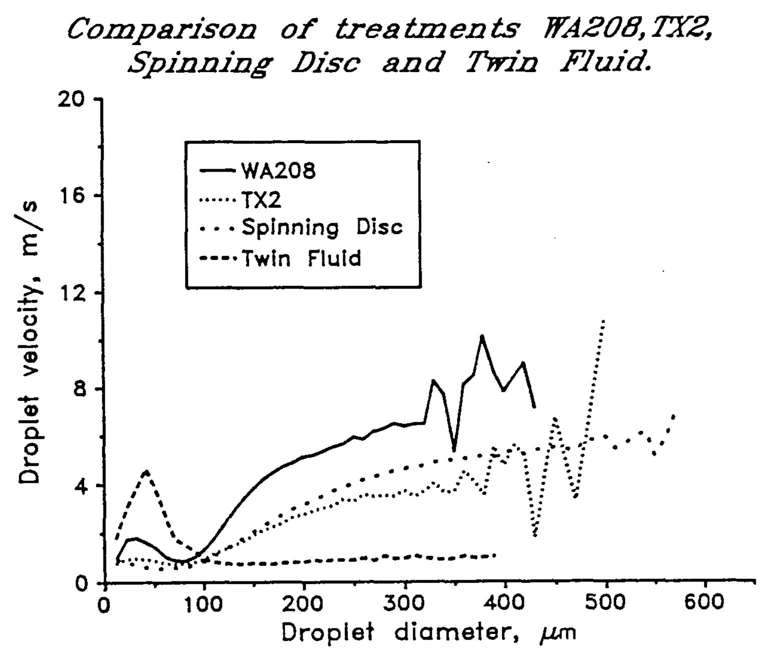
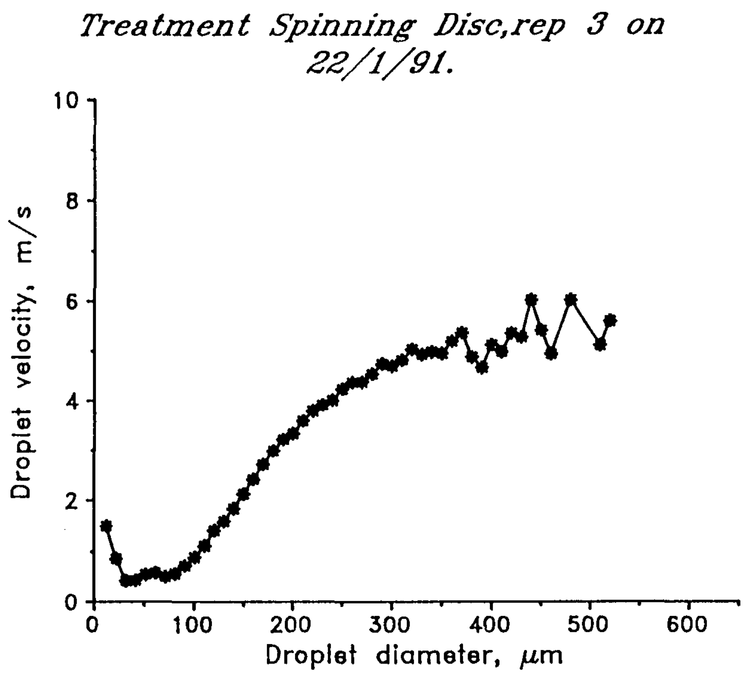


Figure 7 : Droplet size and velocity profiles measured with the Particle Measuring Systems analyser



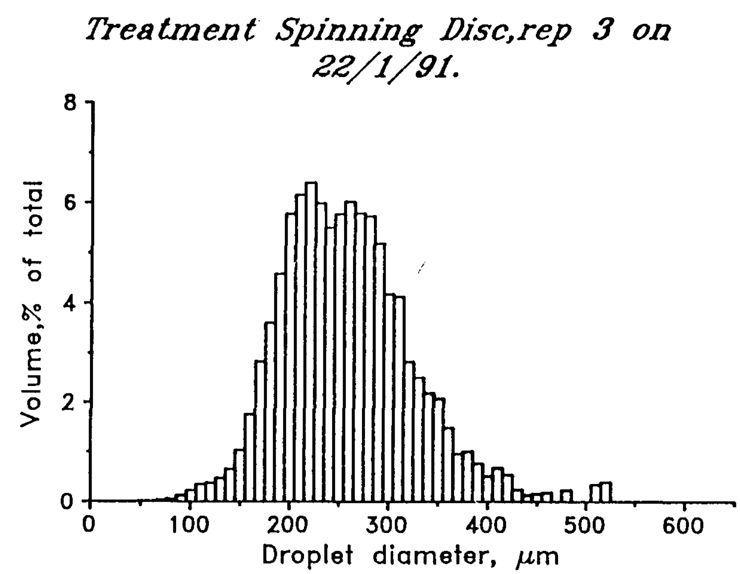


Figure 8 : Droplet size and velocity distributions measured with the Particle Measuring Systems analyser

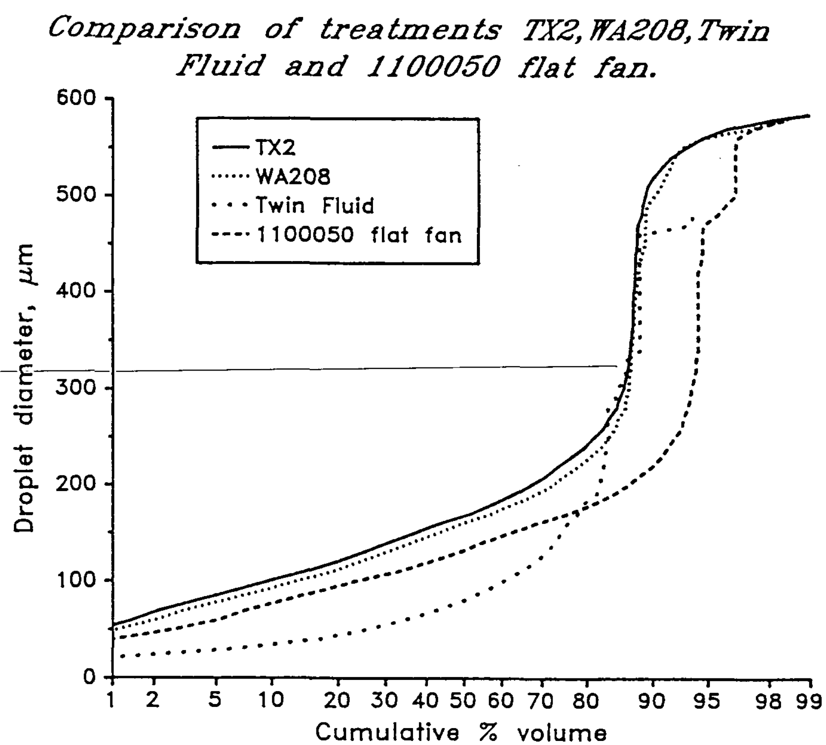
orifice size which dominates differences in droplet size distribution due to the different cone angles of the two nozzles. The form of the droplet size/cumulative volume curve for the twin-fluid nozzle in Figure 7 had a different characteristic to that of the other spray generation systems with a large proportion of the spray volume in very small droplet sizes. The form of the droplet velocity profile measured by the PMS for the twin-fluid nozzle is also unusual in that all droplets $> 100\ \mu m$ in diameter were found to be travelling at approximately 1 m/s. It is possible that the spray from the twin-fluid nozzle has droplets with "air inclusions" since this phenomenon has been observed with other twin-fluid nozzle spraying systems used in agriculture (Miller et al. 1990). Further evidence that the spray formation from the twin-fluid nozzle differs from that of the other systems is shown by results of measurements with the Phase Doppler analyser (Figures 9 and 10). The droplet size and velocity distributions measured with this instrument (Figure 9) were very variable and suggested that the spray being sampled requires further detailed study.

The three comparable droplet size/cumulative volume plots for the WA 208, TX2 and twin-fluid nozzle measured by both the Phase Doppler and PMS instruments showed reasonable relative agreement although the form of the curves differed for the two instruments. The reason for these differences can be seen from a direct comparison of the measurement with the WA 208 nozzle with both of the systems (Figure 11). The main part of the droplet size distribution measured by the Phase Doppler analyser is in droplets somewhat smaller than measured by the PMS. However, some very large droplets in the 500-600 μm categories have been detected by the Phase Doppler analyser which have not been measured by the PMS. There is reasonable agreement between the droplet velocity profiles measured with the two instruments.

The high percentage of spray volume in droplets $< 100\ \mu m$ in diameter in the spray from the twin-fluid nozzle would probably mean that much of this volume fraction would not impact a moving grain stream even though the initial droplet velocities may be higher than for a conventional cone nozzle (N.B. the two analysers give different velocity values). Because the work was mainly concerned with using coarser "sprays" as a means of increasing retention and accepting a less uniform treatment (at an individual grain scale), no detailed application experiments were conducted with the twin-fluid nozzle.

3.1.2 Spray volume distribution pattern

The spray volume distribution pattern is important because it may be necessary to apply a uniform spray volume across the width of the treatment duct and to avoid excessive contamination of the side walls which may lead to run down and loss. Typical measured distributions are shown in Figure 12. The narrowest pattern was recorded with the WA nozzle series (nominal spray angle = 80^{o}). These nozzles are useful for spraying into conveyors with minimal wetting of side walls. The distribution from the spinning disc gave a uniform pattern in the centre of the sprayed swath (Figure 12) although at a height of 150 mm the spray pattern was too wide for treating grain in a 150 mm conveyor duct. The unit was therefore operated closer than 150 mm above the grain surface and this increased the risk of grain entering and jamming the disc mechanism and necessitated the addition of a baffle in the treatment duct. Changes to the geometry of the shrouded spinning disc could also be used to change the effective spray angle.



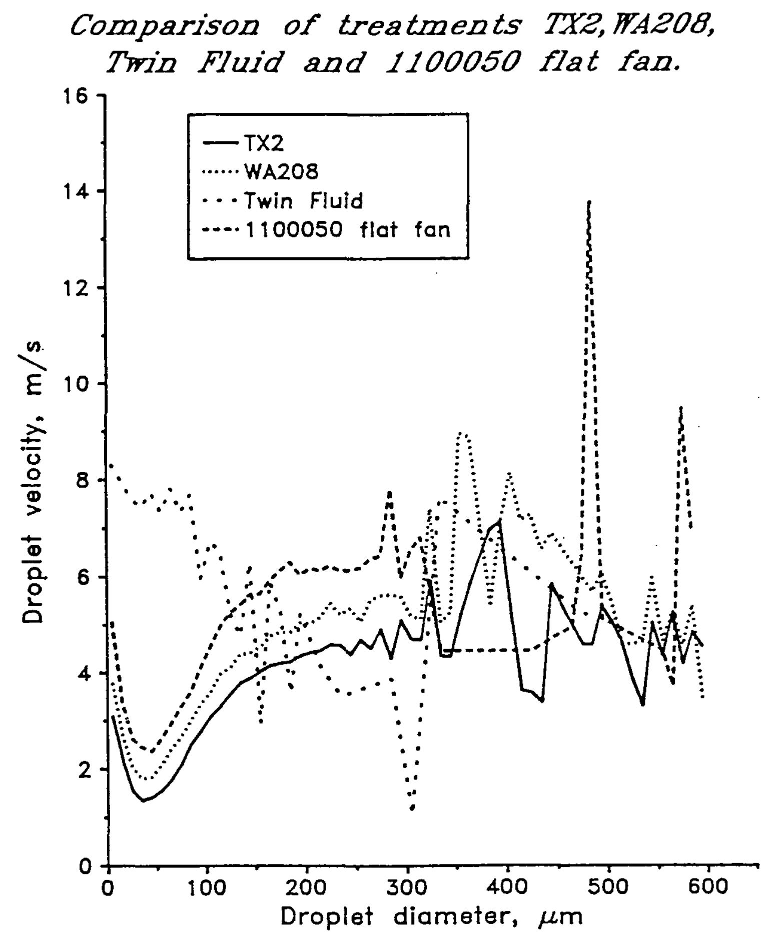


Figure 9 : Droplet size and velocity profiles measured with the Phase Doppler analyser

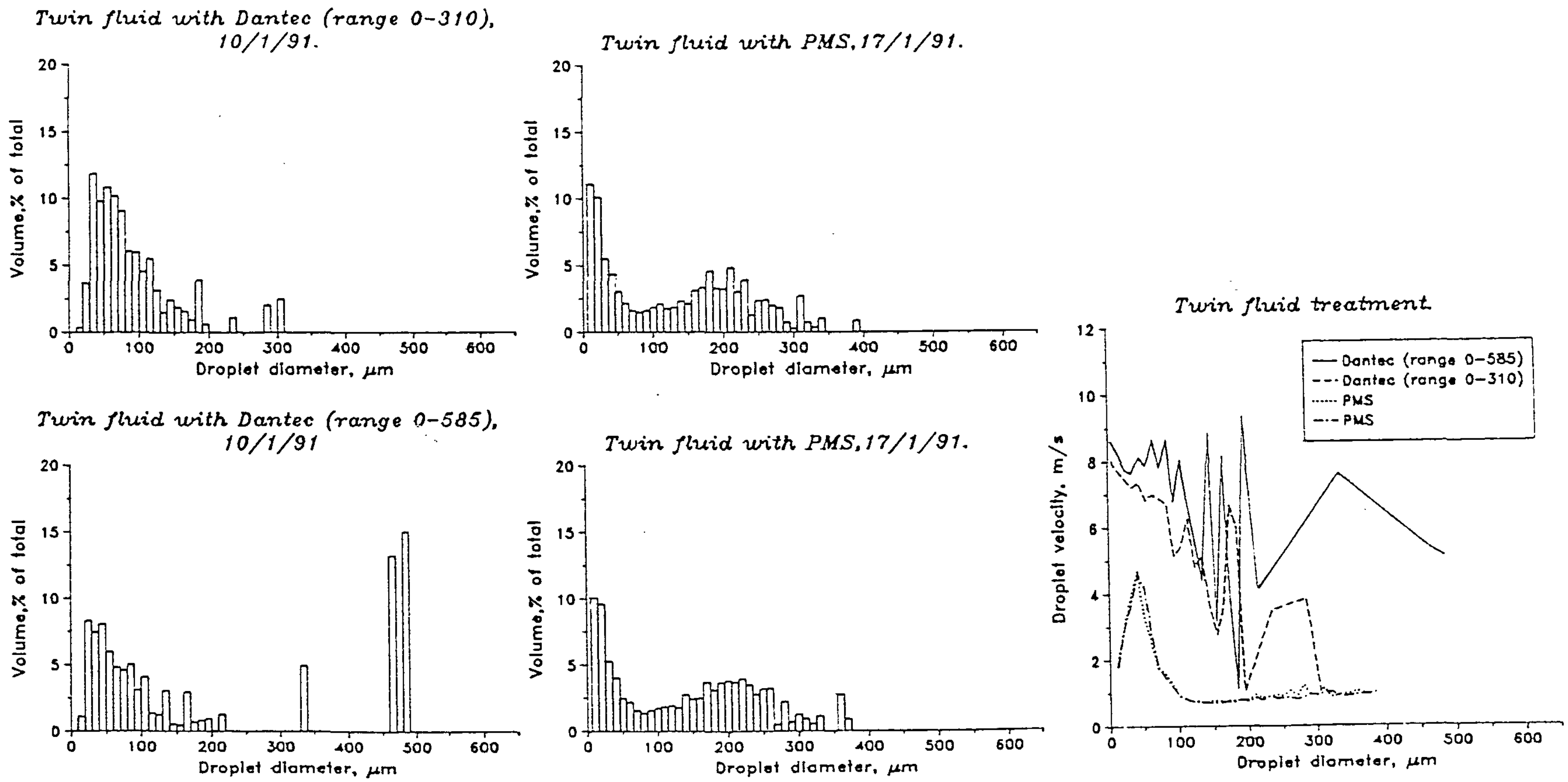


Figure 10 : Droplet size and velocity distributions for the twin-fluid nozzle measured with both the Particle Measuring Systems analyser and the Phase Doppler instrument

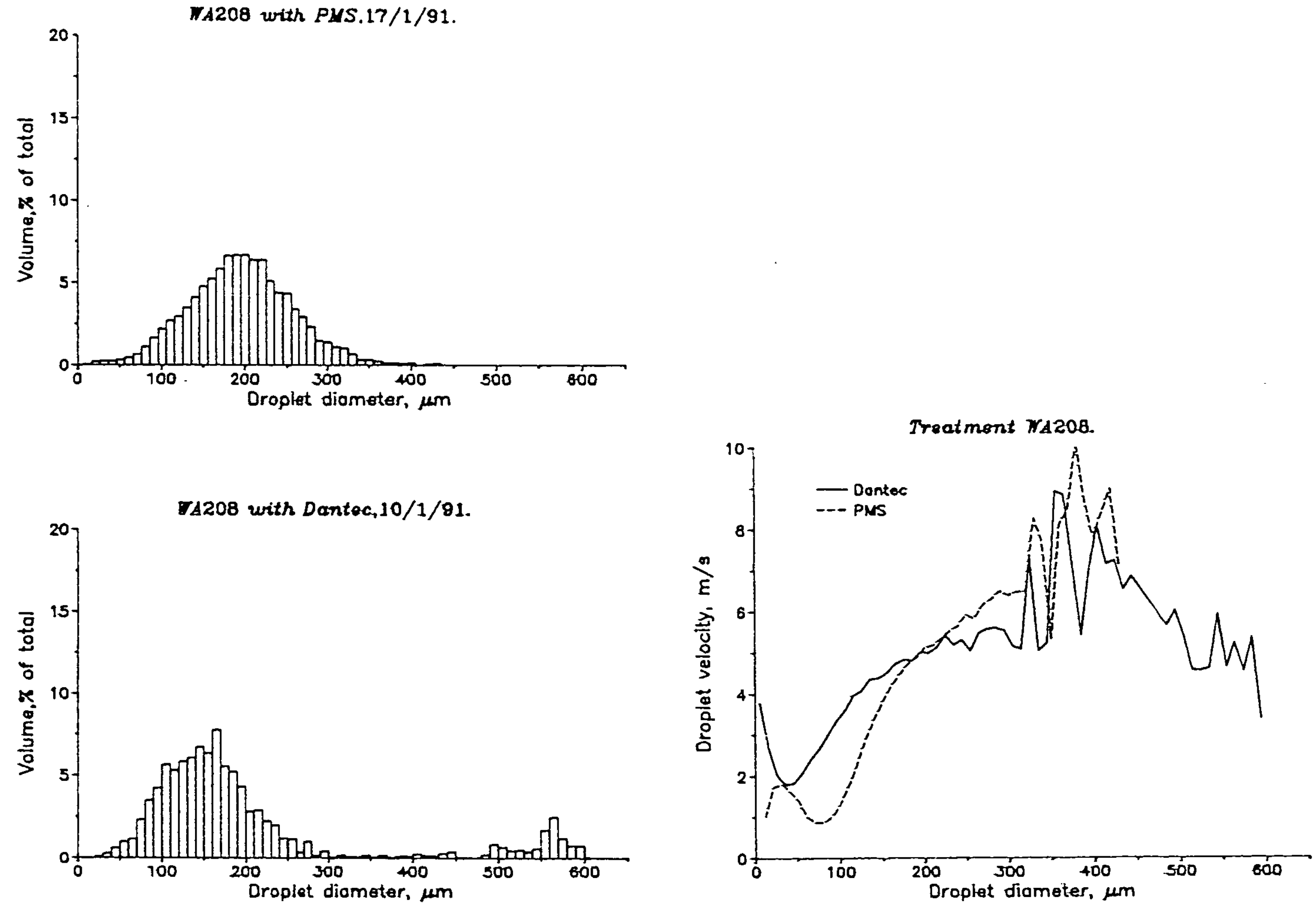


Figure 11 : Droplet size and velocity distributions for the WA 208 cone nozzle measured with both the Particle Measuring Systems analyser and the Phase Doppler instrument

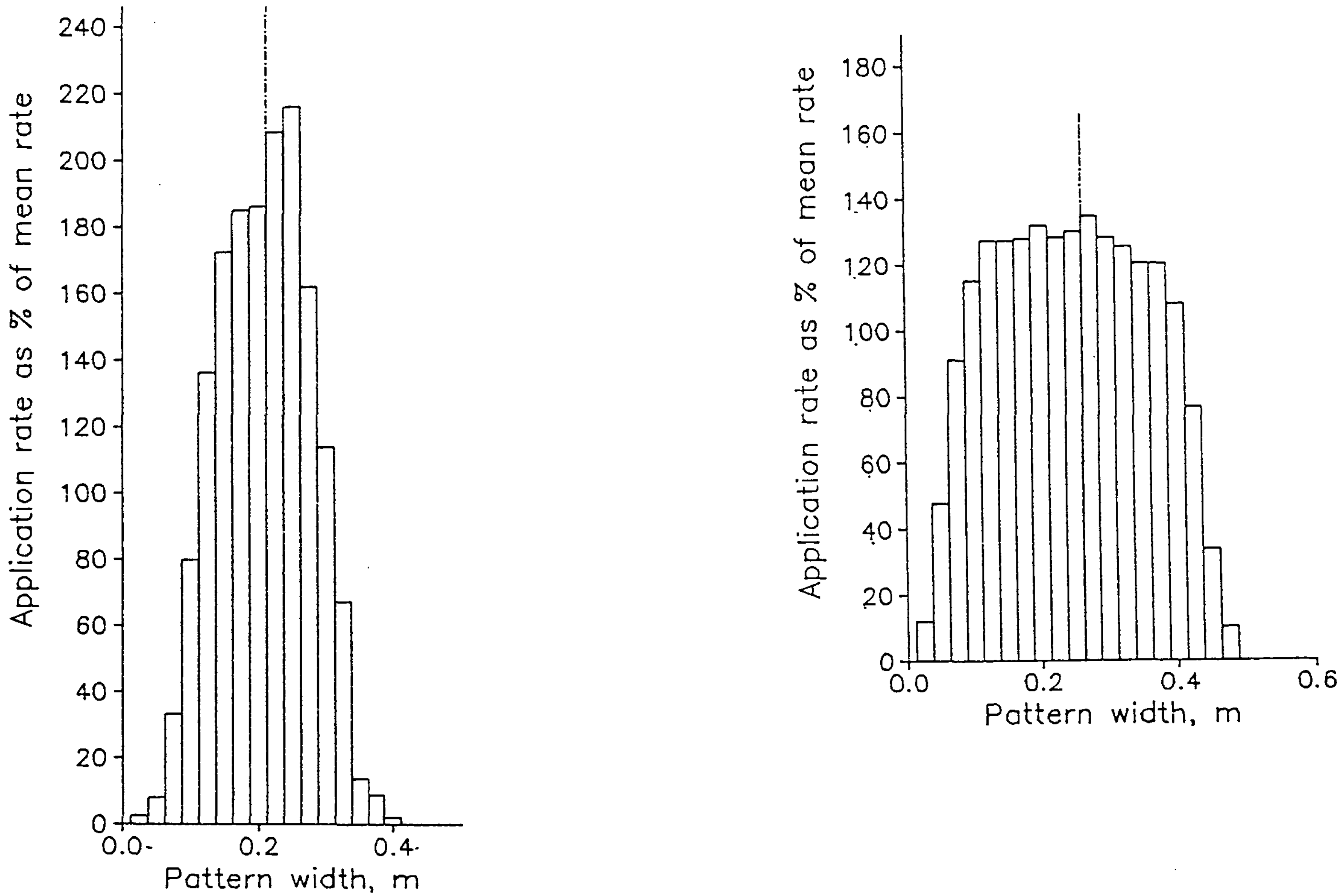


Figure 12 : Measured spray volume distributions on a standard patternator
Left: WA 208 nozzle, 150 mm from surface
Right: Spinning disc system, 150 mm from surface

3.2 Liquid retention on the grain stream

3.2.1 Tracer dye assessments

The results from four series of runs spraying grain flows in the inclined treatment duct are summarised in Table 4. The first series of runs gave analyses, particularly in terms of background levels, that were directly comparable with the validation experiment reported in Section 2.4. Total recoveries in this run were in the order of 80% and there was no significant difference between the WA 208 and TX2 cone nozzles used in the work. The results in the second and third series involved grain that gave high background readings for the dye detection and low levels of recovery. This was thought to be due to high levels of dust in the grain samples for these experiments and it was noted that dust accumulations bound together with the liquid tracer were found in the treatment duct at the end of the experiments in series III. It is likely therefore that the data in this series are unreliable.

Where reliable data were obtained, dye recoveries were in the range 75 to 90%. Results were reasonably consistent and there was some evidence that the coarser spray from the disc system gave higher recoveries although the differences were small and not statistically significant. The quantity of "free" spray liquid measured at the duct outlet was less than 3% of the applied spray liquid in all cases. This indicates that the water based spray applied to the dry grain surface is rapidly absorbed, and changes in spray distribution within the treated grain are unlikely to result from grain to grain contact in subsequent mixing and handling processes.

Results from a fifth series of runs with the dribble bar system are plotted in Figure 13. Sub-samples taken from the main sample collected at a given time gave little variation in the amount of recovered dye as shown by the small standard errors on Figure 13 and this indicates that the treatments received by each 50 g sample were relatively uniform. There was however considerable variation in mean recovery levels with time during the run, with figures in the range 61.7 to 85.3%. This is not thought to be related to the output of the dribble bar system but may have resulted from non-absorbed spray liquid collecting in parts of the grain duct. The overall levels of capture agree reasonably well with those measured from the spinning disc system during the earlier series of experiments.

3.2.2 Pesticide recoveries

The recovered pesticide doses from three separate experiments (numbered consecutively) are summarised in Figure 14 with detailed results for two of these runs shown in Tables 5 and 6. The results showed considerable variability between the three experimental runs but the following main trends were identified:

(a) There was a consistent trend to detect higher levels of pesticide in the grain in the hopper when sampled seven days after treatment compared with the results obtained from samples taken on the day of treatment. At this stage of the work, no satisfactory explanation of this apparent increase in pesticide recovery with time can be offered but some further examination of the analytical methods for determining pesticide residues is warranted. Some variations in recovered doses of pesticide applied to grain after different time periods have been found in other work (Thomas et al., 1987; Adams, 1985) but these do not help account for the observations made in the work reported here.

Table 4 : Summary of spray capture results on grain flows

Series	Application system	Flow rates		Measured retention on grain (per 25g sample)			Free spray captured in 15 s, μl	Spray captured	
		Grain t/h	Spray l/min	Recorded μl (s.d.)	Background μl	Net μl		l/tonne on grain	% of applied
I	Cone nozzle WA 208	5.7	0.085	19.5(1.8)	1.4	18.1	NR	0.72	80.9
	Cone nozzle Tx2	5.7	0.10	22.9(1.6)	1.4	21.5	NR	0.86	81.8
II	Cone nozzle WA 208	5.2	0.085	27.0(3.6)	8.5	18.5	NR	0.74	75.5
	"	5.2	0.085	26.7(6.3)	8.5	18.2	217	0.73	74.4
	Spinning disc 6 Volt	Grain	jammed	in disc	-run	abandoned	-	-	-
III	Spinning disc 6 Volt	5.4	0.075	22.7(2.3)	12.1	10.6	270	0.42	52.3
	Cone nozzle WA 208	5.4	0.09	20.2(5.6)	12.1	8.1	267	0.32	33.6
IV	Cone nozzle WA 208	5.3	0.086	20.3(14.7)	1.5	18.7	410	0.75	78.9
	Spinning disc 6 Volt	5.3	0.055	15.6(5.3)	2.2	13/4	274	0.54	88.1

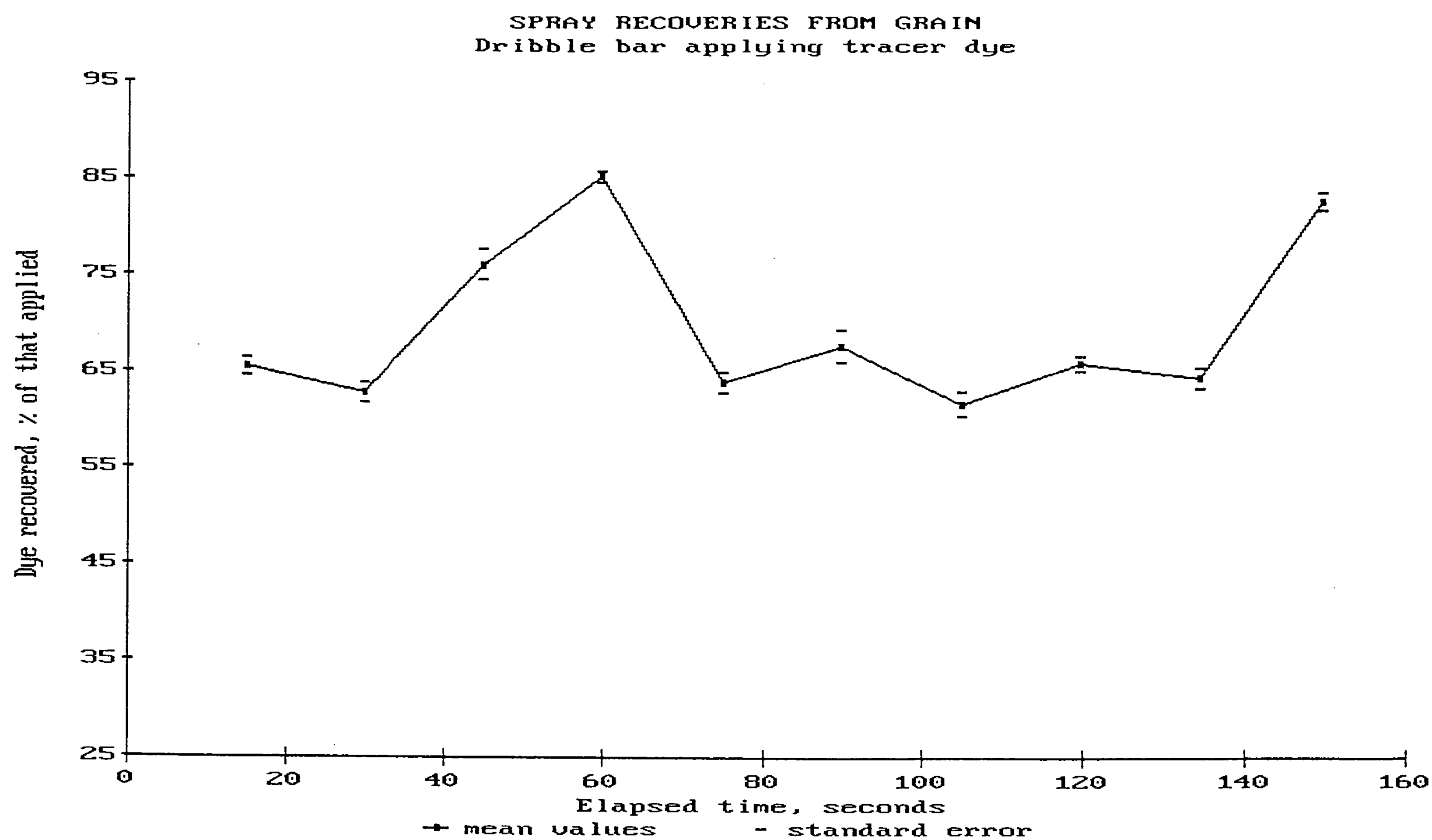


Figure 13 : Spray recoveries from grain treated with tracer dye from the dribble bar plotted against time over the experimental run A

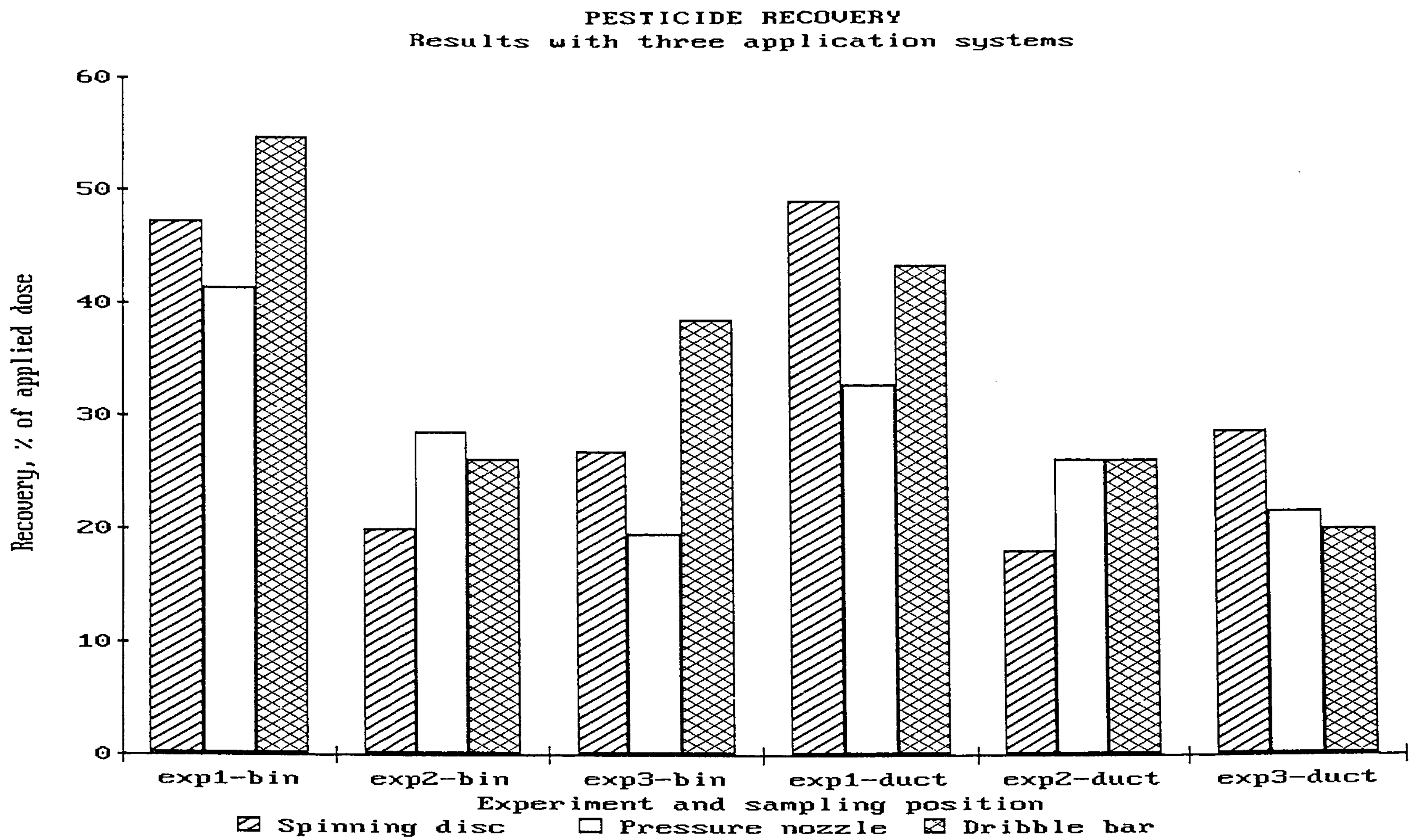


Figure 14 : Pesticide recoveries from grain taken at the outlet duct and from a storage bin for grain treated with different pesticide application systems

Table 5 : Recovered doses in Experiment 2, when applying pirimiphos-methyl to grain using 3 different methods of application

Method	Applied dose (mg kg^{-1})	Assessment period	Recovered dose (mg kg^{-1})			
			Mean	Median	Standard deviation	S.E. MEAN
			0.058	0.06	0.005	0.002
			0.072	0.07	0.013	0.006
			0.11	0.10	0.020	0.010
Nozzle	0.42	During treatment	0.11	0.11	0.013	0.006
		Day of treatment (from container)	0.12	0.12	0.019	0.009
		7 days after treatment (from container)	0.20	0.21	0.026	0.013
Dribble bar	0.42	During treatment	0.11	0.11	0.024	0.012
		Day of treatment (from container)	0.11	0.11	0.030	0.018
		7 days after treatment (from container)	0.18	0.18	0.024	0.012

Table 6 : Recovered doses in Experiment 3, when applying primiphos-methyl to grain using 3 different methods of application

Method	Applied dose (mg kg^{-1})	Assessment Period	Recovered Dose (mg kg^{-1})			
			Mean	Median	Standard deviation	S.E. MEAN
Spinning disc	1.05	During treatment	0.31	0.31	0.040	0.015
		Day of treatment (from container)	0.29	0.28	0.037	0.013
		7 days after treatment (from container)	0.33	0.33	0.031	0.011
		2 weeks after treatment	0.45	0.42	0.039	0.014
		4 weeks after treatment	0.35	0.34	0.047	0.017
Nozzle	0.51	During treatment	0.11	0.10	0.022	0.008
		Day of treatment (from container)	0.10	0.09	0.022	0.008
		7 days after treatment (from container)	0.20	0.20	0.057	0.020
		2 weeks after treatment	0.20	0.19	0.074	0.026
		4 weeks after treatment	0.21	0.20	0.065	0.030
Dribble bar	0.65	During treatment	0.13	0.13	0.019	0.0067
		Day of treatment (from container)	0.25	0.20	0.15	0.054
		7 days after treatment (from container)	0.24	0.19	0.10	0.036
		2 weeks after treatment	0.26	0.24	0.12	0.042
		4 weeks after treatment	0.21	0.21	0.068	0.024

(b) Overall recoveries from all three of the application methods were less than 60% and were noticeably lower in experiments 2 and 3. These recovery rates of primiphos-methyl from treated wheat are not unexpected as similar losses have been reported in earlier research (Patourel, 1994). The losses may also be due to the lower dose levels used in these two experiments which may then have resulted in residue levels getting sufficiently close to the limits of analytical detection to affect the accuracy of the analysis. However, it was expected that the analysis would be able to detect pesticide residues down to 0.01 mg kg^{-1} with an accuracy of $\pm$ 5%. The result may also have been related to the fact that experiments 2 and 3 were conducted with grain that had been stored for a substantial period which may have resulted in higher dust levels within the grain. Anderegg and Madisen (1983) treated samples of wheat containing different percentages of ground wheat, with malathion and showed that the amount of malathion recovered from the ground wheat and dust increased significantly both as the ratio to ground wheat and whole grains increased and as the storage time increased.

(c) The spinning disc tended to give the more uniform treatment (lower standard errors in Tables 5 and 6) of grain samples, with the dribble bar giving the largest variability in recovered quantity of pesticides between samples, as expected.

(d) There were no large or significant differences in pesticide recovery from the different methods of application. The spinning disc and dribble bar tended to give higher values of recovery in experiments 1 and 3 as expected but not so in experiment 2 (Figure 14).

(e) Apart from the results with the dribble bar in experiment 3, there was reasonable agreement between the recoveries measured from grain samples taken at the outlet duct and from the collection hopper.

Details of the recovered pesticide dose level and the associated level of biological control are given in Appendix II.

3.3 **Insect responses**

The applied dose in experiment 1 was well in excess of the target 0.25 mg/kg^{-1} for all application methods and this resulted in a complete knock-down of the *Oryzaephilus surinamensis* (484) and a 96 to 100% knock-down of the *Tribolium castaneum* (CTC 12). It should be noted however that the pesticide concentration for this experiment was slightly higher than the label recommendations for the commercial use of the formulation at high grain flow rates but much higher than recommended for grain flows of 5 tonnes h^{-1}.

Results from experiments 2 and 3 have been combined onto three dose response curves (Figures 15, 16 and 17), plotted with the same scales for the three methods of pesticide application studied. Data plotted on the dose response curves are from grain samples taken at the outlet duct and the hopper on the day of the treatment and from the hopper seven days after treatment.

The application in experiment 2 aimed at achieving 0.25 mg kg^{-1} of pesticide on the treated grain. Some allowance for loss of spray during application was made but, because spray capture during this experiment was considerably less than 50%, the actual dose rates achieved were in the range 0.05 to 0.23 mg kg^{-1} with all the application systems used. As expected this gave some response with the *Oryzaephilus surinamensis* but only very low levels of control with the *Tribolium castaneum* for all three application methods and with no discernable differences between the methods. It was therefore decided to increase the pesticide dose for experiment 3 by 60% by increasing the concentration (to 4.0 ml l^{-1}) such that the achieved dose rates would be in the order of 0.25 mg kg^{-1}. Modifications were also made to the grain supply arrangement with the objective of improving the control of flow rate throughout the period of a run. This modification however did not give good control of grain flow rate and this gave a variation in the actual dose rates achieved in experiment 3.

Results in experiments 2 and 3 with the standard hydraulic pressure nozzle shown in Figure 15 indicate that the dose rates on the grain and insect responses achieved in these two experiments were very similar. The increased pesticide concentration used in experiment 3 was off-set by the fact that the grain flow rate was higher than the expected 5 tonnes h^{-1}. The results plotted in Figure 15 also show that the insect response to the pesticide or the recovery of the pesticide residues is time dependent. All values on Figure 15 giving a dose rate below 0.15 mg kg^{-1} were from samples taken on the day of treatment either from the treatment duct or the collection hopper. All samples giving dose rates greater than 0.15 mg kg^{-1} of pesticide on the grain were obtained from those collected seven days after treatment. Although the levels of pesticide are higher there is no evidence of an increased insect knock-down with either of the species used. This may arise due to:

(i) a loss of activity of the pesticide possibly associated with the loss of volatile components over the seven day period since application. If this were so then the detected increase in pesticide dose with time could be a real effect possibly due to some re-distribution mechanism; or

(ii) the quantity and activity of the pesticide remained constant over the seven day period but some change occurred such that the chemical analysis of the pesticide residues gave higher values at the end of the seven day period.

Further research, particularly examining the characteristics of the pesticide residue analysis, is required in order to resolve which of the above situations is occurring in practice. The same trends cannot be observed on Figures 16 and 17 since different dose rates were achieved in the two experimental runs for the spinning disc and dribble bar application systems. The two experiments with the spinning disc plotted in Figure 17 gave very different dose rate levels on the grain with 0.05 to 0.15 mg kg^{-1} being achieved in experiment 2 and 0.25 to 0.40 mg kg^{-1} achieved in experiment 3.

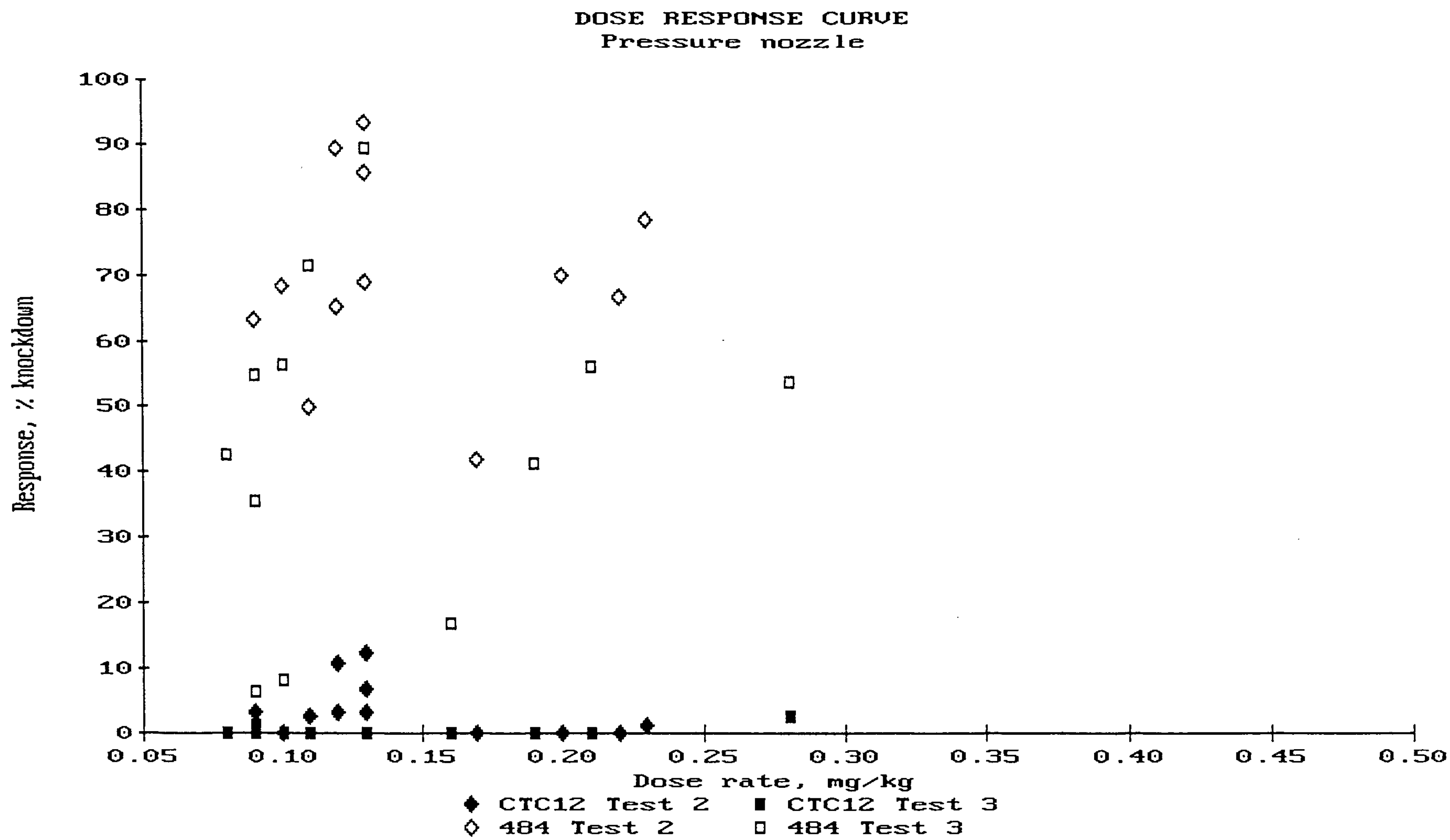


Figure 15 : Dose response curve for grain treated with pesticide from the conventional pressure nozzle in experiments 2 and 3
(Grain samples from both collection hopper and treatment duct)

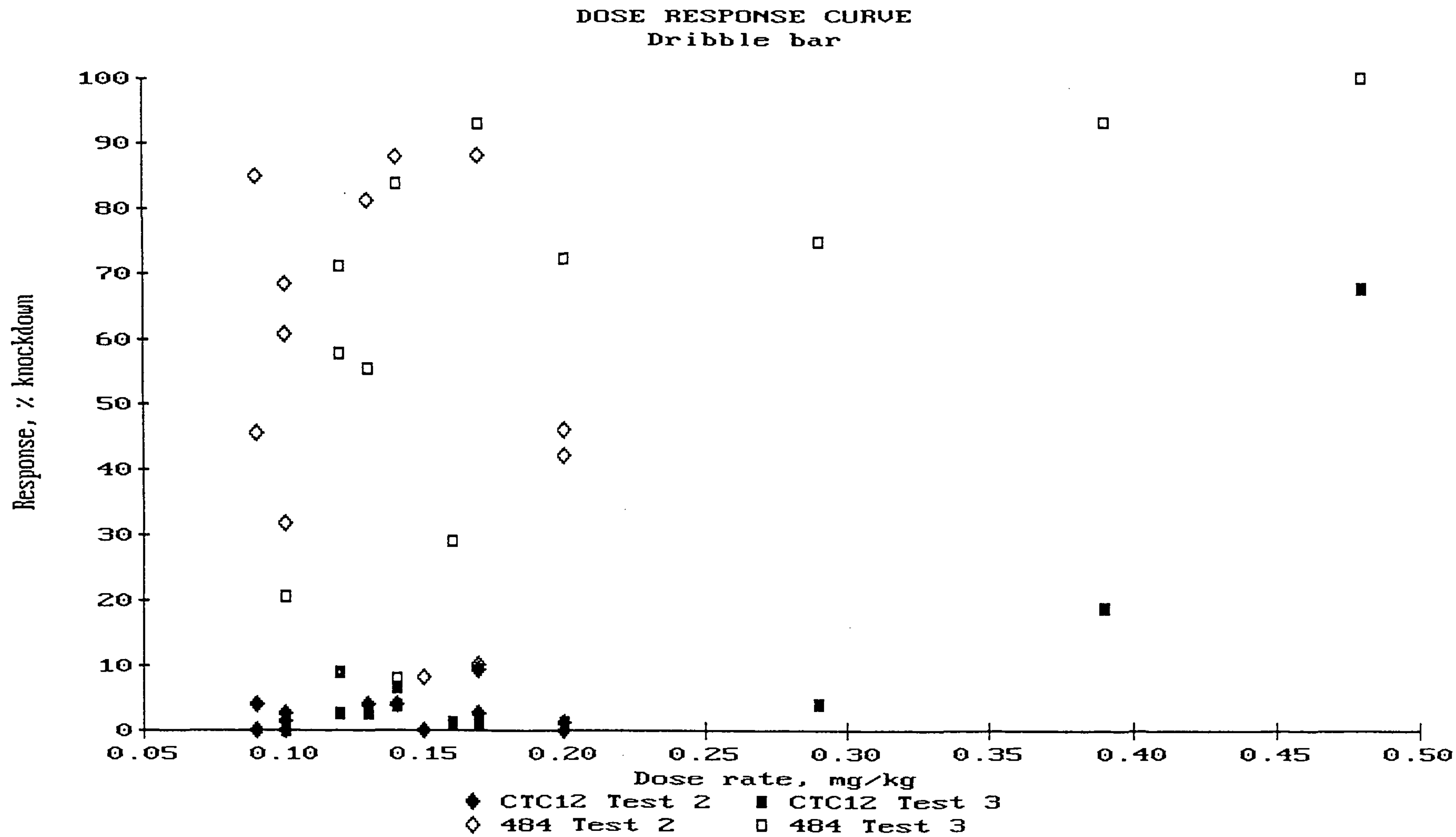


Figure 16 : Dose response for grain treated with pesticide from the dribble bar unit in experiments 2 and 3
(Grain samples from both collection hopper and treatment duct)

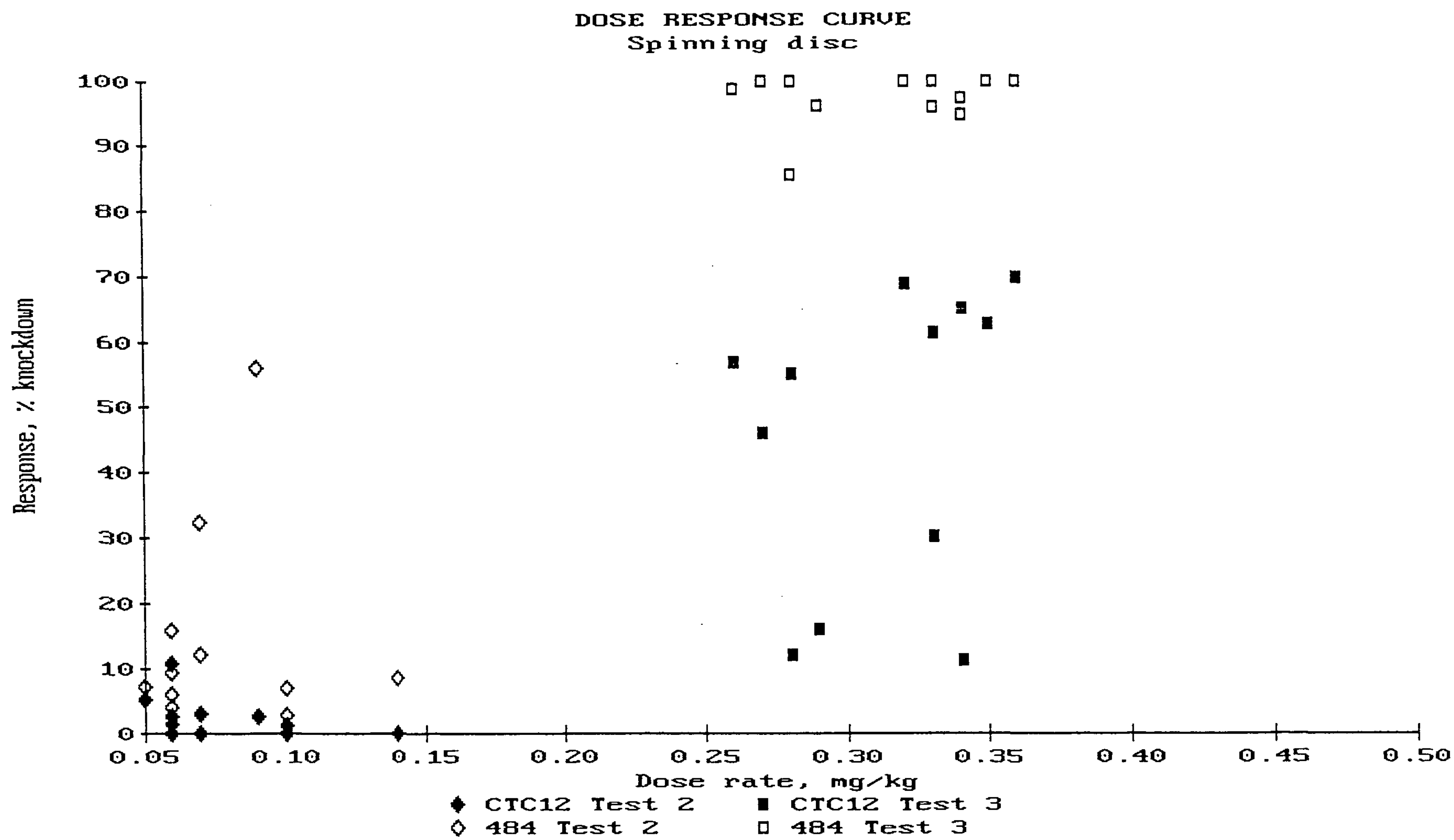


Figure 17 : Dose response curve for grain treated with pesticide from the spinning disc in experiments 2 and 3
(Grain samples from both collection hopper and treatment duct)

The higher dose rates gave an almost 100% knock-down of the *Oryzaephilus surinamensis* and levels of knock-down of between 11.3 and 68.6% for the *Tribolium castaneum*, whereas the lower dose rates gave some control of the former species and almost no effect with the latter.

The results from the dribble bar system plotted in Figure 16 show more scatter as expected with no discernable differences between the two experimental runs. Three samples gave measured pesticide recoveries above 0.25 mg kg^{-1}, two from the hopper seven days after treatment and one from the hopper on the day of treatment in experiment 3, and these tended to give lower insect responses than with the spinning disc in Figure 17. However, this sample size is too small to draw any firm statistical conclusions. Variations in the dose rate received on 50 g grain samples treated with the dribble bar would probably not be detected if there was substantial mixing between the treatment point and the grain store.

Comparing the dose responses from the three methods of application in Figures 15, 16 and 17 suggests that there are no substantial differences in the insect responses to pesticide doses applied with the different systems and that this response agrees well with that determined from laboratory scale testing at the MAFF Central Science Laboratory at Slough.

4. Discussion of results

4.1 Recovery of sprayed chemicals from the treated grain

Tracer dye recoveries from the experimental runs with clean grain were mainly in the range 70 to 90% of the applied spray and suggest that improvements in recovery of more than approximately 10% of applied spray may not be practically achieved by changes to the physical characteristics of the spray. There was some evidence from the results to show that higher recoveries had been achieved when using the coarser sprays with lower losses due to small droplets not impacting the moving grain stream. The results also showed that spray in contact with the grain is rapidly absorbed at the volume rates typically used for insecticide application. This indicates that the distribution within treated grain will be determined at the time of application and that there is little scope for redistribution by grain to grain contact after application.

The condition of the grain at the point of application appeared to substantially influence the results obtained particularly in relation to the presence or quantity of dust and damaged grain in the sample. All the grain used in the experiments was passed through a commercial grain cleaner but there was evidence of dust and liquid accumulations in the treatment duct with some of the grain used. In the experimental conditions of this study, this represented a direct loss of pesticide and would have been one of the mechanisms responsible for lower recoveries. The effect of a relatively high percentage of pesticide being carried in dust in a full-scale commercial or on-farm environment needs to be quantified.

The work demonstrated that the tracer dye technique was a robust and practical method of determining the quantity of liquid retained on treated grain particularly when comparing different application techniques. However, the results with the pesticide formulation gave relatively low recoveries when compared with results using tracer dye techniques. This was particularly the case with the lower dose rates. There was also some apparent inconsistency with pesticide recoveries over time and it is therefore recommended that some further examination of the pesticide residue analysis be undertaken.

4.2 Insect response and biological control achieved

The dose responses measured for the two insect species used in the work showed no difference between those treated with the different application systems and were in good agreement with results from laboratory tests conducted at the MAFF Central Science Laboratory at Slough. This result suggests that the efficacy of the chemical is not critically dependent upon the physical characteristics of the liquid delivery system and the degree of uniformity that is likely to be achieved with the range of practical application systems examined. If therefore improved transfer to the grain could be achieved by using coarse sprays or liquid streams from a dribble bar, as the results of this work indicate, then the overall performance of the application will be improved. There will also be improvements in respect of human safety since less of the spray in small airborne droplets ($< 100\ \mu m$ in diameter) will leave the treatment duct.

4.3 General discussion

One of the major limitations to achieving the required pesticide dose rate on the grain in this work, was the accurate control of grain flow rate in the experimental apparatus. For the first two experiments using actual pesticide, problems were experienced with grain flow in a back-fed conveyor and the modifications made prior to the third experiment aimed specifically at improving the control of grain flow rate. However, the grain flow after the modification was found to be difficult to calibrate and resulted in substantial deviations from the 5 tonne h^{-1} intended for each of the runs. It is also likely that control of grain flow rate will vary in on-farm and commercial scale grain transport operations and this emphasises the importance of designing a pesticide application system that can match pesticide flow rate to grain flow. Both the spinning disc and the dribble bar systems have the potential to operate over a relatively wide range of flow rates without changing the physical form of the spray. Grain flow rates in a conveyor system could be measured using an impact plate type of sensor (Hooper and Ambler, 1979) which, operating with an appropriate control system, could be used to adjust the liquid feed rate to the disc or dribble bar. This would be relatively expensive for on-farm scale equipment but it is likely that improvement over current practice could be obtained using simple level switches to indicate grain flow rate. Other methods of sensing grain flow in a conveyor on, for example, combine harvesters, as a means of producing yield maps (Stafford and Ambler, 1992), may mean that the cost and availability of this type of sensor improves with respect to the application being considered here. Further work is required to develop a control and application system that will directly match grain and pesticide flow rates to enable accurate control of the applied dose.

A pesticide concentration of 4.0 ml l^{-1} applied in a total volume of 0.75 l $tonne^{-1}$ of grain is only 37.5% of the recommended dose of pesticide for small scale, application systems (Anon, 1990) and higher dose rates are recommended for higher grain flow rates. Results of this work therefore suggest that improved application systems do offer some scope for pesticide dose rate reductions although a pesticide concentration rate of 4.0 m l^{-1} may be required to ensure adequate control of all insect species.

5. Conclusions and recommendations

(i) The spinning disc system produced a coarser spray than the conventional cone nozzle with volume median diameters of 252 μm and 195 μm respectively measured with a laser imaging probe. The percentage of the spray volume in droplets <100 μm was 0.3% for the disc compared with 6.1% for the cone nozzle and measured droplet velocities were also higher from the disc system.

(ii) Differences in the pesticide retention on grain treated with the different application systems were small but there was a trend towards higher recoveries from the spinning disc and dribble bar treatments. Grain treated with the disc tended to have received more uniform doses than the conventional cone nozzle whereas those from the dribble bar were less uniform as expected.

(iii) No significant differences were found in the insect responses to pesticides applied with three different systems.

(iv) Spray recoveries from treated grain using tracer dye techniques indicated that between 60 and 85% of the spray applied was absorbed by the grain when using the three application systems. Pesticide recoveries from treated grain were lower than this particularly at the lower dose rates. This may be related to the characteristics of the pesticide residue analysis for the grain. Recoveries may also be increased by minimising spray contact with dust and debris at the edge of the treatment duct.

(v) The spinning disc and the dribble bar are systems that justify further development as methods of applying pesticide to grain with the advantage of being able to match pesticide application to grain flow rates and giving higher percentages of spray retention on the grain.

It is recommended that:

(a) more data are obtained relating to pesticide application with the systems identified in this work to verify the conclusions drawn;

(b) further work examines the characteristics of the pesticide recovery techniques, particularly to examine the effects of time after application;

(c) that further development work examines the use of both the spinning disc and/or dribble bar pesticide application methods in full-scale applications and, in particular, the matching of pesticides and grain flow rates to give an improved control of the applied dose.

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APPENDIX I : POSSIBLE SPRAY GENERATION SYSTEMS FOR APPLYING PESTICIDES TO GRAIN

GENERATION SYSTEM	CHARACTERISTICS	
	ADVANTAGES	DISADVANTAGES
1. Hydraulic pressure cone nozzle		
(a) Pressure cone	Capable of operation at low flow rates. Readily available.	Produce fine spray which may not be well retained. Nozzle wear may be high.
(b) Swirl generated cone	Can produce sprays with relatively few fine droplets. Large orifice so relatively free from blockage problems	Droplets formed with low velocity and may be moved in entrained air stream.
2. Hydraulic flat fan nozzle - conventional design	Commonly available, over a wide range of sizes and spray angles. Small orifice sizes available for small flow rates.	For a given nozzle throughput likely to influence spray quality particularly at low pressure. Blockage of small nozzles would be a problem.
3. Hydraulic flat fan nozzle - "even-spray" design	Uniform distribution across the "swathe" should give improved uniformity at treated grain surface.	Existing designs would only operate in grain flows of greater than 25 tonnes/h.
4. Axial twin-fluid nozzle	Able to spray with low flow rates. Degree of spray break-up and flow rates can be readily adjusted by changing pressures.	Likely to produce a spray that is too fine for many pressure settings.
5. Twin-fluid nozzle with mixing chamber and anvil output section.	Possible to generate a relatively coarse spray with low flow rates and hence maintain retention characteristics.	Few designs available, limited choice. Flow rate characteristic steeply pressure dependent, and likely to be too high except for high grain flow rates.

APPENDIX I (Continued)

GENERATION SYSTEM	CHARACTERISTICS	
	ADVANTAGES	DISADVANTAGES
6. Anvil or deflector nozzle	Can produce a coarse spray. Widely available in agricultural applications. Produce fan shaped spray	Flow rates likely to be too large except when treating very high grain flow rates - greater than 500 tonnes/h.
7. Spinning disc systems	Good control of droplet size distribution - can be set to avoid very small droplet component.	Likely to require a large expanded duct area - eg. in seed treatment plant. Shrouded design may overcome some of those limitations.
8. Electrostatic	Improved control of droplet size.	Possible risk of dust explosions. Unlikely to improve spray distribution on conveyed grain stream unless stream very significantly disturbed. Electrodynamic needs oil based formulations.
(a) Electrodynamic	Existing designs would only operate in grain flows of greater than 25 tonnes/h.	
(b) Induction charged	Likely to produce a spray that is too fine for many pressure settings.	
(c) Corona charged		
9. Non-spray systems		
(a) Dribble bar	No fine droplets that would be carried along in air stream. Relatively simple and cheap to implement although difficult to control.	Likely to produce poor uniformity even on surface of treated grain stream, particularly at the low flow rates required.
(b) Wick or wet surface applicator	As above. May be possible to control in response to depth of grain.	As above with possible losses due to poor contact and transfer. Problems due to drag force of the grain.

APPENDIX II

INSECT RESPONSES TO PESTICIDE DOSES APPLIED WITH THREE DIFFERENT APPLICATION SYSTEMS

CONVENTIONAL NOZZLE TREATMENT

EXPERIMENT 2 APPLIED DOSE = 0.42 mg/kg

THE EFFECT OF PIRIMIPHOS-METHYL ADMIXED WITH GRAIN, USING A STANDARD NOZZLE ON RESISTANT STRAINS OF 2 STORAGE PESTS.

SAMPLE PERIOD	*RECOVERED DOSE* (mg/kg)	*RESPONSE (% knockdown)* *T.castaneum* (CTC12)	*O. surinamensis* (484)
During treatment	0.13	12.2	93.4
	0.10	0	68.4
	0.11	2.7	49.9
	0.12	3.3	65.3
After treatment (From container)	0.13	6.7	85.8
	0.09	3.3	63.2
	0.12	10.7	89.4
	0.13	3.3	69.1
7 days after treatment (From container)	0.20	0	69.9
	0.17	0	41.8
	0.22	0	66.7
	0.23	1.3	78.5

EXPERIMENT 3 APPLIED DOSE = 0.51 mg/kg

THE EFFECT OF PIRIMIPHOS-METHYL ADMIXED WITH GRAIN, USING A STANDARD NOZZLE ON RESISTANT STRAINS OF 2 STORAGE PESTS.

SAMPLE PERIOD	*RECOVERED DOSE* (mg/kg)	*RESPONSE (% knockdown)* *T.castaneum* (CTC12)	*O. surinamensis* (484)
During treatment	0.09	1.3	54.9
	0.09	0	6.4
	0.09	1.3	35.5
	0.10	0	8.2
After treatment (From container)	0.08	0	42.7
	0.11	0	71.6
	0.10	0	56.4
	0.13	0	89.5
7 days after treatment (From container)	0.19	0	41.3
	0.16	0	16.8
	0.21	0	56.0
	0.28	2.7	53.6

APPENDIX II (Cont'd)

SPINNING DISC TREATMENT

EXPERIMENT 2 APPLIED DOSE = 0.36 mg/kg

THE EFFECT OF PIRIMIPHOS-METHYL ADMIXED WITH GRAIN, USING A SPINNING DISC ON RESISTANT STRAINS OF 2 STORAGE PESTS.

SAMPLE PERIOD	*RECOVERED DOSE* (mg/kg)	*RESPONSE (% knockdown)*	
		T.castaneum (CTC12)	*O. surinamensis* (484)
During treatment	0.06	2.7	9.3
	0.05	5.3	7.2
	0.06	1.4	4.1
	0.06	10.7	15.9
After treatment (From container)	0.07	3.0	12.1
	0.06	0	5.9
	0.09	2.7	56.0
	0.07	0	32.3
7 days after treatment (From container)	0.10	1.3	2.9
	0.10	0	6.9
	0.14	0	8.6
	0.10	0	0

EXPERIMENT 3 APPLIED DOSE = 1.08 mg/kg

THE EFFECT OF PIRIMIPHOS-METHYL ADMIXED WITH GRAIN, USING A SPINNING DISC ON RESISTANT STRAINS OF 2 STORAGE PESTS.

SAMPLE PERIOD	*RECOVERED DOSE* (mg/kg)	*RESPONSE (% knockdown)*	
		T.castaneum (CTC12)	*O. surinamensis* (484)
During treatment	0.26	56.8	98.7
	0.34	65.0	97.3
	0.36	69.7	100
	0.35	62.7	100
After treatment (From container)	0.28	55.1	100
	0.27	46.0	100
	0.32	68.8	100
	0.33	61.3	100
7 days after treatment (From container)	0.29	16.0	96.1
	0.28	12.0	85.6
	0.34	11.3	94.7
	0.33	30.3	96.0

APPENDIX II (Cont'd)

DRIBBLE BAR TREATMENT

EXPERIMENT 2 APPLIED DOSE = 0.42 mg/kg

THE EFFECT OF PIRIMIPHOS-METHYL ADMIXED WITH GRAIN, USING A DRIBBLE BAR ON RESISTANT STRAINS OF 2 STORAGE PESTS.

SAMPLE PERIOD	*RECOVERED DOSE* (mg/kg)	*RESPONSE (% knockdown)* *T.castaneum* (CTC12)	*O. surinamensis* (484)
During treatment	0.10	2.7	60.8
	0.13	4.0	81.3
	0.09	4.0	85.0
	0.14	4.0	87.9
After treatment (From container)	0.10	1.4	68.5
	0.09	0	45.6
	0.17	9.3	88.2
	0.10	0	31.7
7 days after treatment (From container)	0.20	1.3	46.0
	0.15	0	8.1
	0.20	0	42.0
	0.17	2.7	10.2

EXPERIMENT 3 APPLIED DOSE = 0.65 mg/kg

THE EFFECT OF PIRIMIPHOS-METHYL ADMIXED WITH GRAIN, USING A DRIBBLE BAR ON RESISTANT STRAINS OF 2 STORAGE PESTS.

SAMPLE PERIOD	*RECOVERED DOSE* (mg/kg)	*RESPONSE (% knockdown)* *T.castaneum* (CTC12)	*O. surinamensis* (484)
During treatment	0.13	2.7	55.4
	0.12	8.9	57.8
	0.12	2.7	71.2
	0.14	6.6	83.7
After treatment (From container)	0.10	0	20.5
	0.17	1.3	93.0
	0.48	67.6	100
	0.20	1.3	72.1
7 days after treatment (From container)	0.16	1.3	29.0
	0.29	4.0	74.7
	0.39	18.7	93.2
	0.14	3.9	7.9