1.
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Pesticide Application Systems

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CHARACTERISTICS OF BOOM AND NOZZLE SPRAYING - A ROBUST, SAFE AND EFFICIENT SYSTEM FOR THE FUTURE?

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ABSTRACT

The advantages of the conventional boom and nozzle system are outlined. The vulnerability of the system to poor operation is discussed and the need for training stressed. Suggestions for improving the rate of work of the system are made together with comments on operator safety and spray drift. Proposals are made that due recognition should be given to the skilled operator and that a code of practice including more precise description of the operating system should be published.

INTRODUCTION

The conventional boom and nozzle sprayer is the result of over 50 years of development. It has not changed in basic layout, and improvements have been as a result of evolution rather than revolution. This paper examines the reasons for the present day supremacy of the boom and hydraulic nozzle system, points to some shortcomings and discusses whether these are likely to be overcome in the foreseeable future.

With increasing antagonism from the environmental lobby and the general public, are we in a position to specify a safe and efficient application system? How can the operator who is trained to adopt a professional and caring attitude be rewarded? Should the "cowboy" be prosecuted?

THE ADVANTAGES OF THE BOOM AND HYDRAULIC NOZZLE SYSTEM

Effective

The vast majority of farmers are content with the performance of their sprayer. A very small percentage of claims arise as a result of contested efficacy. When studied in detail, most of these cases relate to problems of timing or meteorological conditions affecting soil and/or growth habit. It is very rare for a farmer to claim crop loss due to the failure of the machine to function correctly.

Versatile

A typical arable farm grows at least six crops, and each will have different weed, pest and disease problems. It is possible to specify an application system ideally suited for one particular pest, but in real life the farmer must have a machine to deal with all eventualities. Only very large businesses can afford separate machines for particular crop and pest problems, and the versatility of the boom and nozzle system makes the sprayer one of the most important tools on the farm.

Efficient

How do we measure efficiency? When considering the amount of active ingredients necessary to achieve satisfactory control of the target organism, pesticide application has been described as "the least efficient industrial process on earth". But few industrial entrepreneurs would invest money to produce goods when their raw materials may arrive early or late and in unspecified quantities (rain, sunshine), when the part finished product may be damaged or destroyed by vandals (pests and diseases).

Efficiency is thus a term which must be placed in context. We need to apply a certain quantity to produce a satisfactory result. This application must be reliable and repeatable, and it has been shown (Cooke et al 1985) that the hydraulic nozzle produces consistently reliable results on which the farmer can depend.

Fast

Although pest forecasting techniques are improving, some crop problems appear with little warning. Speed of application is thus an important factor in deciding success or failure of the treatment. It has been suggested (Rymer 1978) that a farmer should be able to treat his entire acreage in three working days. At present volumes of 200 litres per hectare, not many farmers are able to achieve this target, but good organisation and work planning is vital and this is an area where there is scope for improvement.

Safe

The safety record (H & SE 1983) of the agro-chemical industry, their farmer customers and the tractor operators is a success story of which we should all be proud. The facts speak for themselves and despite warnings of impending doom from certain pressure groups, the hydraulic boom and nozzle sprayer will continue to apply most of the pesticides used on farms for the foreseeable future. It has been shown (Lloyd & Bell 1982) that this can be achieved with minimal risk to the operator, bystanders and the environment. We must not, however, be content with a good past record. Let us strive to improve the situation further if at all possible.

THE SCOPE FOR IMPROVEMENT

Training

There is no doubt that the weakest link in the pesticide application system on the farm is the operator. A survey (MAFF 1977) has shown that there is great scope for training to improve operator awareness and understanding of his machine, the target organism and their inter-relationship with the environment. There is scope to raise the prestige of the spray operator among his peers. A premium wage or craftsman status to holders of a recognised training certificate would be a move in the right direction. Should contract spray operators be licensed to guarantee their competence for this particularly responsible duty? Is the industry able to control the "cowboy" operator? Perhaps NAAC/ATB could take the initiative here before the environmentalists impose restrictions by legislation.

Machine maintenance

No matter how well designed and equipped when new, all machines wear and deteriorate. The humble nozzle is perhaps the most abused and neglected precision component on the farm. Many nozzle tips made of the modern composite materials now cost less than £1 each. This nozzle dispenses pesticide of equivalent value in only 500 metres of travel every 4-5 minutes. If the nozzle is worn and delivers a 10% overdose, the chemical wasted in less than one hour would buy a new one.

And still we see nozzle tips made to "last" 2 or 3 years. Awareness of these facts and training must be stressed again and again, however basic the message may seem.

Rate of work

The swing to autumn cereals has increased the need for fast efficient operation of all machines. Work schedules are shortened and farmers are looking for faster rates of work. What scope is there to improve the hydraulic boom sprayer in this respect? There are four possibilities:-

1. Faster ground speed

Recent progress in boom suspension systems (Nation 1980) means that tractors can now travel faster without imparting the violent shock loads to the boom. Increases in the order of 20% have been reported.

2. Wider boom

The advent of tramlines has tended to inhibit this option. 12 metres is now in general use but some larger holdings are looking for the ideal match of drill, fertilizer spreader and sprayer in a larger module. The debate hinges around the drill. 6 metres x 3 or 4 metres x 5? Either solution will make a significant contribution to the rate of spraying.

3. Reduced volume of diluent

The early hormone weedkillers were generally applied at about 50 litres per hectare with satisfactory results. Reasons for increasing the amount of diluent included filtration and blockage problems and the risk of drift. The advent of suspensions and other newer formulations in the 1950's also led to higher recommended volumes until 200 litres per hectare became the "standard". But now, 20 years later, formulation technology has improved and excellent self-cleaning filters are available. There is much scope to reduce the volume down to 100 litres per hectare and even below in certain circumstances. ADAS experiments and manufacturers' trials (Bryant 1984) are all pointing in this direction which will not only improve rate of work but also enable reduced loads to be carried when soil conditions are unfavourable.

4. The use of a nurse tank

On larger or scattered holdings, the use of a nurse tank has been shown (Nation 1978) to achieve significant improvement in rate of work compared with returning to the farmstead from distant fields.

Operator safety

The operator is at the greatest risk when handling the concentrate pesticide. A recent trend in USA to introduce self-filling and concentrate metering must be one to follow. Another feature on some machines which is not costly but most welcome is a small tank to hold clean water to flush the sprayer and for operator hygiene.

Spray drift

The trend towards lower volumes will in some cases be achieved by smaller nozzles. This will produce a finer spray. Recent developments with electrostatics now offer the promise of reduced drift of the very smallest drops below 50 µm. If these experimental results (Johnstone et al 1982) are borne out in the field, one of the major drawbacks of the hydraulic nozzle will have been removed.

THE WAY FORWARD

We have seen that the hydraulic sprayer reigns supreme for UK pesticide application in 1985. New technology in formulation and electrostatics are likely to strengthen the case for retaining boom and nozzles in the future.

But let us beware of the environmental pressures on our industry and take a positive step to ensure that future.

Physicists and engineers are aware of certain circumstances where the hydraulic boom and nozzle sprayer may be misused or abused in the hands of an inexperienced operator. Let us be specific about how the machine should be selected, prepared and used for maximum efficiency and minimum risk. Some sort of code of practice or guidelines may be required by future legislation to allay fears and suspicions by the general public. General guidance on machine maintenance and operation exists (MAFF 1983) but we need to be more specific on the type of spray used - the "quality" of spray in terms of drop spectrum. No spray operator needs to be bothered with drop sizes - even if we could agree how to measure them. Let the operator be encouraged to use familiar words and to select a "coarse", "medium" or "fine" spray. British Agrochemical Association and Agricultural Engineers Association members have now agreed that these should be specified as part of the label recommendation and mentioned in machine instruction manuals. The characteristics of the "quality" of these sprays are given in Table 1 (ADAS 1982).

TABLE 1

Type of nozzle	Coarse	Medium	Fine
Characteristics of spray	Mostly coarse Few fine drops	Wide range of all drop sizes	Mostly fine Few large drops
Retention on leaf surface	Poor	Moderate	Good
Potential drift hazard	Negligible	Low	High
Typical target/ pesticide	Soil-acting herbicides	Broad-leaf weeds, mixed species	Fungicides Insecticides Grass weeds

ADAS now provides nozzle recommendations in this format for all the major nozzle manufacturers, both in written form and on Prestel.

This concept will not be accepted or adopted overnight but the operator is the man who needs most help and we must consider his viewpoint. He need not know about drop spectra - does he know the compression ratio of his car?

He need not delve into the VMD and NMD - does he know the octane rating of the petrol he buys?

No, all he needs to know is the quality of the spray - coarse, medium or fine - just as he understands the quality of the petrol he buys - 2 star, 3 star, 4 star.

CONCLUSION

The hydraulic sprayer is a robust, versatile and safe machine to apply pesticides. Improvements are being developed which will further strengthen its position.

In order to demonstrate our faith in the system, the industry should publish a code of practice for pesticide application on UK farms. In this way we can show that the agricultural industry and its suppliers are taking a positive step to preserve our unequalled past safety record and our environment for future generations.

REFERENCES

ADAS (1982) Safe and effective spraying. MAFF

Bryant, J. E. et al (1984) Partitioning of pesticide spray on and under a cereal canopy. Proceedings 1984 British Crop Protection Conference - Pests and Diseases

Cooke, B. K. et al (1985) A comparison of alternative spray techniques. British Crop Protection Council Monograph No. 28

Health & Safety Executive (1983) Agricultural Inspectorate, statistics of poisoning incidents.

Johnstone, D. A. et al (1982) Preliminary trials to examine the drift of charged spray droplets. Proceedings 1982 British Crop Protection Conference - Weeds 3, 1025-1032

Lloyd, G. A.; Bell, G. J. (1982) Relative contamination of humans and the environment by spray drift. Proceedings 1982 British Crop Protection Conference - Weeds 3, 1045-1053

MAFF (1977) The utilisation and performance of field crop sprayers. Farm Mechanization Study No. 26.

MAFF (1983) Guidelines for applying crop protection chemicals. Booklet 2272

Nation, H. J. (1978) Logistics of spraying with reduced volumes of spray and higher forward speeds. Proceedings 1978 British Crop Protection Conference - Weeds 2, 641-648

Nation, H. J. (1980) The performance and stability of booms. British Crop Protection Council Monograph No. 24, 145-157

Rymer, J. S. (1978) The farmer's viewpoint. British Crop Protection Council Monograph No. 22, 271-275

THE ULVA SYSTEM - CAN WE GAUGE ITS SUCCESS?

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ABSTRACT

An attempt has been made to evaluate the ULVA system and its impact on pest control, primarily in the overseas context, over the past twenty years. The features which the system introduced and which led to its successful extension are reviewed. At the same time those aspects which have proved restrictive to its more widespread adoption are identified.

INTRODUCTION

What is the so-called ULVA system? Has it really been proved a success, and if so, by what criteria, and for whom? To what extent has the system been rewarding for the pioneer sprayer manufacturers, Micron and Turbair? How far has it proved a successful venture for those chemical companies which have chosen to become involved and has it been rewarding for the farmers who have adopted the methodology in preference to other alternatives? These are just a few of the questions the title of the paper poses.

With regard to the system, the guiding principles on which the use of the portable, battery-powered, ultra-low volume applicator (ULVA) has been based have been expounded at previous BCPC symposia and conferences by that persevering originator, Mr Edward Bals, in his capacity as proprietor of Micron Sprayers and former Director of Turbair Ltd (Bals 1969, 1970, 1971, 1973, 1974, 1978, 1982). There has also been sustained coverage of specific applications, - for the "system" is not without variations. The author has been professionally associated for a number of years with some of the proving trials and extension work carried out with these sprayers in developing countries overseas and would welcome some regular, widespread feedback on the overall impact which such work has been achieving to date.

How then can we set about quantifying success? Both Micron and Turbair have built up a steady market for their machines, and in 1975 Micron Sprayers were in receipt of the Queen's Award for Industry. Both firms can be considered commercially successful at their respective levels of turnover. Their battery-powered, rotary atomisers have been closely copied by rival manufacturers in other countries (e.g. by Technoma and Berthoud in France, Thomson Motoronics and ASPEE in Idea, Taurus in Zimbabwe, and so on, to name but a few). On the other hand, it is now nearing 20 years since the original Turbair prototype appeared and yet sprayers of the ULVA type are still greatly outnumbered by the lever-operated knapsack and pneumatic hand sprayers employed in many overseas situations. Why then, despite a great deal of R and D effort devoted to a system which appears to have certain obvious advantages, has not the take-up been greater? What factors have limited its more widespread adoption?

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BACKGROUND

Before attempting to answer some of these economic questions it is worth recalling the scientific principles on which the early ULVA developments were based and the sequence of advance.

In crop protection the familiar requirement is for the correct dose to reach the appropriate place, at the right time for maximum effect.

To achieve this, spray coverage can be critical, since the probability of hitting the target is determined to a great extent by the number of droplets dispersed into the target area (Graham-Bryce 1977). Logistic considerations indicate that the volume of spray liquid applied should be minimised (Johnstone 1974). When taken together, these requirements can be met in increasing degree by using smaller droplets; that is until such considerations as more rapid evaporation and reduced aerodynamic collection efficiency indicate that a limit has been reached (Johnstone 1978). Of course the concentration of active ingredient may have to be adjusted as the volume rate is reduced in order that sufficient toxicant is available for lethal effect (Johnstone 1973). It does not necessarily follow that reduced volume application is synonymous with reduced rates of application of toxicant (Bals 1970), although there have been instances when such savings have been achieved (Rendell and Thongsakul 1976).

Early problems

With regard to the rotary atomisers, plastic construction led to some early mechanical problems in very hot climates and the maintenance of small electric motors necessitated the acquisition of new skills. Motors were prone to seize with ingress of spray liquid, but these and other faults were overcome with design improvements.

It was originally apparent that water alone was not the ideal carrier liquid, and that formulations available for traditional medium/high volume application were not entirely suitable for what became known as ultra-low volume application. Here perhaps we meet one of the systems principal early snags. Initially, the large chemical suppliers, already possessing capacity for formulating products for traditional high/medium volume aqueous application, could see no justification for providing alternative formulation for an unproven and 'unapproved' application system, which was claimed to operate successfully with lower rates of active ingredient (Bals 1970, 1971). At the same time, conservative approval authorities nursed some concern regarding the possible harmful affects of drift of smaller than usual spray droplets The subject of spray drift is indeed a thorny one and can only be touched on lightly here. The use of the wind as an agent for spray dispersal has natural advantages, for deposition by inertial impaction is effected by the wind (and the power of the wind comes free!). It has been a matter for experiment to determine how far the force of the wind can be utilised to assist dispersion and deposition (e.g. Johnstone et al, 1974), but certainly its optimum use has been an important factor in the development of ULVA technique.

MAJOR FIELDS OF USE

Because of their pronounced upright growth habit, Bals considered that the tropical cereal crops, rice, maize, sorghum, etc., would collect drifting sprays of small droplets particularly well, so that insect and disease control in rice served as a predominant motive for the development of the Turbair X. However, it has been the major chemical market for the protection of cotton against insect attack which has provided the principal outlet for sprayers of the ULVA type (Bals 1974, Matthews 1973, Morton 1973). In controlling the key cotton bollworms, the traditional philosophy has been to provide a residually-active insecticide deposit with a sufficient coverage at those strategic points on the plant which will enable the interception of 1st instar larvae on their march from the sites of oviposition to the fruiting bodies (at which points they become more or less inaccessible to superficial spray deposits, or the drifting spray).

The early Turbair X and Micron ULVA machines provided a droplet spectrum with vmd in the range 70-90 µm - a size well suited to production of a spray coverage of 20-50 droplets/cm^2 on the key points of the cotton plants at the early flowering stage, at a volume application rate of about 3 l/ha using a bandwidth of 2-5 rows, so the fundamental ingredient for success was there.

Several major chemical companies, notably CIBA/Geigy, Hoechst and the Shell Chemical Co., developed waterless ULV insecticide formulations retailing in 1 litre plastic bottles designed to screw directly into the sprayers, while in Mozambique the use of co-ordinated teams of spraymen was tried to accelerate the treatment of large areas of cotton.

SOME PROS AND CONS

The lightness and convenience of the ULVA machine has invariably had instant appeal to tropical smallholder farmers, but the advantage of electrical power has been offset to some extent by erratic variations in the supply and quality of the dry cells (torch and lantern batteries) required to power the machines. The original ULVA sprayer had a power consumption of ~8 watts and battery life was an important economic consideration (Johnstone et al, 1973, Beedon 1975). The very low current consumption of the recently-introduced MICROULVA represents a big improvement in this respect. (Where mains power, or generators are available, rechargeable motor-cycle batteries can show economic advantage in larger scale use and these are being marketed now along with the sprayers in the Indian cotton areas of Gujarat, Maharashtra and Andra Pradesh).

The use of reduced volume application has normally required a higher concentration of active ingredient in the spray mix which, coupled with waterless formulation, has increased the toxicity hazard resulting from accidental dermal contamination. Some cases of poisoning resulting from this cause have been reported (Smith 1977) and in the interest of safety it is desirable that the choice of chemicals should be restricted to those which pose an acceptable risk in the event of such contamination.

SYSTEM MODIFICATIONS

The availability of suitable waterless formulation for ULV application at costs which could compete realistically with alternative application methods has been an on-going problem. The big increase in the price of oil and oil products in the early 1970's caused the price of waterless ULV application to rise relative to aqueous application. An analysis of data from Malawi showed that a modified technique, which became known as very-low volume, or water-based ULV (WULV) spraying, could provide a practical and economic alternative (Huntington and Johnstone 1973). The use of standard e.c. or wdp formulation, at slightly higher flow and application rates of ca. 10-15 l/ha, results in slightly higher droplet size (100-120 µm vmd), but ensures that a good residual spray coverage is maintained. Complementary work in Rhodesia in the early 1970's led to the development of aquamol formulations (in which the standard, commercially-available, water-dispersible formulations were mixed with 20% aqueous solution of molasses), for application at 5-10 l/ha (Gledhill 1970, 1971). The action of the molasses has been twofold. It provides a liquid residue, maintaining an effective droplet size in those small droplets from which the water evaporates. It may also have a residual attractant (or bait) effect for adult moths.

The big expansion of cotton production taking place in Zimbabwe over the past ten years has seen a growing use of the aquamol technique using the Taurus Hi-spin battery-operated atomiser and it would appear that the bulk of the smallholder production of ca.150000 bales in 1983/4 received some protection in this way.

The system has also proved attractive to the larger commercial growers in Zimbabwe, who find it economic to apply the early season sprays by teams of ULVA spraymen, before switching to application by aircraft as the cotton matures beyond 1.5m tall.

Mineral oils have been proposed as carriers (Wrigley 1973), or additives to be used in a similar way to molasses, but the additional material and distribution costs have rather restricted their use in this way.

The rapidity with which small areas of cotton can be treated using an extended swath width of several metres led to trials with daily applications of insecticide at low dosages to control cotton insect pests (Matthews 1971, Nyirenda 1982), but no advantages over the more usual weekly spray interval were demonstrated.

OTHER OUTLETS AND SUPPORTING REQUIREMENTS

The use of the ULVA-system for cotton insect control has been emphasised, with insect control in tropical cereal, pulse and vegetable crops as a less frequent outlet, or role (Raheja 1976). Disease control in such field crops as groundnuts, market garden crops such as tomatoes (Quinn et al 1975), and certain vegetables, has been well researched, but here the system has been less widely taken up.

It does appear that adoption of the ULVA system has been, and will continue to be, dependent on adequate technical support, either from local extension services, or from the marketing departments of those chemical companies which choose to become involved.

CONCLUSIONS

The overall success of the ULVA system on a worldwide basis is not readily quantifiable, but the worldwide demand for portable machines of the ULVA type appears to be increasing and on this basis alone it may be fair to claim that the full potential of the system, including its various modifications, has yet to be realised.

REFERENCES

Bals, E.J. (1969) The principles of and new developments in ultra-low volume spraying. Proceedings 5th British Insecticide and Fungicide Conference, Brighton 1, 189.

Bals, E.J. (1970) ULV and ULD spraying. Cotton Growing Review 47, 217-221.

Bals, E.J. (1971) So e thoughts on the concept of ULD (ultra-low dosage) spraying. OEPP/EPPO Bulletin No.2 27 -35.

Bals, E.J. (1973) Some observations on the basic principles involved in ultra-low volume spraying. Pesticides Abstracts New Summaries 19, 193-200.

Bals, E.J. (1974) The operation of portable ULV atomisers. BCPC Monograph No.11, 138-142.

Bals, E.J. (1978) Reduction of active ingredient dosage by selecting the appropriate droplet size for the target. BCPC Monograph No.22 101-109.

Bals, E.J. (1982) The principles of and new developments in ULV spraying; Some reflections. Proceedings of British Crop Protection Conference: Weeds 3, 1033-1037.

Beedon, P (1975) Service life of batteries used in portable ULV sprayers. Cotton Growing Review 52, 375-385.

Graham-Bryce, I.J. (1977) Crop protection: a consideration of the effectiveness and disadvantages of current methods and the scope for improvement. Philosophical Transactions of the Royal Society, London B, 281, 163-179.

Gledhill, J.A. (1970) Notes on the use of one gallon water-based spray volumes in aerial spraying. Rhodesian Farmer 30 October 1970.

Gledhill, J.A. (1971) Further notes on the use of one gallon water-based spray volumes in aerial spraying. Rhodesian Farmer 12 November 1971.

Huntington, K.A. and Johnstone, D.R. (1973) Cost comparison of methods of hand spraying of cotton in Malawi. COPR Miscellaneous Report No.15 10pp. COPR London.

Johnstone, D.R. (1973) Insecticide concentration for ultra-low volume crop spray application. Pesticide Science 4, 77-82.

Johnstone, D.R. (1974) Physical and chemical requirements for ultra-low volume application. BCPC Monograph No.11 73-79.

Johnstone, D.R. (1978) The influence of physical and micrometeorological factors on the deposition drift of spray droplets of controlled size. BCPC Monograph No.22 43-57.

Johnstone, D.R., Huntington, K.A. and King, W.J. (1973) Battery-operated ULV hand-sprayer. COPR Miscellaneous Report No.7 10pp. COPR London.

Johnstone, D.R., Huntington, K.A. and King, W.J. (1974) Micro-meteorological and operational factors affecting ultra-low volume application of insecticides onto cotton and other crops. Agricultural Meteorology 13, 39-57.

Matthews, G.A. (1971) Reduced volume of spray on cotton. Proceedings of Cotton Insect Control Conference, Blantyre 172-181. ARC Malawi.

Matthews, G.A. (1973) Ultra-low volume spray application onto cotton in Malawi. Pesticides Abstracts and News Summaries 19, 48-53.

Morton, N. (1973) The use of the hand-held ULV atomisers for cotton pest control. Pesticides Abstracts and News Summaries 19, (4), 548-556.

Nyirenda, G.K.C. (1982) Daily applications of ultra-low volume (ULV) insecticides at low dosages to control pests of cotton in Malawi. Crop Protection 1, (2) 213-220.

Quinn, J.A., Johnstone, D.R. and Huntington, K.A. (1975) Research and development of high and ultra-low volume sprays to control tomato leaf diseases at Samaru, Nigeria. Pesticides Abstracts and News Summaries 21, 388-395.

Raheja, A.K. (1976) ULV spraying for cowpea. Pesticide Abstracts and News Summaries 22, (3), 327-332.

Rendell, C.H., and Thongsakul, S. (1976) ULV application of three insecticides for cotton protection at recommended, half and one quarter recommended rates of active ingredient. Report of the Pesticide Application Research Project No. T/76/3 Department of Agriculture, Bangkok.

Smith, D.M. (1977) Organophosphorus poisoning from emergency use of a hand-sprayer. Practitioner 218, 877-883.

Wrigley, G. (1983) Mineral oils as carriers for ultra-low volume spraying. Pesticide Abstracts and News Summaries 19, (1) 54-61.

BIOLOGICAL CONSEQUENCES OF SPRAYS EMITTED BY HORIZONTAL ROTARY ATOMISERS

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ABSTRACT

A general account on the biological performance of pesticides applied by rotary atomization. Reference is made to why there are differences in spray deposit forms and how they can be modified. Pesticide type and performance is described and some conclusions drawn.

INTRODUCTION

Rotary atomizers are usually associated with

: low volumes of spray liquid (<30 l/ha)
: the production of drops in a narrow size range
: drops that free-fall onto the target surface from a circular horizontal distribution

The target surface may therefore be exposed to sprays of different

: drop masses
: drop numbers
: concentration of formulated product

The initial form and location of spray deposits on the target surface will therefore almost always differ from that given by hydraulic nozzles used in the traditional manner.

It has often been thought that such contrasts in form of deposit applied by rotary atomizer and hydraulic nozzle offer scope for changes in biological response.

In practice, the extent of such differences will be modified by

: pest location, size, shape
: formulation of the pesticide and its post-spraying behaviour
: weather

In this paper I will try to summarize what is known to date but recognise there are obvious difficulties. Whilst many biological observations have been made, the full interpretation of the results has not often been possible. Research in which comparisons are made between applications from rotary atomizers and hydraulic nozzles have been based on a whole set of changed features rather than one individual component. Pesticides differ widely in their mode of action and are applied to an equally wide range of target surfaces. The post-spraying behaviour of pesticides will also vary as an intrinsic feature of that chemical or through extrinsic influence such as the weather. Despite these major considerations, biological claims are made and summed up as 'success or failure' of rotary atomization.

However, patterns of pesticide performance can be seen and for reasons of brevity alone I have generalised in my conclusions.

Biological Observations

It has often been shown that pesticides which act through the soil are almost totally insensitive to spray volume rate. Even quite large differences in local distribution appear not to be finally important. In these instances a uniform film over the whole target surface does not need to be achieved. Success of products applied non-uniformly is dependent on the final zone of activity of the pesticide and the size of area within which the pest can or cannot safely survive. In the extreme example of volatile pesticides that require mechanical incorporation this mixing process is an additional aid to redistribution leading to uniformity. Soil-acting presticides applied by rotary atomizers usually give the same level of control as that from a hydraulic nozzle.

There is however, no consensus of opinion with foliar-acting pesticides. All possibilities are claimed from imporved - to less - effectiveness. Increased activity has been shown with a few products. For example, glyphosate formulated as Roundup, is more effective - a response well-researched. Such increased activity is now believed due to the change in surfactant concentration rather than differences in spray cover. However, most systemic foliar applied pesticides show no major differences in response. If the same amount of active ingredient is deposited on the target surface, the location and distribution of drops appears of little final consequence. In these cases, it is assumed the pesticide is moved adequately throughout or over the target to reach the site of action. Research has shown that despite more active ingredient being retained by the target, there is not a corresponding increase in activity. The reasons for this 'balancing in performance' are not clear.

Contact-acting presticides applied by rotary atomizers lose some of their activity to a greater or lesser extent. Such products have very limited zones of activity - the cover of the surface by the drops and/or the concentration of the product on the drop - is a restraint. Both a reduction in concentration and more surface cover are necessary to restore activity. In this and other examples, conventionally formulated pesticides applied in low volume (<30 l/ha) by rotary atomisers are therefore restricted in performance when applied at dose rates recommended for use with hydraulic nozzles.

The location of the pesticide on the target may also have a contributory effect. Some target sites are more effective than others. There are examples, especially with insecticides, where free-falling drops from a rotary atomizer will preferentially reach these more effective sites. In contrast, the herbicide difenzoquat is more effective after application to the younger, more upright leaf of the wild oat (Avena spp) rather than the older flatter leaves. To reach vertical surfaces, drops may need low angle trajectories - often provided by the low volume cloud.

In the more complex situation of preferentially attempting to deposit spray on one type of plant but not another - as in selective herbicide use - drop speed at impact may be a further factor. Fast, large drops are not well retained on steeply sloping waxy plant surfaces such as cereal leaves. Drops with these characteristics may bounce or shatter to have a further opportunity of being deposited on other surfaces. Selective post-emergent herbicides do reply in part on this application component to avoid crop damage.

Pesticide activity can be modified by the weather conditions too. For example, activity can be lost after rain if the deposit is washed off the target surface. In contrast activity can be increased - if moved to a more sensitive zone. (Wind has also been shown to extend the area of activity of vapour-acting fungicides). Plants covered with dew which have received spray drops derived from a rotary atomizer, may produce a deposit form similar to that from a conventional hydraulic nozzles.

CONCLUSIONS

Rotary atomizers have allowed many pesticides to be applied without loss in efficiency in much reduced spray volume rates. In instances where larger drops are produced and applied, there may be increased opportunities to spray under a greater range of wind speeds without long distance drift. Both these factors usefully allow speedier and more timely applications to be made.

Controversy focuses on maintained effectiveness at reduced dose rate of a.i. Using conventinal formulations such claims are not well founded. In practice the major issues that appear to dictate success of the pesticide are

: the identification and timing of the delivery to the target

: the dose of active ingredient

: the ability to overcome and mask deficiencies in application, modified in some instances by the weather

: major contributory effects derived, for example, from crop competition on weed growth or beneficial predators on target insects.

ACKNOWLEDGEMENTS

I am indebted to my former colleagues at the AFRC Weed Research Organisation who so actively supported the application project.

PATTERN OF INSECTICIDE DEPOSITION AND CONTROL OF APHIDS ON POTATOES AFTER SPRAYING WITH HYDRAULIC, ROTARY CAGE ATOMISER AND CONTROLLED DROPLET APPLICATION SPRAYERS

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ABSTRACT

Field experiments compared a standard hydraulic nozzle sprayer with a rotary cage atomiser sprayer in 1983 and a controlled droplet application sprayer in 1984 for spray penetration of the potato canopy and aphid control. The potato aphid (*Macrosiphum euphorbiae*) was controlled better by insecticide when it was applied by the hydraulic sprayer than by either the rotary cage atomiser sprayer or the controlled droplet application sprayer. Neither the rotary cage atomiser sprayer nor the controlled droplet application sprayer applied insecticides to give a more effective control of the peach-potato aphid (*Myzus persicae*) than the hydraulic sprayer. The relative control of aphids by the different sprayers could be explained only partially by tracer deposition of the sprays on the different leaf strata of the potato canopy. The difficulty of interpreting the data from field experiments comparing different spraying techniques for crop insect pest control is discussed.

INTRODUCTION

The effectiveness of commercial hydraulic nozzle applications of insecticide to potatoes at controlling aphids and leaf roll virus spread was determined by McKinlay and Franklin (1983; 1984). Good control of potato aphids was not necessarily associated with good suppression of leaf roll virus spread. Sprays appeared to be more effective at controlling aphids in the upper horizon of the potato canopy. As the peach-potato aphid (*Myzus persicae*), a most efficient vector of potato leaf roll virus, is usually found in larger numbers in the lower horizon, field experimental work began in 1983 to compare different spraying techniques with the standard hydraulic nozzle sprayer for spray penetration of the potato canopy and aphid control.

MATERIALS AND METHODS

Three treatment plots were replicated three times in a field of cv. Maris Piper potatoes during 1983. Each plot was approximately 22.9 m long and 20 x 76 cm drills wide covering an area of 0.035 ha. Six of the nine plots were sprayed on 20 July with demeton-S-methyl insecticide, three plots using a hydraulic nozzle (H) sprayer and three plots using a fan-assisted rotary cage atomiser (RCA) sprayer. The remaining three plots were not sprayed with insecticide. The experiment was designed as a randomised block. Demeton-S-methyl ('Metasystox 55') was applied with the H sprayer at the manufacturer's recommended rate of 243.6 g a.i./ha in 225 l of water through Lurmark F80-20 flat fan nozzles, each delivering 1.1 l/minute at an operating pressure of 258.6 kPa and a forward speed of

6.4 km/hour. Demeton-S-methyl was applied with the RCA sprayer at 243.6 g a.i./ha in 227.5 l of water through Micronair atomisers, each delivering 4.6 l/minute at an operating speed of 5,000 rpm and a forward speed of 8.0 km/hour. The experimental site (National Grid Reference NT 150721) was level and 50-60 m above sea level. When sprayed, the leaves of individual potato plants were touching across the drills and the plants were flowering.

The potato aphid (*Macrosiphum euphorbiae*) and the peach-potato aphid were counted on 20 randomly chosen potato plants per plot. The plants were sampled using the three leaf (upper, middle and lower; Anscombe, 1948) method 2, 7, 14, 21 and 28 days after treatment.

Adjacent to the aphid control field experiment of 1983, two plots were replicated three times. Each plot was approximately 13.7 m long and 20 x 76 cm drills wide covering an area of 0.02 ha. The six plots were sprayed with a demeton-S-methyl-Saturn Yellow mixture, three plots using the H sprayer and three plots using the RCA sprayer. The insecticide-pigment mixture was applied at the same sprayer settings as the insecticide alone. The amounts of pigment deposited on 18 mm diameter discs from upper, middle and lower leaves were determined subsequently by fluorimetry. The Saturn-Yellow-fluorimetry technique for determining pesticide spray deposition patterns on plants was reported by Sharp (1974).

As in 1983, three treatment plots were replicated three times in a field of cv. Maris Piper potatoes during 1984. Each plot was approximately 34.7 m long and 34 x 91.4 cm drills wide covering an area of 0.1 ha. Six of the nine plots were sprayed at more or less fortnightly intervals on 15 and 29 June, 13 and 30 July and 10 August with deltamethrin + heptenophos insecticide, three plots using an H sprayer and three plots using a controlled droplet application (CDA) sprayer. The remaining three plots were not sprayed with insecticide. The first spray date was about 10 days after the spray warning issued by the Scottish Agricultural Colleges under their aphid spray warning scheme for seed potato growers (Woodford *et al.*, 1977). The experiment was designed as a randomised block. Deltamethrin + heptenophos ('Decisquick') were applied with the H sprayer at the manufacturer's recommended rate of 7.5 g a.i./ha of deltamethrin and 120 g a.i./ha of heptenophos in 225 l of water through Lurmark F80-20 flat fan nozzles each delivering 1.1 l/minute at an operating pressure of 258.6 kPa and a forward speed of 6.4 km/hour on 15 June and through Teejet 8004 flat fan nozzles each delivering 1.5 l/minute at an operating pressure of 275.8 kPa and a forward speed of 8.0 km/hour on 29 June, 13 and 30 July and 10 August. Deltamethrin + heptenophos were applied with the CDA sprayer at 5.0 g a.i./ha of deltamethrin and 79.8 g a.i./ha of heptenophos in 44.9 l of water through Lely Hydraspin spinning disc atomisers each delivering 600 ml/minute at an operating speed of 4,000 rpm giving a target 150 µm diameter spray droplet and a forward speed of 6.4 km/hour on 15 and 29 June. The following variations to this basic pattern of CDA sprayer settings and insecticide doses occurred: on 13 and 30 July and 10 August, deltamethrin + heptenophos were applied at 7.5 g a.i./ha of deltamethrin and 120 g a.i./ha of heptenophos; and on 30 July and 10 August, the insecticides were applied in 67.4 l of water/ha through the spinning disc atomisers each delivering 900 ml/minute at an operating speed of 5,000 rpm giving a target 120 µm diameter spray droplet. On 15 June, the leaves of individual potato plants were touching in the same drill; on 29 June, the leaves of individual plants were touching across the drills; and on the remaining spray dates, the crop had developed a full leaf canopy. The experimental site (National Grid Reference NT 590779) was level and 15-30 m above sea level.

As in 1983, adjacent to the aphid control field experiment of 1984, two plots were replicated three times. Each plot was 34.7 m long and 14 x 91.4 cm drills wide covering an area of 0.04 ha. The six plots were sprayed with a deltamethrin + heptenophos-dysprosium mixture on 13 July, three plots using the H sprayer and three plots using the CDA sprayer. The insecticide-tracer mixture was applied at the same sprayer settings given above for the insecticide alone on 13 July. The amounts of dysprosium deposited on 18 mm diameter discs from upper, middle and lower leaves were determined subsequently by neutron activation analysis. The dysprosium tracer-neutron activation analysis technique for determining pesticide spray deposition patterns on plants was reported by Dobson *et al.* (1983).

The aphid data from potato plots sprayed with the H and RCA sprayers in 1983 and the H and CDA sprayers in 1984 were transformed by $\sqrt{x + 0.5}$ and statistically analysed using "Student's" t-test. The amounts of Saturn Yellow pigment and dysprosium tracer deposited on discs from upper, middle and lower leaves of plants sprayed by H and RCA sprayers in 1983 and H and CDA sprayers in 1984 were computed as percentages of the total pigment or tracer deposited on all leaves. Angular transformations of the percentage data were then statistically analysed using "Student's" t-test.

RESULTS

The relative proportions of Saturn Yellow pigment deposited on upper, middle and lower leaves after one application of demeton-S-methyl + pigment to potato plants by RCA and H sprayers on 20 July 1983 are given in Table 1. The proportions of pigment deposited on upper and middle leaves by the RCA sprayer were not significantly different ($P < 0.05$). The RCA sprayer did apply however a significantly lesser ($P < 0.05$) proportion of pigment to lower than to middle leaves. The H sprayer applied significantly lesser ($P < 0.05$) proportions of pigment to middle than to upper leaves and to lower than to middle leaves. The two sprayers did not differ significantly ($P < 0.05$) in the proportions of pigment deposited on the same leaf positions.

The mean numbers of *M. persicae* and *M. euphorbiae* on upper, middle and lower leaves at different time periods after one application of demeton-S-methyl to potato plants by RCA and H sprayers on 20 July 1983 are given respectively in Tables 2 and 3. The numbers of *M. persicae* on the different leaves did not differ significantly ($P < 0.05$) between RCA and H sprayers at any date. The numbers of *M. euphorbiae* on the different leaves did not differ significantly ($P < 0.05$) between the two sprayers except on middle leaves and on upper + middle + lower leaves 2 days after treatment and on upper leaves 7 days after treatment. Two days after treatment, significantly lesser ($P < 0.05$) *M. euphorbiae* were counted on middle leaves and on upper + middle + lower leaves of plants sprayed with the H sprayer than the RCA sprayer. By contrast, 7 days after treatment, significantly lesser ($P < 0.05$) *M. euphorbiae* were counted on upper leaves of plants sprayed with the RCA sprayer than the H sprayer.

TABLE 1

Mean angular transformations of percentage deposition of Saturn Yellow pigment on upper, middle and lower leaves after one application of demeton-S-methyl to potato plants by rotary cage atomiser (RCA) and hydraulic (H) sprayers on 20 July, 1983. Standard error of difference when comparing means within one type of sprayer is 3.63; standard error of difference when comparing means between two sprayers is 2.96.

Type of Sprayer	Position of Leaf		
	Upper	Middle	Lower
RCA	42.4	36.2	26.3
H	44.9	36.2	22.8

The relative proportions of dysprosium tracer deposited on upper, middle and lower leaves after one application of deltamethrin + heptenophos-tracer to potato plants by CDA and H sprayers on 13 July 1984 are given in Table 4. The CDA sprayer deposited a significantly greater ($P < 0.05$) proportion of tracer on upper than middle leaves. The proportions of tracer deposited on middle and lower leaves by the CDA sprayer were not significantly different ($P < 0.05$). The H sprayer did not apply significantly different ($P < 0.05$) proportions of tracer to upper and middle leaves. It did apply however a significantly greater ($P < 0.05$) proportion of tracer to middle than to lower leaves. The CDA sprayer deposited a significantly higher ($P < 0.05$) proportion of tracer on upper leaves than the H sprayer. The H sprayer, on the other hand, applied a significantly greater ($P < 0.05$) proportion of tracer to middle leaves than the CDA sprayer. The two sprayers did not differ significantly ($P < 0.05$) in the proportions of tracer deposited on lower leaves.

The mean numbers of *M. persicae* and *M. euphorbiae* on upper, middle and lower leaves several days after each of five applications of deltamethrin + heptenophos to potato plants by CDA and H sprayers during 1984 are given respectively in Tables 5 and 6. The numbers of *M. persicae* on the different leaves did not differ significantly ($P < 0.05$) between CDA and H sprayers at any date. The numbers of *M. euphorbiae* on the different leaves did not differ significantly ($P < 0.05$) between the two sprayers except on upper leaves on 5 July and 2 August and on lower leaves and upper + middle + lower

TABLE 2

Mean numbers of peach-potato aphids *(Myzus persicae)* on upper, middle and lower leaves at different time periods after one application of demeton-S-methyl to potato plants by rotary cage atomiser (RCA) and hydraulic (H) sprayers on 20 July 1983. SED is standard error of difference.

Date	Days after Treatment	Position of Leaf	Aphid Numbers				
			Actual		Transformed		
			RCA	H	RCA	H	SED
20 July	0	Upper	0.0	0.0	0.71	0.71	0.00
		Middle	1.3	3.7	1.27	1.87	0.67
		Lower	3.7	2.7	1.86	1.64	0.77
		Upper + Middle + Lower	5.0	6.3	2.32	2.34	0.86
22 July	2	Upper	0.1	0.1	0.79	0.79	0.11
		Middle	0.4	0.1	0.93	0.79	0.15
		Lower	1.1	0.4	1.20	0.95	0.25
		Upper + Middle + Lower	1.6	0.6	1.41	1.08	0.26
27 July	7	Upper	0.4	0.1	0.93	0.79	0.15
		Middle	1.6	0.5	1.36	1.00	0.38
		Lower	2.0	1.6	1.54	1.44	0.25
		Upper + Middle + Lower	4.0	2.3	2.03	1.64	0.46
3 August	14	Upper	0.3	0.9	0.85	1.19	0.15
		Middle	1.5	1.1	1.38	1.18	0.33
		Lower	3.9	3.1	2.08	1.87	0.19
		Upper + Middle + Lower	5.6	5.1	2.46	2.32	0.34
10 August	21	Upper	0.5	0.8	0.99	1.10	0.27
		Middle	2.1	1.3	1.59	1.29	0.38
		Lower	2.1	1.5	1.61	1.40	0.16
		Upper + Middle + Lower	4.8	3.6	2.29	1.99	0.30
17 August	28	Upper	0.0	0.1	0.71	0.79	0.08
		Middle	0.4	1.1	0.93	1.25	0.14
		Lower	0.4	1.3	0.93	1.30	0.29
		Upper + Middle + Lower	0.8	2.5	1.13	1.72	0.23

TABLE 3

Mean numbers of potato aphids *(Macrosiphum euphorbiae)* on upper, middle and lower leaves at different time periods after one application of demeton-S-methyl to potato plants by rotary cage atomiser (RCA) and hydraulic (H) sprayers on 20 July 1983. SED is standard error of difference.

Date	Days after Treatment	Position of Leaf	Aphid Numbers				
			Actual		Transformed		
			RCA	H	RCA	H	SED
20 July	0	Upper	35.3	44.0	5.82	6.42	1.62
		Middle	66.6	32.3	7.97	5.67	1.47
		Lower	33.6	28.6	5.83	5.16	1.16
		Upper + Middle + Lower	135.3	105.0	11.63	10.18	1.10
22 July	2	Upper	5.5	2.0	2.39	1.48	0.53
		Middle	7.5	1.2	2.82	1.29	0.18
		Lower	6.8	2.3	2.64	1.52	0.62
		Upper + Middle + Lower	19.7	5.5	4.48	2.43	0.31
27 July	7	Upper	0.1	0.8	0.79	1.14	0.08
		Middle	0.3	0.3	0.87	0.87	0.11
		Lower	0.3	0.3	0.85	0.85	0.20
		Upper + Middle + Lower	0.6	1.3	1.05	1.34	0.22
3 August	14	Upper	1.6	2.6	1.43	1.64	0.51
		Middle	0.6	1.1	1.05	1.23	0.23
		Lower	0.4	0.5	0.93	1.01	0.14
		Upper + Middle + Lower	2.7	4.3	1.77	2.11	0.39
10 August	21	Upper	3.2	2.5	1.87	1.60	0.58
		Middle	2.8	2.1	1.74	1.54	0.51
		Lower	1.5	1.3	1.37	1.33	0.29
		Upper + Middle + Lower	7.5	6.0	2.76	2.45	0.64
17 August	28	Upper	0.3	0.4	0.87	0.93	0.15
		Middle	1.2	1.7	1.28	1.49	0.17
		Lower	1.1	2.7	1.18	1.76	0.34
		Upper + Middle + Lower	2.5	4.8	1.73	2.28	0.23

leaves on 16 August. On 5 July and 2 August, significantly lesser ($P < 0.05$) *M. euphorbiae* were counted on upper leaves of plants sprayed with the H sprayer than the CDA sprayer. On 16 August, significantly lesser ($P < 0.05$) *M. euphorbiae* were counted on lower leaves and upper + middle + lower leaves of plants sprayed with the H sprayer than the CDA sprayer.

TABLE 4

Mean angular transformations of percentage deposition of dysprosium tracer on upper, middle and lower leaves after one application of deltamethrin + heptenophos to potato plants by controlled droplet application (CDA) and hydraulic (H) sprayers on 13 July 1984. Standard error of difference when comparing means within one type of sprayer is 4.96; standard error of difference when comparing means between two sprayers is 4.07.

Type of Sprayer	Position of Leaf		
	Upper	Middle	Lower
CDA	53.6	27.4	19.5
H	39.1	42.6	19.5

DISCUSSION

In 1983, the control of *M. euphorbiae* by demeton-S-methyl was not as good 2 days after spraying with a RCA sprayer as with an H sprayer. However, the numbers of *M. euphorbiae* on all the sprayed plants at this time were about 90% less than the numbers on unsprayed plants. Nevertheless, a significant difference in the aphicidal effectiveness of insecticide application by the two sprayers was measured soon after treatment. The reason for this difference in aphid control is not obvious and is not explained by the Saturn Yellow pigment deposition data on upper, middle and lower leaves.

M. euphorbiae was controlled better by insecticide when it was applied by an H sprayer than a CDA sprayer in 1984. This result is not easily explained by the dysprosium tracer deposition data on upper, middle and lower leaves. The CDA sprayer might have been expected to give better aphid control than the H sprayer because the CDA sprayer applied a greater proportion of the insecticide spray to upper leaves where *M. euphorbiae* is usually found in larger numbers. The CDA sprayer applied a larger proprotion of a smaller volume of more concentrated insecticide to upper leaves than the H sprayer. The aphicidal effectiveness of insecticides may be greater when they are applied by H sprayers because reasonable proportions of larger volumes of less concentrated insecticide reach the target leaf strata. The main conclusion which can be drawn from these comparative studies of different spraying methods for control of *M. euphorbiae* is that

TABLE 5

Mean numbers of peach-potato aphids *(Myzus persicae)* on upper, middle and lower leaves several days after each of five applications of deltamethrin + heptenophos to potato plants by controlled droplet application (CDA) and hydraulic (H) sprayers during 1984. SED is standard error of difference.

Date of Spraying	Date of Sampling	Position of Leaf	Aphid Numbers: Actual CDA	Aphid Numbers: Actual H	Aphid Numbers: Transformed CDA	Aphid Numbers: Transformed H	Aphid Numbers: Transformed SED
		Upper	0.0	0.0	0.71	0.71	0.00
		Middle	0.0	0.3	0.71	0.88	0.17
	14 June	Lower	0.0	0.0	0.71	0.71	0.00
		Upper + Middle + Lower	0.0	0.3	0.71	0.88	0.17
		Upper	0.3	0.0	0.88	0.71	0.17
		Middle	0.3	0.0	0.88	0.71	0.17
15 June	21 June	Lower	1.7	0.7	1.35	1.00	0.50
		Upper + Middle + Lower	2.3	0.7	1.55	1.00	0.56
		Upper	0.0	0.0	0.71	0.71	0.00
		Middle	0.3	0.3	0.88	0.88	0.24
29 June	5 July	Lower	3.7	0.7	1.60	1.05	0.91
		Upper + Middle + Lower	4.0	1.0	1.65	1.17	0.98
		Upper	3.3	0.0	1.79	0.71	0.56
		Middle	14.0	3.0	3.32	1.71	1.42
13 July	19 July	Lower	32.0	48.7	5.34	7.01	1.42
		Upper + Middle + Lower	49.3	51.7	6.74	7.22	1.50
		Upper	0.7	0.0	1.00	0.71	0.29
		Middle	6.0	13.3	2.34	3.69	0.78
30 July	2 August	Lower	20.7	15.0	3.50	3.90	2.14
		Upper + Middle + Lower	27.3	28.3	4.25	5.32	2.26
		Upper	0.3	0.3	0.88	0.88	0.24
		Middle	1.7	0.7	1.26	1.00	0.62
10 August	16 August	Lower	1.0	1.3	1.17	1.27	0.42
		Upper + Middle + Lower	3.0	2.3	1.62	1.65	0.70

TABLE 6

Mean numbers of potato aphids *(Macrosiphum euphorbiae)* on upper, middle and lower leaves several days after each of five applications of deltamethrin + heptenophos to potato plants by controlled droplet application (CDA) and hydraulic (H) sprayers during 1984. SED is standard error of difference.

Date of Spraying	Date of Sampling	Position of Leaf	Aphid Numbers: Actual CDA	Actual H	Transformed CDA	Transformed H	Transformed SED
	14 June	Upper	5.7	0.0	2.00	0.71	1.04
		Middle	0.3	0.0	0.88	0.71	0.17
		Lower	1.7	0.3	1.39	0.88	0.39
		Upper + Middle + Lower	7.7	0.3	2.45	0.88	1.05
15 June	21 June	Upper	3.3	0.0	1.74	0.71	0.64
		Middle	1.7	0.0	1.35	0.71	0.41
		Lower	10.0	3.7	2.99	1.79	1.13
		Upper + Middle + Lower	15.0	3.7	3.74	1.79	1.10
29 June	5 July	Upper	7.0	0.3	2.71	0.88	0.32
		Middle	46.0	9.3	6.63	2.92	1.39
		Lower	51.0	20.3	6.96	4.41	1.50
		Upper + Middle + Lower	104.0	30.0	9.96	5.42	1.79
13 July	19 July	Upper	121.3	7.7	7.70	2.45	5.69
		Middle	483.0	27.0	18.17	4.54	8.95
		Lower	330.3	168.7	17.69	12.59	3.78
		Upper + Middle + Lower	934.7	203.3	27.31	13.83	10.04
30 July	2 August	Upper	10.0	2.0	3.15	1.42	0.72
		Middle	62.7	20.0	7.79	4.45	1.25
		Lower	87.0	46.3	8.83	6.63	2.49
		Upper + Middle + Lower	159.7	68.3	12.25	8.06	2.63
10 August	16 August	Upper	2.0	0.0	1.43	0.71	0.48
		Middle	9.3	2.0	3.05	1.52	0.58
		Lower	10.3	2.0	3.28	1.56	0.27
		Upper + Middle + Lower	21.7	4.0	4.68	2.08	0.47

the aphicidal effectiveness of an insecticide spray depends to some extent on the method of application.

Neither the RCA sprayer in 1983 nor the CDA sprayer in 1984 applied insecticides to give a more effective control of *M. persicae* than the standard H sprayer. This result is related presumably to the poor penetration of the lower leaf canopy by insecticide applied by all sprayers. Aphicidal control of *M. persicae* was not increased by the fan-assisted RCA sprayer or the spinning disc CDA sprayer. Because *M. persicae* is a very efficient vector of potato leaf roll virus, it is very important in seed potato production. No evidence has been found so far from comparison of RCA and CDA sprayers with the H sprayer to suggest that seed potato growers should consider changing from H sprayers to some other types of sprayer for applying insecticides for aphid control.

One interesting observation made in 1983 was that demeton-S-methyl which is recommended by the manufacturers to be applied to seed potato crops every two weeks was found to be quite aphicidal even four weeks after treatment.

Comparison of spraying techniques for crop insect pest control by field experimentation is fraught with large sources of variation making difficult the interpretation of results. An example of experimental variation from these studies is the difference between the proportions of pigment or tracer deposited on upper and middle leaves by H sprayers in 1983 and 1984: a significantly greater ($P < 0.05$) proportion of the applied spray was deposited on upper than on middle leaves in 1983, but not in 1984. With such inherent variation in comparative sprayer studies, much careful experimental work needs to be done by agricultural engineers and biologists before any sprayer should be either accepted or rejected by them for commercial use. More complex measurements than simple insect pest counts and spray deposition data need to be made to develop a full understanding of the sprayer in crop protection eg droplet number, size and distribution, full meteorological records at the experimental site and not at some nearby weather station, stage of crop growth, etc. Future comparative studies of different spraying techniques for potato aphid control will involve further work with the CDA sprayer and the use of electrostatics, fans, adjuvants, etc.

ACKNOWLEDGEMENTS

I should like to thank Miss H. Crossley, Mrs D. Russell, Mr K. Kasperek and Mr J. Cheyne, Crop Protection Department and Mr W. Jeffrey, Agricultural Engineering and Mechanisation Department, Edinburgh School of Agriculture, for technical assistance; Ransomes, Sims and Jefferies PLC for Micronair rotary cage atomisers; Messrs J. Holme, C. Burnham and M. Barrow of Lely Import Ltd for Hydraspin spinning disc atomisers and assistance with application of insecticide; Imperial College at Silwood Park for neutron activation analysis of dysprosium deposits on potato leaf discs; and Bayer UK Ltd (Agrochem Division) and Hoechst UK Ltd (Agriculture Division) for 'Metasystox 55' and 'Decisquick' respectively.

REFERENCES

Anscombe, F.J. (1948) On estimating the population of aphids in a potato field. *Annals of Applied Biology* 35, 567-571.

Dobson, C.M.; Minski, M.J.; Matthews, G.A. (1983) Neutron activation analysis using dysprosium as a tracer to measure spray drift. *Crop Protection* 2, 345-352.

McKinlay, R.G.; Franklin, M.F. (1983) Potato aphid and leaf roll virus control: insecticide granules and sprays. *Proceedings 10th International Congress of Plant Protection* 3, pp. 1204. Croydon:BCPC.

McKinlay, R.G.; Franklin, M.F. (1984) Potato aphid and leaf roll virus control: timing of first spray. *Proceedings Crop Protection in Northern Britain*, pp. 166-170. Dundee: Scottish Crop Research Institute.

Sharp, R.B. (1974) Spray deposit measurement by fluorescence. *Pesticide Science* 5, 197-209.

Woodford, J.A.T.; Shaw, M.W.; McKinlay, R.G.; Foster, G.N. (1977) The potato aphid spray warning scheme in Scotland, 1975-1977. *Proceedings 1977 British Crop Protection Conference - Pests and Diseases* 1, 247-254.