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THE IMPORTANCE OF CONTROLLED DROPLET APPLICATION (CDA) IN PESTICIDE APPLICATIONS

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Summary A new term, CDA, has been coined because CDA (Controlled Droplet Application) is much more relevant to efficient spray applications than the term ULV (Ultra Low Volume). CDA is concerned with the uniformity of droplet spectra irrespective of droplet sizes. The droplet size should be commensurate with its intended function and can vary from 300 µm for drift-free herbicide application with 15 l/ha to 20 µm for efficient mosquito control with 5 ml/ha. In both instances the same number of droplets per unit area of target will be deposited which ensures the desired control, which could not be achieved with lower droplet density on the target. Both application rates are, therefore, minimal volume spraying. The term ULV has, unfortunately, by now become confused with a certain fixed amount of spray liquid per ha which is rather irrelevant. The paper further deals with ideas based on CDA with small droplets which might, if the assumptions are correct, provide a cheap, quick and simple pest management programme for developing countries.

You will forgive me if I start with a few generalisations about the war we have to fight against nature in order to get our disproportionately high share of natural products for the ever increasing number of our fellow men. Make no mistake, pest control is an all out war with an enemy who may attack on a broad front or produce a series of damaging raids when we have relaxed our vigilance.

These military analogies are, I think, particularly appropriate when you consider that our main weapons are poison gases and solids, hormones, bacteria and, lately, pheromones to disrupt the sexual behaviour of insects. There is certainly no reference to the Geneva Conventions in our methods of warfare.

Pests, be they insects, fungi or weeds, are our enemies as they are continually competing against us in consuming food or preventing the efficient growth of raw materials which we want to use ourselves.

The longer I observe this war the more I am forced into two conclusions. One is that the generals are too often absorbed by the local battles to properly plan the overall attack along a broad front. The other is that, while the chemicals for pest control become more sophisticated, too little thought has been given to the weapons of delivery whether they be large missiles or humble bullets.

On the first point I can but offer food for thought; on the second, I can expand my long held views in the light of more recent experience and observations.

First, can I briefly expand my suggestions on the overall scale of the war. Too often are we concerned with the plant protection in one field or group of fields without considering the surrounding environment in which the pest most probably originated. From this host environment the enemy can easily strike again in a guerilla offensive once we have deluded ourselves of having controlled the pest in the crop.

Consideration, in the long term, must be given to the ideas of Vernon Joyce with his concept of pest management versus plant protection. Plant protection, in this context, is the protection of one field against pests in order to maximise its yield whilst pest control looks further and tries to suppress the pest attack on a much wider area in order to enable a village or region to grow crops with a minimum of losses.

The best example of pest management on a gigantic scale is the Desert Locust Control operation which could not have succeeded but for international and even intercontinental cooperation.

It is of no use destroying a locust swarm on a 10 ha field in order to save the crops of that particular farm. It is not even much use destroying a swarm threatening a whole country. These attacks against the pests are much too late as considerable damage will have been done already. The only effective answer is to seek out the breeding areas of the hoppers and to control them there before they become a threatening pest. This was done very effectively in the fifties and little has been heard of locusts since. That was pest control on an inter-continental and efficient scale done with military precision and intelligence.

The other example I would like to cite is that of the Sudan Gezira Board where, to all intents and purposes, a monoculture of cotton exists and where many hundreds of km^2 are treated regularly. Even so, this is on too small a scale for real efficiency. This is because the rotation of crops within the area is undertaken at a village level. If the rotation were to be organised on an area level so that the total cotton planting were to be concentrated into one area at a time, it would be possible to treat this area on a pest management basis rather than on a plant protection basis. Or, rather, pest management and plant protection would become synonymous.

Furthermore, host plants are cultivated during the crop rotation which do not receive the same attention with regard to crop protection as the main cash crop, cotton, and thereby weaken our defences considerably.

We started monoculture, with all its perils, the moment we started agriculture. Now is the time to go one step further and plan monoculture not on a farm but on a village and, perhaps, even on a regional level. Thereby we can concentrate our enemies in one area and make the task of their destruction that much easier.

If we then, furthermore, plan our crop rotation in such a way that the neighbouring crops are not host plants, we deny the pests the food for their survival except in the clearly defined large areas where we have herded them together and can fight and control them on a pest management basis. It is, therefore, up to us to decide the location of the battle and every strategist would agree that choosing one's battle ground is half the battle won.

Forgive me for taking so long over these initial thoughts but I do feel strongly that, when we have moved from plant protection at field level to pest management at regional or national level, then ULV/ULD spraying will really come into its own.

Understandably, the Desert Locust operation was the first to appreciate the advantages of ULV and ULD spraying and, without it, would not have succeeded.

Many definitions of ULV spraying are bandied around by people who have not understood the fundamental principle of the concept. They talk in definitions of 1 l, under 5 l, or even 20 l/ha. One litre of what? Per hectare of what? What is the pest we have to control? At what stage of its development? There are so many variations within these definitions and yet, as I say, the true point will have been missed. ULV spraying or, better still CDA (Controlled Droplet Application) is concerned with using droplets commensurate with the target we wish to attack, be it insect, fungus or weed and to utilise the active chemical ingredient to its maximum efficiency, without doing irreparable harm to plants or predators. The total volume of liquid applied can range from 5 ml to 15 l/ha. 5 ml/ha of chemical in the form of small droplets of 10 - 20 µm will efficiently wipe out flying insects such as mosquitos. 15 ml of 30 - 40 µm droplets will control tsetse fly whilst, if the aim is accurate drift-free weed control on a controlled swath with 300 µm droplets, 10 - 15 l will be required per ha in order to achieve the required droplet density on the target for efficient control.

Therefore, the total amount of liquid used bears no relation to the effect achieved. The important aspect is the study of the behaviour of a droplet and its ability to impinge on its selected target relative to its size and the amount of active chemical carried. For this reason four main parameters have to be taken into consideration.

1. The definition of the target.
2. The behaviour of droplets of different sizes.
3. The macro and micro climatic conditions during which the operation takes place.
4. The degree of concentration of the chemical needed and its suitable formulation to give effective control with a given droplet size.

The most important but, unfortunately, the most neglected parameter is the definition of the target.

The only target in insect control is the nerve centre of the insect. Any chemical not reaching this target has to be considered a waste and, at the same time, contamination of the environment. We should aim, therefore, to get a deposition of our chemical on the insect itself wherever possible. That this method is possible has amply been demonstrated in tsetse fly and mosquito control where usually 10 ml per ha gives a near 100% control. Why is this method not used in other pest control operations? In my humble opinion, for the simple reason that it has just not been tried.

I would like to remind some listeners that the ULVA and its unconventional spraying method encountered much scepticism in the plant protection world until it was discovered that it was not a joke but quite a serious tool.

There is, in my opinion and from my practical, very non-scientific observations, every chance that we can revolutionise crop protection by basing most of our future insect control operations on adulticiding. All insects in their adult stage of development are either flying around like mosquitos or are resting under leaves like tsetse fly, thereby presenting a target which is ideal for small droplets to impinge, hardly leaving any residue on the leaves and, certainly, none on the glass plates hopefully laid out on the ground by eager scientists. However, one area on the plant will collect such small droplets (20 - 40 µm) very efficiently. That is the hairy surfaces of the plant and the hairs will filter these droplets out even before they are reaching their base and, thereby, prevent them from anchoring themselves firmly to the leaf.

A simple analogy will show why I think that this is important. After a heavy rain it is quite possible to walk dry-footed on a road avoiding the occasional puddle whilst, after even a light dew, a few steps on a lawn will leave shoes unavoidably dripping wet because the dewdrops on the grass blades are easily detached and transferred. The order of magnitude between hairs on a plant and grass, as well as insect and human legs, is roughly comparable.

So why waste valuable chemicals and cause unnecessary contamination with large droplets firmly anchored to the leaves of plants when, with a little bit of planning, better results can be achieved with less chemicals and effort.

If I am correct in my assumptions all our past quantitative assessments of spray deposits might be a waste of time and qualitative assessments are difficult, if not impossible, to carry out. Furthermore, droplets of this order do not allow replicated trials as we are now dealing with pest management on a macro-scale and not plant protection on a micro-scale.

The fact that adulticiding can successfully be achieved with minute quantities of total spray liquid as well as small amounts of a.i. has been proved beyond doubt in the few instances where it has been tried.

My contention is that it will equally well succeed in most other crop situations and I am quoting two examples which point that way.

EXTRACT FROM A SUDAN GOVERNMENT REPORT 1952 (JOYCE) [1]

Trials were carried out with a Micron air-blast sprayer. This machine, which was trailed behind a Land Rover travelling at a speed of 3 m.p.h., was calibrated to an output of 0.5 gals. per minute, and the spray allowed to drift downwind. No accurate method was available for measurement of the percentage of the total output recovered but, since the droplets, which are produced by a rapidly rotating aerofoil working at low output, were found to be extremely uniform, a useful approximation of the spray across the swathe was considered to be obtained from a count of the droplets collected on glass slides placed at varying distances from the point of emission. The results of experiments with this machine are summarised in table 15.

Table 15
Trials with Micron Sprayer.

Percentage recovery of droplets across a swathe

(Means of 2 trials)

Distance across swathe in metres	Droplets		
	No. per 100 sq. cm.	% of total	Accumulative per cent.
10	1098	43	43
30	873	34	77
60	433	16.8	93.8
70	94	3.7	97.5
90	37	1.4	98.9
110	9	0.3	99.2
130	7	0.3	99.5
150	1	-	-
170	5	-	-
190	2.2	-	-
210	0.7	-	-
230	0.2	-	-
250	0.5	-	-
270	0.5	-	-
290	0.3	-	100

In these trials nearly all the spray recovered fell within 50 metres of the point of emission and the total amount recovered across the complete swathe is believed to represent the vast bulk of the total output.

When a 7 percent emulsion of DDT was applied to a 5 feddan plot of cotton by this method, the estimated dosage of DDT across the swathe was calculated, and the effect of this dosage on a population of jassids assessed by means of counts. The results are summarised in Table 16.

Table 16

Trials with Micron Sprayer.

Control of cotton jassid across a swathe

(jassid nymphs per 100 leaves)

Distance from period of emission	Estimated mean dose of DDT (lbs./fed.)	Jassids								Mean post spray
		Before spraying	Days after spraying							
			6	7	13	21	27	34	41	
25 metres	1.4	97	18	21	0	0	5	28	21	13
50 metres	0.3	94	15	26	23	0	6	26	18	16
75 metres	0.1	96	5	30	0	0	6	26	19	12
Mean	0.6	96	13	26	8	0	6	27	19	14
Boom spray	1.0	45	1	19	4	41	49	155	138	58

The dosages achieved were lower than that used in the normal rates of application, but the results were encouraging. The same trend of jassid numbers was apparent as with boom spraying, an initial reduction being followed by a rise 7 days after spraying due to hatching of nymphs from eggs, followed 21 days later by complete elimination. The duration of protection given was better than with that achieved by the standard methods.

EXTRACT FROM A CENTO RESEARCH REPORT (HUNTER-JONES, HODJAT) [2]

The experimental plot, measuring 360m by 85m and covering about three hectares was sprayed across wind with 95% Folithion. Only one spray run was made and that only the long side of the plot. The actual spraying time was 90 seconds, during which time about 45 ml. of spray was used. When the plot was examined two and a half hours after spraying, the plot was divided into five zones, each about 20m wide, running parallel to the line taken by the spraying apparatus. The results showed that in the 20m zone nearest to the spray line, the population had been reduced by 99%. Mortality in the other four zones was 91%, 67%, 57% and 57% in the zones progressively further from the spray line. When the plot was re-surveyed, five days after spraying, the mortalities in the five zones were 91%, 97%, 91%, 91% and 85%. The zone nearest the spray-line is shown first (Table 1).

The area was examined before spraying, and dead beetles were not present on the ground. Many dead beetles were seen on the ground when the area was re-examined after spraying, however, but it was not possible to estimate the number of dead beetles because the soil had been tilled and beetles were obscured by the rough texture of the soil.

TABLE 1: The effect of one spray run on ULV Folithion on reduction of infested plants and beetle population in each zone. Each zone was 360 x 20 metres. The zone nearest the spray line is No. 1.

	TIME	1 0-20m	2 20-40m	3 40-60m	4 60-80m	5 above 80m
Percentage Population Reduction	2.5 hrs. after	99	91	67	57	57
	5 days after	91	97	91	91	85

2.5 hours after spraying Folithion in the field the reduction in pest population and percentage infested plants was highest at first zones and gradually decreased in the following zones. However, five days after spraying there was not a significant difference between the reduction of pest population or infested plants between the zones. This suggests that zones farther away from the spray line received lowest amount of spray droplets. It suggests that the residual action of pesticide on plant the farthest zones from the spray line was sufficient to give similar percentage kill for all zones five days later. Most beetlés in the first zone were killed immediately because of direct hit by spray deposits.

These preliminary results with ultra-low-volume spraying against Bulaea Lichatschove Hum. agreed closely with results obtained by similar spraying against thrips infesting cotton (Hodjat and Hunter-Jones, 1970)

In the current results with Folithion, an area of three hectares was cleared of the infestation in 90 seconds. These areas may have been overdosed.

In Joyce's experiment carried out in 1952, the droplets were anything but uniform varying from 200 - 20 µm. Droplets under 50 µm, due to the winnowing effect were probably prevalent at the end of the swath and were apparently not collected on glass plates but provided, unbeknown to the author, with about 5% of the normal dosage rate, the best knockdown and residual control as is shown in Table 16.

In Hunter-Jones' report it is interesting to note that the residual action of the probably smaller droplets in Zones 3, 4 and 5 was excellent whilst the knockdown in these zones was poorer due, in all probability, to the very low dosage applied. This experiment was carried out with an ULVA where approximately 90% of the spray produced is in the range of 50 - 100 µm normally settling out in the first 50 m. Therefore, the spray deposited in Zones 3, 4 and 5, consisting of droplets smaller than 50 µm, is probably nearer 1.5 ml/ha than 15 ml/ha, the total dosage used.

It is, further, interesting to see that, in Zone 1 (0 - 20 m) the kill from direct hits, with probably the largest droplets from the range emitted, was highest whilst the residual effect was poorest due, in my opinion, to these droplets being deposited on large surfaces, firmly anchored and not available for pickup.

This, though not proof, provides food for thought that quality of residual deposit is much more important than quantity.

If this is correct a number of preconceived ideas on the level of contamination needed for residual action have to be re-examined.

Conclusions

The Micron ULVA, which is probably well enough known by now, was designed on an ad hoc basis in order to prove that a dusting technique with liquid particles, or an aerial spraying technique without an aircraft, is feasible with a cheap and simple to use spraying machine. It has done just that in various fields of plant protection on a commercial scale utilising only natural forces for the distribution of droplets generated by it. The droplets produced by the ULVA are of a 70 - 80 um vmd, a size arbitrarily chosen in order to make a start with such spraying operations.

The time has now come to utilise the experience gained and, as a first step, the Micron HERBI was designed. This unit delivers controlled 300 µm droplets and has already proved invaluable in herbicide applications. Firstly, by reducing the total amount of spray liquid used; secondly, by avoiding any drift hazard; and, thirdly, by enabling us, in all probability, to reduce the amount of a.i. needed due to its extremely good CDA characteristics. This unit will be discussed in this session in a paper read by Taylor (W.R.O.)[3]

As a second step, and in order to enable workers in the field to prove or disprove the theories outlined in this paper, we have designed the Mini ULVA which will be available in commercial quantities early in 1976. This unit can be used on a "dial a droplet" basis and can be set to produce droplets of 30, 40, 50 or 60 µm with a much narrower droplet spectrum than that produced by the ULVA. This has been achieved by designing a new single disc, or rather cup, which, due to its configuration, delivers a more even flow to the 360 zero issuing points on the disc periphery. This ensures an even sized ligament formation and, thereby, a narrower droplet spectrum, The atomising unit of the Mini ULVA is incorporated in the unit for mosquito control described in this session in the paper read by Boize, Matthews and Kuntha (Imperial College)[4]

In my paper, read at the 1969 Brighton Conference[5], I stated:

"The efficiency of a spraying machine is inversely proportional to the range of droplet it emits whilst its suitability for a specific problem depends on the actual size of the droplets emitted."

Now, six years later, both of these objectives have been achieved:-

1. A very narrow droplet spectrum which ensures maximum utilisation of costly chemicals due to a more even distribution on the target.
2. A choice of droplets to enable us to determine in advance on which targets the majority of these droplets will impact and, thereby, a further saving of chemicals and a reduction of unnecessary contamination.

For these reasons, CDA (Controlled Droplet Application) is much more to the point than ULV (Ultra Low Volume) which is so often misinterpreted due to its obsession with the absolute volume needed for effective control.

The Micron HERBI, with its 300 µm droplets, achieves a drift-free spray and adequate coverage with 10 - 15 l/ha.

With the Mini ULVA we can now use a very narrow droplet spectrum with a droplet size chosen according to the target we are intending to hit.

If the conclusions drawn from the two trials quoted are correct, the best control, both from a knockdown and residual point of view, was achieved with minute quantities of droplets under 50 µm. We are now in a position to produce a droplet spectrum of these dimensions and, by omitting from the spectrum the unsuitable droplets of over 50 um, we need only apply approximately 10% of the spray liquid used in the trials in order to get the same droplet density on the target.

As the concentration of a.i. used in these trials achieved the desired results, it stands to reason that the same concentration can be used at these lower application rates with a tremendous saving of costly and scarce chemicals.

This might open up undreamt of possibilities of pest management especially in food crops like rice, wheat and sorghum in the developing countries and, if correct, it would enable even the smallest subsistence farmer to use this method and, thereby, increase the food production to levels at which nobody need be hungry especially if it is done in conjunction with the new high yielding strains of wheat and rice, which need pest control much more than the indigenous strains.

To conclude:

If the assumptions in this paper are correct, it might follow that, with minute quantities of spray liquid and very much reduced dosage rates of a.i., large areas can be pest managed in a very short time with a wide swath width, minimal skilled labour and a spray unit which is cheap and which lends itself to local production especially in those countries which would need them most.

I plead with all concerned to investigate this aspect and prove or disprove it for the sake of the hungry millions.

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SOME PHYSICAL ASPECTS OF THE PERFORMANCE OF EXPERIMENTAL EQUIPMENT FOR CONTROLLED DROP APPLICATION WITH HERBICIDES

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Summary

The development at the Weed Research Organization of experimental field equipment, which is used to apply herbicides in controlled drop applications at very low volumes of spray liquid, is described. A new design of rotary atomizer is utilized for uniform-drop formation. The advantages of reduced spray liquid volumes and limitations of conventional hydraulic nozzles are considered. Field measurements on spray distribution show that reduced spray volumes can be applied, with a degree of uniformity, comparable to a conventional hydraulic system. Theoretical considerations of such measurements are discussed. Movement of spray drops through cereal canopies in a few field experiments indicated that there was no major difference from a conventional system.

INTRODUCTION

The sale of herbicides by larger UK manufacturers now amounts to some £19 million per annum (UK Dept. of Industry, 1975). The cost of developing a successfull new herbicide has been stated to be almost £4 million (Price Jones, 1974). While much time and money are spent in searching for new herbicides, the equipment which is used to apply these products has received relatively little attention and has for many years remained essentially unchanged.

At the Weed Research Organization (WRO) the biological importance of factors concerned with the application of herbicides are being investigated. It has long been apparent that hydraulic nozzles have many limitations, both in practical farm use and on experimental equipment. They produce sprays which consist of drops of very diverse sizes. Other methods of applying pesticide sprays which use rotary atomizers are increasingly exploited to apply systemic insecticides and fungicides often at volume rates less than 5 l/ha (Maas, 1971). The majority of herbicides used in the UK are at least partly systemic in action. Many of the advanatages of ultra low volume (<5 l/ha) and very low volume (<56 l/ha) controlled drop size spraying are likely to apply to herbicides as well as other pesticides. The object of this paper is to both present the advan tages of very low volume spraying and to provide data on some physical aspects relating to this type of application.

Some practical advantages

Many logistic advantages are offered by a reduction in the spray volume rate. Lower quantities of water, less frequent fillings of the spray tank and fewer journeys to the water source, result in a saving of time, labour and fuel. Limitations due to the weather, such as wind and wet soil and the need to apply many herbicides at specific crop and weed growth stages increase the problems of spraying (Tottman and Phillipson, 1974). In an attempt to maximise spraying opportunities larger spray tanks and heavier equipment are often used. These can cause soil compaction, more serious crop damage and may not be useable under wet conditions. The number and type of pesticides which are regularly used on farms are steadily increasing. Materials are now being applied at a wide range of crop growth stages. Frequent passage of a tractor and sprayer through growing crops often causes severe physical damage. There would be obvious advantages in using a relatively light machine which could apply pesticides in very low volumes of diluent. Low volume techniques would also assist from the formulation aspect. If a product could be used undiluted, or with only a minimum of dilution, problems such as those associated with hard water would be largely avoided. Low volume techniques would also avoid the need for adding large amounts of surfactants to formulated products.

The limitations of hydraulic nozzles

When advocating the use of new methods or new equipment it is often helpful to discuss the limitations of existing techniques, in this instance the application of herbicides by means of hydraulic nozzles.

Hydraulic nozzles have been used to apply pesticides in a diverse range of volume rates, sometimes even as undiluted formulations from the air. Often, success depends on the systemic activity of the products. The most important functional part on a conventional sprayer is the nozzle. This performs the three major functions of metering, transversely distributing and atomizing the spray liquid. The metering of pressurised liquids is affected by slight variability in orifice size. In spite of the attempts of manufacturers individual nozzles of any given size or type often differ and differences become accentuated during use by erosion and corrosion. Distribution of spray liquid from most nozzles depends on their use at a certain minimum height above the target. The need to place nozzles well above the crop subjects the sprayed liquid to higher wind velocities and increases the risk of evaporation and drift. Finally in the disintegration of liquid sheets produced by a nozzle, drops are produced which vary enormously in size. Depending on orifice size and spraying pressure, spray spectra with differing characteristics are produced (Courshee, 1959).

High travelling speeds and small nozzle orifice sizes are necessary if very low volumes are to be applied from the ground. Both factors tend to increase non-uniformity of spray deposits and drift. The latter would be most serious in countries like Britain where many small fields of high value crops are grown and a diverse range of herbicides are used. Conversely, increasing nozzle orifice size and/or lowering the hydraulic pressure shifts the spray spectrum towards coarser drops. Large drops are not readily retained on plant foliage, especially on leaves with a 'waxy' cuticle such as those of many grass crops and weeds. The chances of large drops being retained are still further diminished if they impact on leaves at high velocities. The number of drops produced decreases with increasing size and at very low volume rates the incidence of hitting small targets is reduced. From a consideration of both physical and biological factors, therefore, very low volume application should take the form of relatively large numbers of moderate sized drops. These should be small enough to be retained on leaves but not so small as to drift.

DEVELOPMENT OF EXPERIMENTAL EQUIPMENT FOR CONTROLLED DROP APPLICATION (CDA)

Rotary atomizers can produce a narrower range of drop sizes than hydraulic nozzles, and have thus been developed commercially to apply insecticides and fungicides (Bals, 1973). For example, the ULVA* disc, operated at 6000 - 9000 rev/min produces drops in the range 70 - 120 µm VMD, and these are released into an artificially induced or natural wind current. The size of these drops is such that they drift for a limited trajectory across the target crop on which they ultimately impact. By slowing the ULVA disc to 1840 rev/min larger drops (about 280 µm in diameter) are produced, although some small satellite drops may be formed. In certain circumstances, where the margin between pest control and crop damage is wide, discs of this

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* Manufactured by Micron Sprayers Ltd., Bromyard.

kind can safely be used with some herbicides. The application of atrazine to maize and 2,4-D to cereals are examples (Larch, 1974, Sokolov et al, 1970). In 1972 the WRO built an experimental tool which was used to obtain information on the biological efficiency of herbicides when applied in very low volumes. This machine embodied ULVA discs, which were used in the slowed down mode. Spray drops leave the disc on a trajectory which is dependent on their mass and initial velocity. The resulting spray deposit takes the shape of an annulus, or narrow circular band. However, to improve this inherently poor distribution the discs were mounted in shrouds designed to emit only one sector of the spray formed, a 60° arc. The rest of the spray was caught by a surrounding shroud and recirculated. Spray distribution studies with this experimental machine demonstrated the possibilities of applying herbicides in VLV as effectively as with a conventional plot sprayer using very much higher volume rates (Taylor and Merritt, 1974a).

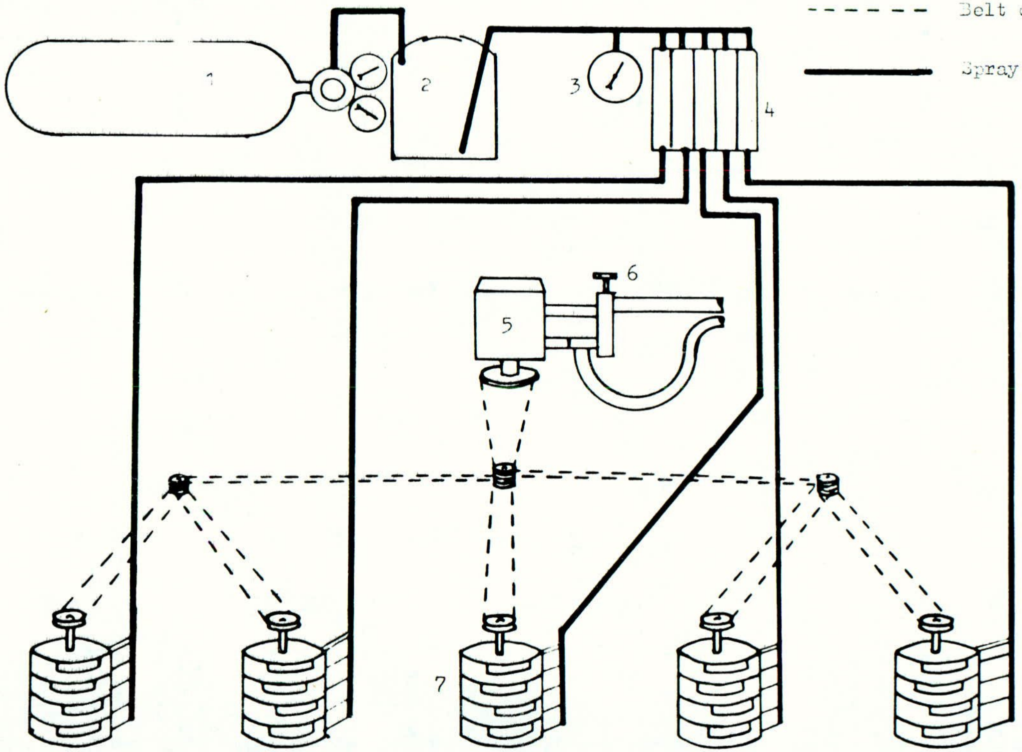
Field experiments were carried out only with the oil solutions of herbicides. Although the number of herbicides studied could have been extended by 'solubilizing' aqueous herbicides (Turner and Loader, 1974), there is evidence that this formulation method may reduce activity. In addition to being restricted to use with oil solutions further limitations of the equipment were its inability to produce a range of sizes of drop and the need to use slow tractor speeds.

In July 1974 Mr E Bals (Micron Sprayers Ltd., Bromyard, Herefordshire) kindly loaned the WRO a prototype disc designed to obtain more uniform atomization of water based as well as oil based materials. Using these new discs a second, more versatile experimental machine was built for use in spring 1975 (Taylor et al 1975). To increase spray liquid emission and to avoid recirculation of non-emitted liquid, a technique of 'stacking' discs, five in this case, was developed. With this arrangement non-emitted liquid is retrieved by a shroud and drained onto the disc immediately below it. The bottom disc is not shrouded. The inherently poor distribution from the bottom disc is compensated by the spray from the other discs (Fig. 1). This new experimental tool has allowed detailed investigation in the course of which information pertinent to many types of pesticide has been obtained.

SPRAY DISTRIBUTION WITH THE CDA

Preliminary results show that, with volume rates down to about 18 l/ha and with drop sizes between 150 and 350 µm, distribution of pesticide solutions can be comparable to that obtained with a conventional medium volume sprayer (Taylor et al, 1975). However at lower volume rates (c.6 l/ha) with either 150 µm or 350 µm drops, the experimental machine does not distribute spray liquid (coefficient of variations are respectively 41% and 39%) as evenly as a conventional application at c.200 l/ha (coefficient of variation 28%). The larger drops (350 µm) are produced in too small numbers per unit area, and the smaller drops (150 µm) do not have a sufficiently well defined trajectory. With a drop size of 250 µm, distribution over 0.1 m x 0.1 m areas at 6 l/ha was comparable to that obtained with a conventional sprayer. These variabilities are inherent to the machine and type of application. Further variability due to external factors such as wind and crop interception is irregular in nature and less easily understood. The experimental machine is designed to apply herbicides to field plots some 3 m wide and 20 m long. Information on spray variability over such an area was obtained in a cross wind of about 1.8 m/s. When the machine was operated at 30 cm above the targets the coefficients of variation of spray recovered were increased from 27 to 45% (150 µm drop), 14 to 59% (250 µm drop) and 20 to 56% (350 µm drop). The theoretical rate of application was 15 l/ha but the actual spray recovery was 12.7 l/ha with the 350 µm drop, 9.7 l/ha with the 250 µm and 8.7 l/ha with the 150 µm. There was a lateral displacement of the swath dependent on drop size. This displacement is less liable to occur with a conventional sprayer. Here the smaller drops in the spray remain air borne for longer periods of time and are lost. Therefore, differences between the mean deposits which can be determined in practice and theory, should be considered when studying spray distribution.

Fig. 1. A diagrammatic representation of the new WRC controlled drop applicator.



1. Compressed air cylinder 2. Spray liquid container 3. Pressure gauge 4. Flow meters

5. Hydraulic motor used to revolve discs, operated by tractor hydraulic system

6. Bypass valve for speed control 7. Spray unit (diagram not drawn to scale)

Lateral displacement of drops from a controlled applicator was examined in more detail using a CDA spray unit loaned from Horstine Farmery Ltd. This unit, producing drops 250 µm in diameter over a 1.2 m swath was fixed to a rig mounted on tyreless bicycle wheels which could be made to run along a tubular track. To avoid turbulence, both this CDA unit and a conventional hydraulic nozzle were positioned at the extreme front of the rig, which was pushed from behind. The spray solution was water with added surfactant (o.1% v/v Agral) and fluorescent pigment (0.1% w/v Fluorescein LTS). 0.1 m x 0.1 m petri dishes were laid both under the path of the nozzles and down wind at 0.4 m intervals to a total distance of 4.5 m. With cross-winds of 2.7 - 3.6 m/s there was a lateral displacement of about 1 m and at wind speeds of 3.6 - 5.4 m/s the swath width was approximately doubled and displaced by 1 - 3 m downwind. Under similar conditions using a hydraulic nozzle (Spraying Systems 'Teejets' 8002 at 2.8 bars), little spray solution was detected on those dishes away from the swath - the drift component apparently remaining air borne.

Interception of spray drops by crop plants

A further factor which has been studied is the degree of interception of spray drops by a cereal crop. Work under laboratory conditions suggested that the mode of application might have relatively little effect on crop penetration (Taylor and Merritt, 1974b). To obtain more information of this important aspect spray deposits were measured during field experiments. Square 0.1 m x 0.1 m petri dishes were placed in similar positions relative to the applicator, either between rows of fully tillered spring barley or in adjacent areas where the crop had been removed. A fluorescent tracer pigment (Fluorescein LTS) was added to the spray solution. Immediately after spraying the dishes were removed and placed in a dark box to prevent decay of the pigment. Deposits were measured fluorometrically and expressed as volume rates (Fig.2). Differences attributable to the presence or absence of a crop were greatest with the higher volume rates. There was also a tendancy towards larger standard errors at the lower volume rates, notably at 5 l/ha. However, in general, crop penetration with the conventional system was no better than with the controlled drop applications. Under field conditions, wind is probably also important, interacting with the crop canopy by affecting the angle of trajectory of the spray drop.

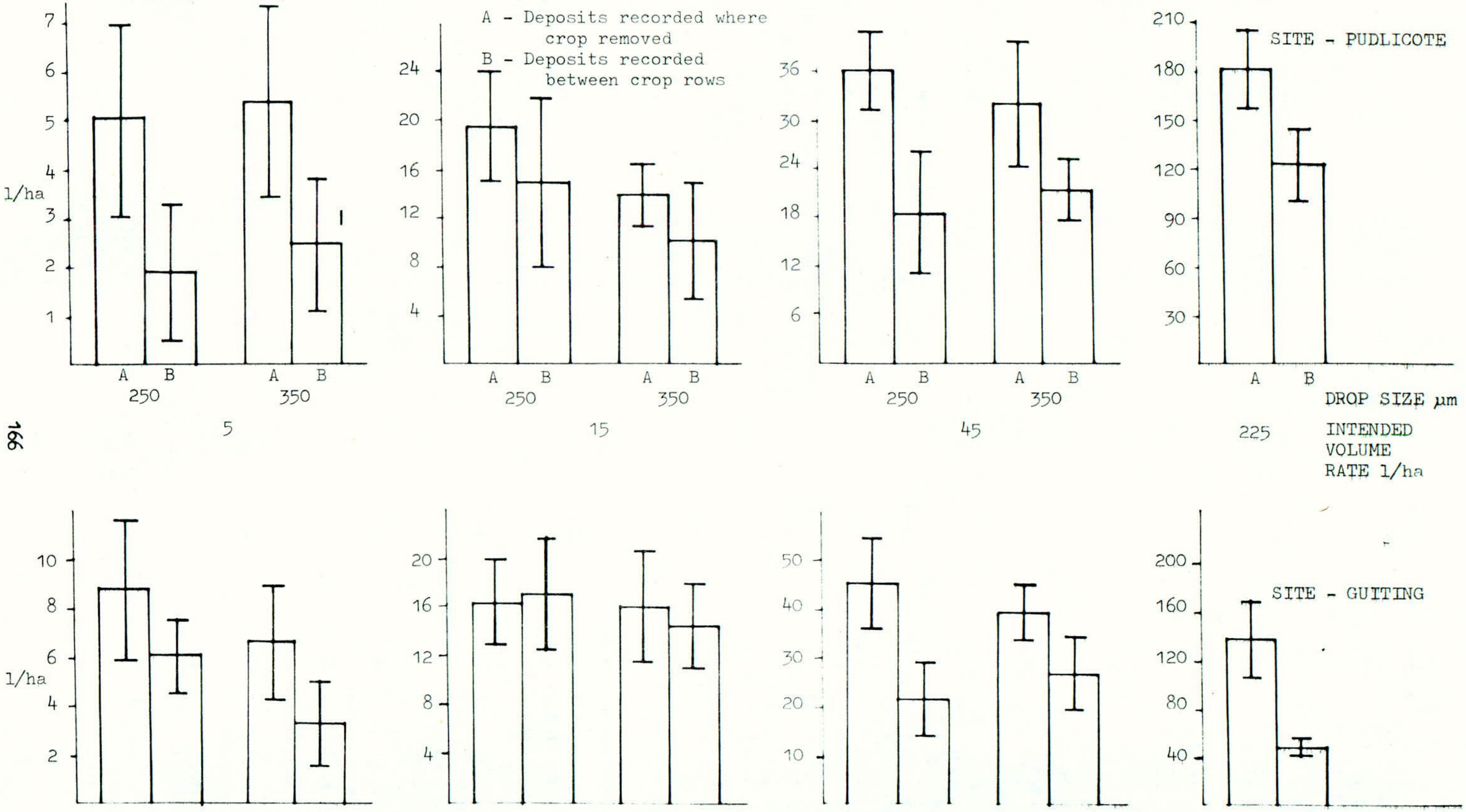
The choice of sample area for distribution studies

The studies described above involve the use of a single size of sample area, chosen empirically. Most previous workers who have studied spray distribution, have not used the same size areas and so estimates of variations of distribution are not usually suitable for making comparisons between sprayers. The influence of two differing areas, which could be used to sample variability of spray deposit has been demonstrated by the authors. Square 0.1 m x 0.1 m petri dishes, sub-divided into 25 compartments each with an area of 400 mm^2, were laid beneath the experimental spray rig described above. Spray deposit in each compartment of the dishes was measured fluorimetrically. The results (Table 1) show that the variability of deposits on 20 mm x 20 mm sample areas was highest when applications were made with the rotary atomizers. However the variation between deposition on 0.1 m x 0.1 m areas (*ie* whole dishes) was similar for both applicators.

The sample area which is used for spray distribution studies should be similar to that of the target organism or that area of the organism on which application of a given quantity of spray is known to produce a particular biological effect. However the concept of a defined target is elusive and difficult to resolve in many situations. For example, organisms of different species or individuals of the same species but with different sizes may be targets for the same spray.

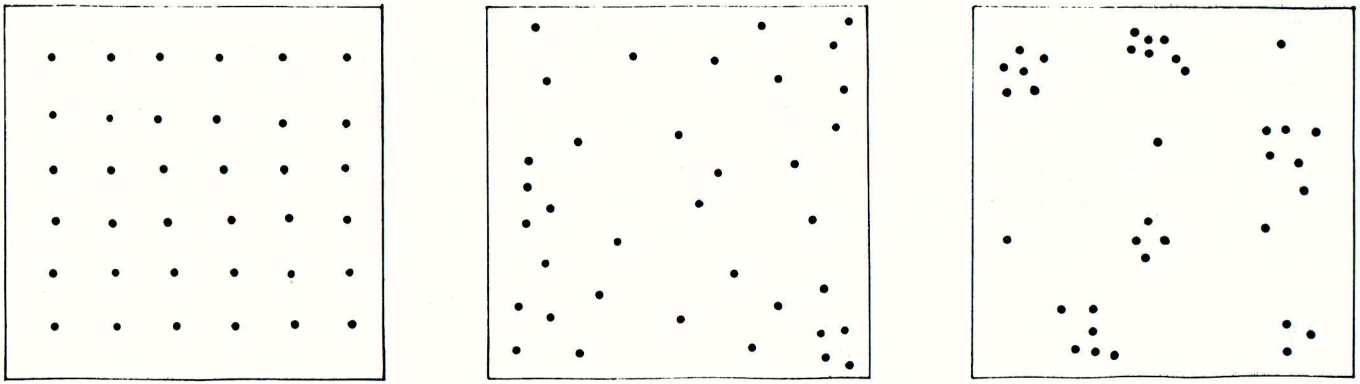
The optimal target area for contact herbicides may be different from that for materials which act systemically through the soil. It is however still necessary to decide on a suitable target area for use in spray distribution studies. In the case

Fig. 2 Spray deposits measured between crop rows when applied in three volume rates and two drop sizes with the controlled drop applicator. For comparisons a conventional volume rate (225 l/ha) was applied with hydraulic nozzles.



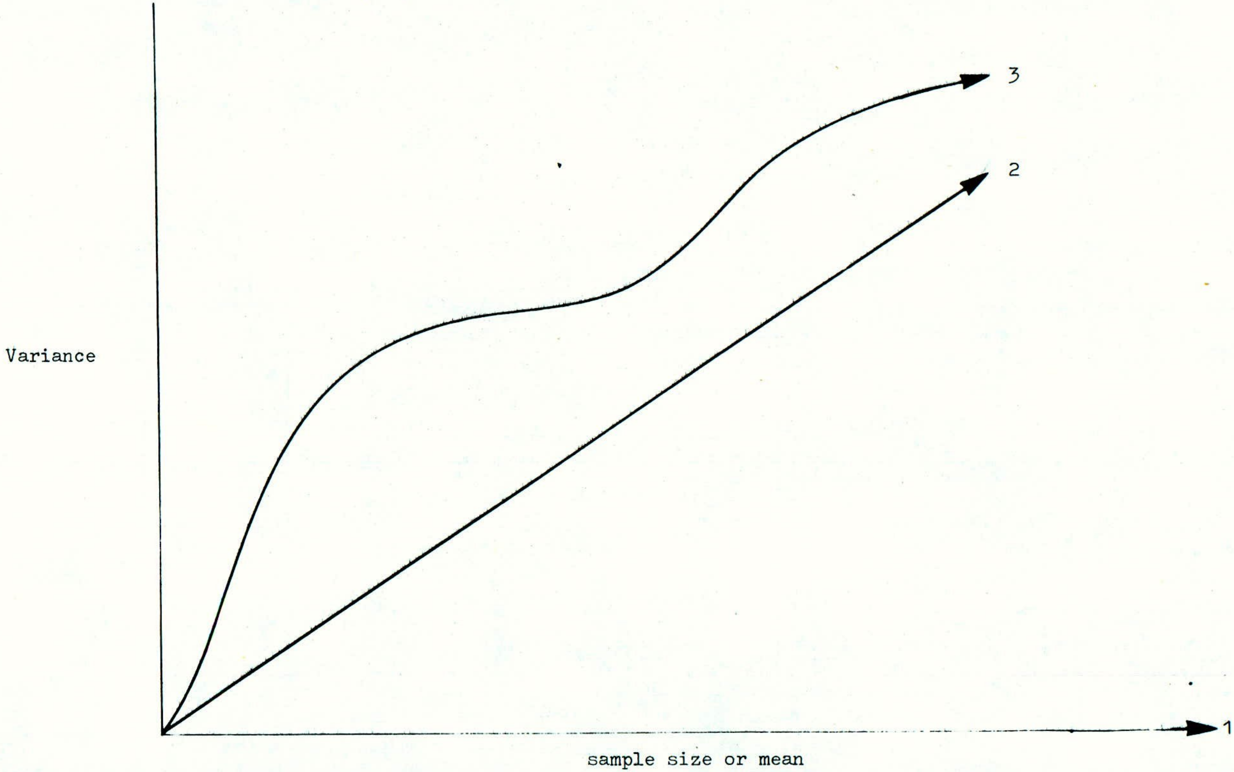
SITE		WIND SPEED m/s	CROP	GROWTH STAGE	CROP DENSITY No/m^2
SITE	PUDLICOTE	1.34 - 1.79	SPRING) cv PROCTOR	MAIN SHOOT	235
	GUITING	2.23 - 3.13	BARLEY) cv MAZURKA	4-9 + TILLERS	162

Fig. 3.   The three theoretical forms of distribution of uniform sized spray drops



1. Regular   2. Random   3. Aggregated

Fig. 4. The relationships between sample variance and sample size or mean for the three theoretical forms of spray distribution



1. Regular distribution (variance = 0)
2. Random distribution (variance = mean)
3. Aggregated distribution (variance > mean)

N.B. The above curve for an aggregated distribution represents only an example of the type of relationship obtained.

Table 1 Coefficient of Variation (CV) of deposit from a rotary atomiser and a hydraulic nozzle measured over sample areas of 400 mm^2.

Applicator	CV for individual dishes (%) I	II	III	IV	V	overall CV for 5 dishes
Rotary atomiser 12.3 l/ha	20.6	20.5	16.2	14.8	11.6	21.0
Nozzle 176 l/ha	10.5	7.1	9.2	7.1	6.0	19.6

of controlled drop applicators statistical studies of spray distribution are relatively simple. The overall drop number/unit area can be calculated provided that the volume rate and drop size are known (Table 2). Certain general considerations apply to the distribution of these drops. In theory at least distributions may take one of three forms, either regular, random or aggregated (Fig.3). Depending on the type of spray distribution a particular relationship will exist between the variance of samples and the sample area (Fig. 4).

Table 2 Theoretical mean number of drops per 100 mm^2 at various volume rates and drop sizes.

Drop diameter (um)	Drop volume (ul)	VOLUME RATE (l/ha) 1	5	10	15	20	45
100	5.24×10^{-4}	19.10	95.5	191.0	287.0	382.0	861.0
150	1.77×10^{-3}	5.65	28.3	56.5	84.8	113.0	254.0
200	4.19×10^{-3}	2.39	12.0	23.9	36.0	47.8	108.0
250	8.19×10^{-3}	1.22	6.1	12.2	18.3	24.4	54.9
300	1.42×10^{-2}	0.70	3.5	7.0	10.5	14.0	31.5
350	2.25×10^{-2}	0.44	2.2	4.4	6.6	8.8	19.8
400	3.35×10^{-2}	0.30	1.5	3.0	4.5	6.0	13.5

If deposition was found to be completely random the distribution would follow the Poisson series (e^{-m}, me^{-m}, $\frac{2m}{2!}$, e^{-m}, ...). However since most distributions are found to be of the third type - that is aggregated - it is necessary to determine practically the variance/sample area relationship for each particular set of circumstances. Once this has been done the effects of external factors such as wind, crop canopy etc can be studied in relation to the actual distribution of spray drops.

DISCUSSION

Any attempt to explain the performance of spray machinery must take into account many factors. These may vary in importance with the mode of action of the pesticide and the situation in which it is used. For example, uniform distribution may be less important for a volatile pesticide but absolutely essential for a contact action herbicide. Consideration must also be given to factors other than uniformity of distribution. The successful retention of a pesticide drop on a plant surface depends, in part, on the form, velocity and trajectory in which the drop is presented to the plant surface.

Controlled drop application is now a practical possibility for farm use. Many soil applied and systemic herbicides have been applied at VLV often without loss in efficiency. However, as with conventional sprayers a full understanding of relationships between type of deposition and biological activity has not yet been achieved. Artificial targets are useful for assessing the physical nature of sprays but should be discussed with caution. Observations of biological effects offer the real practical evidence of the effectiveness of a new system. Laboratory and field trials at the WRO have demonstrated that many herbicides can be applied in volumes of spray liquid as low as 15 l/ha - without any loss of biological efficiency. These trials, to be reported in detail elsewhere, are sufficiently encouraging to justify further research and development.

Acknowledgements

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CONTROLLED DROPLET ENGINEERING - THE ENGINEER'S VIEWPOINT

by Horstine Farmery

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Summary A new sprayer is being developed with partially screened spinning disc nozzles which are positioned to achieve a more even spray distribution than with conventional nozzles. A fixed application rate of 15 l/ha has been selected together with a droplet size of 200-300 μm to minimise drift. Droplets falling almost vertically effectively penetrate cereal crops. Reduction in spray volume results not only in a greater work rate but also in less crop damage and soil compaction.

INTRODUCTION

One expects papers at this type of Conference to be a corollary of what has happened in a certain field of research. As an engineer, I feel unqualified to make this kind of presentation, and have confined myself instead to stating my reasons for exploring controlled droplet application, which, I would like to stress, should not be confused with ultra-low volume, a point with which, I know, Mr. Bals in particular would agree.

I was born into, and have lived all my life in, a farming community and therefore I have much sympathy with the farmer's viewpoint. The chemicals with which we equip the farmer are becoming expensive and more and more sophisticated yet, in some cases, they are fast closing the gap towards crop tolerance. Economics and performance are then closely tied to the 'peaks' and 'valleys' of the distribution graph. The greater the variation, the greater the effective cost and the greater the variation in biological performance.

The basic design of spraying equipment with hydraulic nozzles has remained unchanged over three decades. This, in itself, is no reason for changing the machine, but I cannot help thinking that modern technology must be able to contribute something. With granules, the farmer prefers to take delivery of the diluent and active ingredient combined, thereby freeing himself from the need to supply his own diluent and carry out a mixing operation, which may be subject to errors.

My experience in developing and manufacturing both conventional sprayers and granule applicators has shown that increasing the diluent, far from improving distribution of the active ingredient, actually does the opposite. I accept that there may be exceptions to this, but I have arrived at my opinion after much discussion with those engaged in research on this topic. With one particular granular product, even distribution of 4.5 kg or less can equal the performance of a liquid at 20-30 times that weight and volume. Ummel et al (1974) showed this and subsequent trials have confirmed this. So can we justify carting onto a field hundreds of litres of, apparently unnecessary, water diluent?

Granules do have some beneficial effect upon the efficacy of some chemicals, but I doubt if this greatly effected Ummel's findings. They can be distributed more evenly and the size of individual granules is more consistent. With the conventional hydraulic nozzle, the diameter of the larger droplet is some 100 times larger than the smallest, hence 1 million times the volume. Also droplets of conventional sprays below 100 micron (some are down to 10 in conventional spraying) can decrease rapidly in size through volatilisation. Conversely, how can we justify the 1000 micron droplet? There must be an element of local over-kill with such a large droplet. Therefore, 200-300 micron droplets were chosen as the ideal size for herbicide spraying on the basis of experiments at the Weed Research Organisation (Taylor, 1975).

Distribution patterns of conventional nozzles frequently have 2-1 variations. Under field conditions, even larger variations occur. Surely, where there is sufficient active ingredient in the trough of the distribution graph, there must be overkill at the peaks.

As solid granules could only hope to capture a relatively small part of the market, I went in search of the liquid granule. My initial idea was to use air as a diluent, as it is cheaper, lighter, and more readily available than water. I tried to entrain one fluid (water) in another fluid (air) but the physical reactions differed from that of solid granules. Meanwhile Bals (1975) had developed a spinning disc which produced the ideal droplet size and at the WRO, Taylor (1975) had incorporated the disc into an experimental sprayer used in the study of the application of herbicides. I offered to develop a boom sprayer which was practical for the farmer to use, and felt honoured when both parties accepted my offer.

SPRAY PATTERN WITH A SPINNING DISC

Our first priority was to determine the error in the distribution pattern of an unshielded spinning disc. Much time was wasted trying to establish this by conventional pattern equipment.

So, on the drawing board, a disc was drawn with a tangential pattern representing the droplets at 2 degree intervals. These were then projected onto a line drawn at right angles to the direction of travel to represent linear motion. A quadrant of the disc was then divided into eight equal divisions in the same manner and this gave the number of deposits falling within each sector. This then proved a theoretical distribution error of 9.5 : 1 within these divisions.

This pattern was produced on a test rig, after a considerable amount of work on flow rates and other factors. Once the theoretical pattern had been achieved, a mask was then developed to release droplets in such a way as to correct the discrepancies. The droplets remaining captured within the mask were funnelled down to a second disc. This second disc's distribution had the original 9.5 : 1 error, which was corrected by further allowances in the mask on the upper disc. Several means of returning the captured droplets to the upper disc were investigated, but problems in disc design, feeding and wetting are such as to render this impracticable. Probability of droplet agglomeration, due to superimposing 50% of one pattern upon another is not a problem, as the two intersections represent such a small incidence area that the probability is very low indeed. The collision of two 200 micron droplets, if they were to agglomerate into a single sphere, would still keep the size below the desired upper limit of 300. By using the 100% over-lapping technique, we can average out errors in joining disc patterns, whether within the machine itself or through driver error. For instance, within a driving deviation of 1.25 m, the maximum applied will be 150% and the minimum 50%, which is within present accepted errors of the conventional sprayer - without driving deviation being taken into account.

CROP PENETRATION

With hydraulic nozzles improved crop penetration can be obtained by an increase in spray volume. In our system, droplets fall vertically, so very good crop penetration is achieved even at low volumes, especially when spraying cereals. Our work on the 'Microdrop' system suggests that angle of approach, control of droplet size and evenness of distribution are possibly more effective than velocity coupled to mass. To appreciate this, one must realise that all plants position their leaf area in such a way as to obtain maximum daylight exposure. As the average angle of daylight is near vertical, an identical approach to the target plant by the droplet will maximise target deposit. Such foliage as is masked by the crop is unlikely to photosynthesise and, because of this, chemical uptake would be minimal in any case.

DISCUSSION

The efficacy of herbicides with 200-300 μm droplets is being covered at WRO and it is hoped there will be similar experiments with other pesticides in due course. Farmer reaction invariably starts with bewilderment that such things are possible, and then turns to great enthusiasm. So far, chemicals of high mammalian toxicity have been avoided for reasons of caution only. The method of application should prove safer as droplets of low velocity which constitute an inhalation risk to the operator are not produced. The operator's contact with the chemical is certainly no more, and probably less, than with conventional application. This method lends itself to a sealed system, which again should enhance safety. Elimination of small droplets results in less drift than with conventional sprayers, but further research on this aspect is needed.

The operator needs no special skills or training. Should he decide to ignore instructions and exceed recommended speed ($3\frac{1}{2}$ m.p.h. - higher speeds being developed) then the consequences are more serious because, unlike the conventional sprayer, the flow rate cannot be interfered with. As variations in flow rate upset optimum performance, a fixed rate of 15 l/ha has been selected. On the other hand, construction and maintenance are quite simple and therefore costs should be competitive. The real advantage, of course, lies in the elimination of large volumes of water, which not only allows an increase in work rate, but also a reduction in crop damage and soil compaction from wheelings. So far, we have not had an opportunity to test in overseas conditions and it may well be that this method's greatest scope lies in areas remote from water sources and where large fields, at the moment, demand large payloads. So far, conventional, off-the-shelf, formulations have been used and appear quite satisfactory. Nevertheless, there is scope for developing special formulations which may well be cheaper and of improved viscosity. There is also scope for developing further chemicals which failed because of instability in water.

The conventional sprayer has been with us a long time, but the passing of years does not, in itself, make machines out of date, nor does the personal ambition of the developer - it is only a superior mechanism which can outdate another. If there is to be a change from conventional spraying to this technique, then the cost to the farmer must be fully justified. Because, unlike the conventional sprayer, the 'Microdrop' does not rely upon chaos to achieve distribution, it could be construed that it is sophisticated, complicated and expensive - but we are well on the way to proving this assumption wrong.

Although much work has already been done on efficacy, much scepticism must be defeated before the new technique is acceptable on these grounds. The farmer is more likely to be attracted by a X3 factor in the work capacity. Much of this advantage will be lost if we are to compete with the low-flying tractors of the budding Jackie Stewarts, but efficacy will no doubt come to our rescue. To use this system mounted on our modern day Leviathans of the tractor world will be like trying to do the Viennese Waltz in hob-nailed boots, and so a carriage more befitting this petite lady of the pesticide world is called for. The erring ways of our tractor drivers need not haunt them for one-third of the year if we use a slim-wheeled, purpose-designed vehicle. A lot of time and development cash will undoubtedly flow under the development bridge before the British farmer buys, but need those farmers in countries where water is not cheap and readily available as a diluent wait so long - I think not . . .

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PHYSICAL ASSESSMENT OF VERY LOW VOLUME FUNGICIDE SPRAY APPLICATION ON TOMATOES IN NORTHERN NIGERIA

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Summary The effect of change in atomiser height, spray droplet size and meteorological variables on the initial distribution and recovery of very low volume fungicide sprays on an unstaked tomato crop in Northern Nigeria was examined. A wettable powder formulation was applied in only 10-15 l/ha of water, but the initial cover of discrete droplets needs redistribution, partly by rain, but especially by dew for this type of spraying to be effective.

Résumé Les auteurs décrivent une evaluation physique qui examine les effets de modifications de la hauteur de l'atomiseur, de la dimension des gouttelettes de pulvérisation, et des variables météorologiques sur la distribution initiale et la récupération de pulverisations à très faible volume de fungicide sur une culture de tomates san tuteurs cans le Nord du Nigéria. Ils concluent qu'un traitment satisfaisant peut être obtenu avec une formulation de poudre mouillable appliquée dans seulement 10-15 l/ha d'eau; cependant, pour que ce type de pulvérisation soit efficace, la surface initialement couverte par les gouttelettes discrètes doit être étendue par une redistribution, en partie par la pluie, mais surtout par la rosée.

INTRODUCTION

Tomato paste is a major import commodity in West Africa and considerable research and development has taken place at the Institute for Agricultural Research, Samaru, since 1967 on the technical aspects of tomato production and on choice of a suitable area in which to establish a tomato paste industry (Quinn, 1973a). Two paste factories were established by late 1971. While one factory at Gombe has been built on a plantation with an excellent supply of irrigation water, the factory at Zaria relies on supplies of fruit from smallholders who cultivate tomatoes in addition to other market garden crops. The traditional method of watering these smallholdings is from rivers by means of a shadoof but the commercial scheme is providing diesel pumps to facilitate more efficient irrigation. The initial emphasis has been on a dry season crop which suffers little from foliar disease. Extension of production into the wet season to maintain supplies to the factory from June to early October is dependent on control of foliar diseases. In the wet season early blight (Alternari solani), Septoria leaf spot (Septora lycopersici) and Cladosporium fulvum can cause complete destruction of the foliage by the first harvest, impairing fruit quality and exposing fruit to skin damage

Fungicide spraying trials over four years (Quinn, 1973b) have clearly established that weekly or fortnightly applications during the rains more than doubled marketable yield compared with untreated crops, but the application of fungicide at high volume (1000-1500 l/ha) is difficult for the small farmer with limited resources (labour, water, equipment). Therefore very low volume (VLV) methods using battery-operated spinning disc sprayers were tested in 1973, when yields were not significantly different between captafol (Ortho Difolatan 4 flowable, 39% a.i.) fungicide diluted 1:1 in water and applied at 19.4 l/ha and high volume application (1121 l/ha) of mancozeb (Dithane M45) at 2 $kg.ha^{-1}$ or captafol (Ortho Difolatan 80W) at 3.4 kg/ha, (Quinn, 1974). The VLV treatments required about 2 man hours/ha to apply, compared with 50 man-hours/ha for high volume application.

Further trials were conducted in 1974 to compare three fungicides captafol (Ortho Difolatan 80W and Ortho Difolatan 4 Flowable), mancozeb (Dithane M45) and tetrachloroisophthalodinitrile (Daconil 2787) at high and very low volume rates. The physical assessments reported here were undertaken to provide information on the effect of several different application factors on the distribution of very low volume sprays as a guide to optimum spraying practice.

METHODS AND MATERIALS

The crop introduced in Nigeria is of the aroma paste type (cv. Harvester) with a determinate growth form. Plants are spaced 0.6 by 0.6 m on a shallow ridge about 5 cm deep and 0.91 m wide. The crop is generally unstaked and heavily mulched and should be trained onto the ridge to leave a narrow pathway at 1.21 m intervals between the double rows to permit access for spraying and harvesting. With its trailing habit the crop attains a maximum height of about 0.5 m and average height of about 0.25 m. Plants with moderately-open, late season foliage were used in the tests but as some leaves had already been shed much fruit was exposed.

Battery operated spinning disc sprayers (Micron ULVA 16 and ULVA 8) were used. The operator carried the sprayer on his leeward side with the spinning disc over the centre of the ridge at about 0.25 m above average crop height, i.e. about 0.5 m above the ground and commencing from the downwind edge of the plot, treated each successive row. Walking speed averaged 1.11 m/sec.

A site three ridges wide by 6 m long was selected within an area of about 0.5 ha. Nine short wooden posts were set up in the crop, three (numbered 1-3) in each of three rows (A-C), to carry cross-pieces (2.5 cm, square-section, 10 cm long) supported at 0.25 m height. Each of these cross-pieces carried a strip of kromokote sampling paper, 2 cm wide, wrapped around the four sides, identified as top (T), windward (W), bottom (B) and leeward (L). Sample papers were folded around and stapled to three leaves at sites adjacent to each of the nine posts. Papers were also placed on the ground at two positions under the canopy and one in the inter-row. Two tests compared different heights of carrying the spinning disc (T1,T2) and the effect of decrease in battery voltage on partial discharge was compared in two further tests (T3 and T4) (Table 1). Ortho Difolatan 80W, 340 g/l, containing approximately 0.4% lissamine scarlet dye as tracer was used in the tests. Flow rate was checked after each test. Spray was applied for about 10 m beyond each end of the test plots on each pass and for an additional three or four rows upwind of the sampled area. Meteorological data were recorded as described by Johnstone _et al_ (1974) (Table 2).

Table 1

Trials data

Test No.	Flow rate cm^3/min	Motor Characteristics (zero load) volts	rev/min	Height of spinning disc above ground m	Application rate l/ha	Volume recovery %
T1	40*	10.4	8100	0.5	4.8*	88(112)
T2	110	10.5	8400	1.0	13.5	22 (55)
T3	96	11.6	8400	0.5	11.7	17.5(33)
T4	98	5.4	3600	0.5	11.9	73 (110)

* Partial blockage suspected

Application by Micron ULVA 16 sprayer through red flow stem at 1.11 m/sec (1.21 m swath) along direction of rows, i.e. 220-40°M.

Application rates are based on the indicated flow rates and an average walking speed of 1.11 m/sec on a 1.23 m swath. Recoveries are estimated as a percentage from the data in Table 5; unbracketed figures represent overall means, bracketed figures are based on the row with the highest collection.

Table 2

Meteorological Data

Test	Date	Time	Temp °C	R.H. %	Direction °M	Wind $\bar{u}$ m/sec	ΔT °C
T1	28.9	0830	21.0	88	210	1.48	-0.20
T2	28.9	1018	24.5	78	270	1.88	-0.76
T3	30.9	0845	23.6	86	220	3.13	-0.70
T4	30.9	0912	24.0	86	210	2.75	-0.47

$\bar{u}$ is wind speed at 2 m above ground

ΔT is temperature difference between sensors at 4.5 and 1 m levels.

Counts of droplet densities (Number per unit area) were made on all targets and additionally the size distribution on the horizontal targets from the post samples in the first series of tests were ascertained. The spread factor for 34% Ortho Difolatan 80W + 0.4% lissamine scarlet dye in water on kromokote paper was determined in a separate calibration with reference to droplets collected on MgO slides.

RESULTS

Application at about 12 l/ha with a disc speed over 8000 rev/min provided between 76 and 181 droplets/cm^2 on upper leaves in trials 1-3 but at 3600 rev/min the deposit was reduced to 45 droplets/cm^2 (Table3) The shielding effect of upper foliage reduced droplet density levels in the lower part of the canopy by a factor of 0.7 in a wind of 1.5 m/sec (T1) and 0.2 in a wind of 3.1 m/sec (T3), but the average was not less than 27 droplets/cm^2 for T1-3 and 16 droplets/cm^2 for T4.

The reduction in density of droplets deposited was not as great as anticipated by the change in droplet size of 80 to 155 µm 'average' median diameter (Table 4).

Table 3

Comparison of droplet densities (mean no/cm^2) on upper leaves L (mean of three), on ground in shielded position under canopy U (mean of two) and in the inter-row I

	L	U	I
T1	181 (73-353)	126 (18-190)	210 (30-480)
T2	76 (5-177)	41 (1-140)	92 (1-151)
T3	125 (42-368)	27 (13-69)	116 (5-350)
T4	45 (17-85)	16 (7-28)	39 (16-120)

(Bracketed figures indicate range)

From droplet size and densities on the horizontal targets, the volume of spray recovered at different row positions was estimated (Table 5) and expressed as a percentage of the actual volume of spray applied (Table 1). In interpreting these results, allowance should be made for the crosswind in T2 and the full effect of incremental drift was not obtained because an inadequate number of rows were sprayed upwind. The best recovery estimate (Table 1) should be based on row C, i.e. 55% (c.f. 22% overall). An 88% recovery (T1) indicates that best recoveries can be expected when holding the spinning disc low under quite low wind conditions, preferably less than 3m/sec. More droplets were recovered in the light wind conditions of T1 as compared with T3 but relative humidity (Table 2) was also highest.

Table 4

Droplet size data μm

Test No.	By number 16%	50%	84%	By volume 16%	50%	84%	Average median dia. (N50% + V50%)/2
T1	34	54	79	62	86	113	70
T2	41	68	100	76	106	142	87
T3	33	58	92	71	100	133	79
T4	90	130	180	130	180	235	155

A high recovery (73%) was obtained with the large droplets in T4 compared with T3 (17.5%), but the spraymen were slightly off-course in spraying rows B and C of T3 (Table 5) so the estimate of 33% based on row A is a better guide.

The microscope counts on horizontal targets (Table 5) have given somewhat higher counts than the hand lens count performed on the same targets for T1 and T2 (Table 3) as the higher magnification permitted better resolution of the less distinct smaller droplets.

The poor distribution of spray on leeward and under-surfaces of targets (Table 6) indicates the necessity to consider repeating application under different wind conditions to achieve improved spray coverage.

DISCUSSION

Fungicides are normally applied at high volume to obtain thorough wetting of all susceptible foliage, but rain and dew play a considerable part in redistribution of deposited fungal spores (Hislop, 1969) and redistribute fungicide deposits (Hislop and Cox, 1970), provided that the latter are in a suitable form to permit some dislodgement and leaching. Transport may take place by drip and splash. Provided sufficient moisture is available to permit an adequate degree of redistribution, a much reduced volume of application in which the spray is deposited as a sufficiently good cover of discrete droplets might prove just as effective as high volume application. This must be the 'raison d'etre' of VLV fungicide application.

The physical assessment has shown that application at 12 l/ha at a volume median diameter of 100 μm does give a high density coverage of droplets on upward and windward facing surfaces. Although reduced motor voltage appears to give more uniform treatment, the droplet size is increased to 180 μm v.m.d. and there are fewer droplets/cm^2. If redistribution by dew is taking place, coverage in terms of very high no/cm^2 may not be a 'sine qua non' and decrease in battery voltage is clearly partly compensated for by the higher % recovery of the fewer larger droplets.

Table 5

Droplet density n (no/cm^2) and volume recovery V(l/ha) on horizontal targets supported at 0.25 m height (by microscope count)

Row	Post	T1 n	T1 V	T2 n	T2 V	T3 n	T3 V	T4 n	T4 V
A	1	173	2.8	7.5	0.35	75	1.4	83	12.0
	2	550	12.3	10.0	0.14	287	7.8	61	7.7
	3	335	6.2	6.5	0.05	118	2.6	53	5.6
Mean (A)			7.1		0.18		3.9		8.4
B	1	207	2.2	6.5	0.28	85	1.3	27	4.7
	2	215	3.5	68	2.7	35	0.9	27	3.8
	3	430	5.5	32	1.4	44	0.5	43	5.4
Mean (B)			3.7		1.5		0.9		5.0
C	1	126	1.1	197	6.3	18	0.1	81	14.5
	2	280	2.2	330	9.6	56	1.3	105	15.7
	3	192	2.2	178	5.6	166	2.3	53	9.2
Mean (C)			1.8		7.2		1.2		13.1
Mean (All)		281	4.2	93	2.9	98	2.1	59	8.7
Average Droplet diameter (μm)		66		84		81		142	

It appears important to keep the spinning disc low (within 0.25 m of the top of the crop), to spray every row and to avoid too much wind (i.e. greater than about 3 m/sec).

The concentrations of the formulations used at 12 l/ha (e.g. Ortho Difolatan 80W and Daconil 2787 - 34%, Dithane M45 - 29%) are high and it may be advantageous to reduce these slightly to avoid flow problems. In practice a reduction in concentration of about 25% coupled with a similar reduction in walking speed should be satisfactory. This would permit more careful application when necessary to step across the crop to maintain a crosswind line of application.

Quinn (private communication) has provided preliminary yield data (Table 7) for the 1974 wet season tomato fungicide spray trial in which the four formulations referred to in the Introduction were tested by VLV application and by HV application with knapsack sprayer and lance. While yields of VLV treatments are 10-15% lower than HV in the case of Dithane M45 and Daconil 2787, the Ortho Difolatan 80W VLV treatment has provided a 6% greater yield than the corresponding HV treat-

Table 6

Comparison of droplet densities (mean no/cm^2) on top (T), windward (W), bottom (B) and leeward (L) surfaces of targets folded around 2.5 cm square section blocks supported at 0.25 m height (by hand lens count), also ratio of deposition on windward and top surfaces (W/T) as percentage

	T	W	B	L	W/T
T1	150 (70-225)	22 (2-85)	0 (0)	0.3 (0-3)	14 (2.2-38)
T2	56 (4-185)	73 (1-360)	0 (0)	1 (0-9)	163 (17-710)
T3	87 (15-245)	161 (36-500)	0.3 (0-1)	7 (1-34)	318 (19-850)
T4	58 (26-104)	39 (15-73)	0 (0)	2 (0-4)	86 (25-214)

(Bracketed figures indicate range)

ment. The 1974 season was one of extended rains reflected in the low yield of the unsprayed control.

A tentative recommendation for disease control is therefore to use Ortho Difolatan 80W 250 g/l at 16 l/ha applied by ULVA 16 with red feed stem or Turbair X with H2 (No 51 drill) nozzle and 40 mesh filter, at 0.9 m/sec walking speed and to spray every ridge with the spinning disc about 0.25 m over the top of the crop. The practice of spraying early, before 0730 hrs, while dew remains on the crop, is considered to have made an important contribution to the success of the VLV applications in the 1974 season trial and should be noted in the recommendation.

Further work should compare the effect over a season of early morning applications while dew is present on the crop with a later application after dew has gone, using the recommended application. Application with large droplets provided by means of a sprayer with 8 batteries coupled in two parallel banks of four series-connected batteries, should also be investigated to determine whether adequate coverage can be obtained with a low current demand. This could appreciably prolong the working life of batteries and result in worthwhile economies in the cost of their replacement.

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Table 7

Dosage and yield data for the 1974 season trials

Treatment	Dosage kg/ha (a.i.) VLV*	HV**	Yield t/ha (marketable fruit) VLV	HV
Dithane M45	2.2	2.0	27.8	33.4
Ortho Difolatan 80W	3.7	3.4	37.8	35.8
Ortho Difolatan 4 flowable	1.6	3.6 - 7.1	35.6	-
Daconil 2787	3.7	1.7 - 3.4	27.0	30.3
		S.E.	± 5.4	
		C.V.	17%	
Unsprayed control			9.6	

* at 11 h/ha except Difolatan 4 flowable at 4 l/ha

** at 1121 l/ha except Ortho Difolatan 4 flowable at 946-1420 l/ha and Daconil 2787 at 1121-1680 l/ha.

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CONTROLLED DROPLET SIZE APPLICATION FOR RESIDUAL SPRAYING INSIDE DWELLINGS

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Summary A spinning cup sprayer is described. Operated at 10-12v DC, spray drops of 32-43 µm VMD are released in an 8 m/s airstream. With the airstream directed towards the walls and ceiling of an experimental hut and the nozzle held approximately 60 cm from these surfaces, the fall-out of droplets onto the floor is less than that produced by other sprayers which produce a wider range of droplet sizes. Fewer small droplets reduce inhalation hazards. 100% mortality of female *Aedes aegypti* caged for one hour on filter paper placed in the hut during spraying (target dose 0.25 ml/m^2) was achieved over a test period of 58 days with technical malathion and 71 days with technical NRDC 143.

INTRODUCTION

Most mosquito species which enter human dwellings to feed, rest on the walls, and thus interruption of malaria transmission has been successful by spraying residual insecticides inside dwellings to control the mosquitoes. The recommended method of application of such insecticides has been by means of a knapsack compression sprayer fitted with a lance and fan-type hydraulic nozzle, but the technique is laborious. Efforts have been made to reduce the time involved by ultra-low volume applications, and preliminary trials have been encouraging when a motorised knapsack mistblower and hand-held sprayer were used with target doses of 5 ml/room (Pant et al, 1974).

Studies of the distribution of spray deposits inside an experimental hut with a range of currently available sprayers indicate that both large (>70 µm diameter) and small (<30 µm diameter) droplets are liable to sediment on the floor. Also, as the small droplets present an inhalation hazard, the majority of sprayers tested were unsuitable owing to the production of a wide range of droplet sizes (Table 1). To obtain greater control of droplet size within the range of 30-50 µm VMD, the performance of a new spinning cup sprayer (Bals, 1975) was investigated.

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Table 1

Droplet size range produced by various sprayers inside an experimental room (from Boize & Matthews, 1975)

Sprayer	NMD μm	VMD μm	Droplet size range (16-84%)* μm
HCS 1-2 (Micro-Gen)	13	15	10 - 19
R11 (Fontan, Motan gmbh)	19	33	21 - 51
Mity Moe (Buffalo Turbine)	27	48	28 - 74
Tot (Turbair)	36	67	38 - 88
Sprite "	33	46	31 - 68
Scamp "	34	42	36 - 79

* Range of droplet sizes below and above which lie 16% of the spray volume.

Note: Glass slides coated with magnesium oxide were positioned on all surfaces in the room and droplet sizes were measured two hours after spraying. Measurements were made with a Fleming Particle-size Analyser (Matthews, 1975)

DESCRIPTION OF SPRAYER

A prototype sprayer, designed specifically for ULV controlled drop size applications, has been developed by Micron Sprayers Ltd. It consists of a 6 cm diameter plastic spinning cup, mounted on a metal frame, 27 cm in front of a 14 cm diameter guarded fan. Liquid is fed by gravity through a feed stem from a litre plastic bottle, fitted with an air-inlet valve. Separate 12v DC motors which drive the cup and fan were powered by a stabilised voltage transformer operated from the mains during the initial tests. In the field, a re-chargeable battery would be required. Investigations of spray deposits were carried out in an experimental room (2.4 m x 2.4m x 3.7m). The sprayer was switched on before entering the room and operated for 20 s within the room to create air turbulence, before inverting the unit to spray for 12 s. The fan and nozzle were left running for a further 20 s, with no liquid flow, to assist deposition of droplets remaining in the air.

PERFORMANCE OF SPRAYER

With a petroleum oil, viscosity 26 cs (at 21^{o}C), and flow rate of 0.43 ml/s, sprays of 30-50 μm VMD were obtained when the cup was operated at 10-12v (Table 2).

At lower voltages, median drop diameter, the range of droplet sizes increased, while the velocity of the airstream decreased resulting in low recoveries of spray on the walls and ceiling of the room (Table 3). Deposition of droplets on these surfaces was dependent on the relative position of the nozzle, thus increasing the deposit on the ceiling resulted in a lower deposition on the walls. If the nozzle were too far from the walls (generally further than 60 cm), droplets failed to impact and fell to the floor, therefore standing in the doorway to spray the room was ineffective (Table 3).

Table 2

Droplet size and air velocity with new sprayer operated at different voltages

Voltage v	Spinning cup revs/min.	NMD µm	VMD µm	Drop size range (16-84%) µm	Air velocity m/s At cup	Air velocity m/s 60 cm from cup
12	10,500	29	32	24-48	8	6
10	10,000	29	43	29-63	8	5
8	7,650	38	61	41-86	8	4
6	6,000	46	83	57-113	5	3

Note: oil viscosity was selected to lie within the operating range of viscosities of technical malathion (14cs at $40^{o}C$ and 30cs at $25^{o}C$).

Table 3

Volume of spray, proportion of total spray and drop sizes deposited on the walls and ceiling with the sprayer operated at different voltages

A. Sprayer held inside room

Voltage v	Walls Volume ml/m^2	Walls %	Walls drop size range µm	Ceiling Volume ml/m^2	Ceiling %	Ceiling drop size range µm
12	0.011-0.047	4-17	10-86	0.368-0.478	60-78	10-86
10	0.032-0.147	12-56	14-152	0.037-0.282	5-46	14-108
8	0.011-0.016	4-5	14-152	0.018	3	14-215
6	0.001-0.011	0.1-4	27-108	0.061-0.086	10-13	19-152

B. Sprayer held in doorway

Voltage v	Walls Volume ml/m^2	Walls %	Walls drop size range µm	Ceiling Volume ml/m^2	Ceiling %	Ceiling drop size range µm
12	0.006	2.2	8-86	0.018	3	10-80

BIOLOGICAL ASSESSMENTS

Technical malathion (95% a.i.), technical NRDC 143 (93% a.i.) (Elliot, et al 1973) and 10% NRDC 143 (using piperonyl butoxide as the diluent) were applied at target doses of 0.3 ml/m^2 to filter papers fixed to the ceiling, walls and floor within the experimental room. The filter papers were then placed in exposure tubes from a WHO Test Kit and batches of female mosquitoes resistant to DDT were subsequently caged in the tubes for one hourly periods at intervals after spraying. Mortalities were assessed at the end of the exposure period and 24 hours later.

With technical malathion, 100% mortality was achieved within 24 hours for nearly 40 days after spraying, provided over 100 drops/cm^2 were deposited (Table 4).

Table 4

Percentage mortality of Aedes aegypti adults on filter papers from different positions within an experimental room sprayed with technical malathion

Site		Lower wall	Ceiling	Upper wall	Floor
VMD µm		27	37	45	41
Drop density mean no/cm^2		3.6	82	111	721
	Day				
Mortality at end of one hour exposure period at various periods after spray application	4	-	100	100	100
	10	-	50.0	89.7	100
	23	-	0	14.3	80.5
	40	-	0	0	21.2
	58	-	-	0	17.1
	86	-	-	-	0
Mortality 24 hrs. later	4	15.0	100	100	100
	10	-	97.5	100	100
	23	-	100	100	100
	40	-	54.5	97.0	97.0
	58	-	39.5	97.6	100
	86	-	-	-	34.8

Note: Fan and nozzle were not operated for 20s following spray application in these tests. Bioassays at 27-30°C. 60% RH.

With NRDC 143, 100% knockdown occurred within 40 minutes throughout a 71 day test period with a deposit of 300-400 drops/cm^2. A few mosquitoes subsequently recovered, but mortality exceeded 87%. In practice, any mosquito which recovered would probably come into immediate contact with the spray deposit on other surfaces in the sprayed room. When NRDC 143 was diluted to 10% a.i., 100% mortality occurred over a 57 day test period.

DISCUSSION

Compared with existing sprayers, the new spinning disc provides a more uniform droplet size range when operated at 12v and deposits of 400 droplets/cm^2 (target dose of 0.3 ml/m^2) can be achieved on the walls and ceiling of a room.

Important features of this equipment are that with re-chargeable batteries, the machine is light and easily carried and without an internal combustion engine, problems of noise and exhaust fumes are eliminated. Although the proportion of very small droplets has been reduced, operators will require adequate protective clothing in relation to the pesticide applied. The deposit on the ceiling and upper walls of the room, where mosquitoes rest, has been improved and the amount of spray falling to the floor has been reduced. Using technical insecticide, mixing of insecticides is eliminated and the period required for spraying drastically reduced. Even with doses considerably lower than conventional applications (0.2g malathion/m^2 compared with 2g/m^2 with wettable powder formulations), effective control was achieved for over a month. Thus applications can be timed in relation to population densities rather than following a regular schedule. Although more frequent applications may be required during part of the year, less insecticide should be needed.

Encouraging results have been obtained with the new synthetic pyrethroid (NRDC 143) which has a greater persistence and quicker knockdown than malathion.

The equipment described offers a promising new technique for the application of pesticide in public health work, and further evaluation under field conditions is now required.

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