# Application Techniques as a Means of Optimising Pesticide Use

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## Abstract

In the medium and probably long-term development of crop husbandry it is fair to assume there will be a continuing dependence on chemical treatment for pest and disease control in food and fibre production. The acceptance of pesticide technology in both developing and developed agriculture throughout the world has played a significant role in the realisation of crop yield potential. Although advances made in crop production by research workers has proved important, the application equipment designer has been somewhat reticent in addressing the problems of accurate spray targeting. Equipment development has not kept pace with the development of pesticides. Early crop-protection chemicals proved extremely tolerant to abuse in application methods, but the early inexpensive formulations did provide the grower with a degree of repeatable biological control. Pesticide application has emerged as more of an art than a precise science; even today application can be described as a compromise attempting to satisfy the requirements of current formulations. Pesticides are sold as performance products, but occasional disappointing results can frequently be directly attributed to poor spraying. Considering how inefficiently many of today's agrochemicals are applied it is to their credit that they work so well.

## Introduction

Pesticide development, from original synthesis to market introduction, involves many scientific disciplines working to ensure the formulations are efficient, and will not adversely affect their users, bystanders, wildlife and the environment. However, only a fraction of the estimated development cost is apportioned to consider how the product will be handled and applied in the field.

**Table 1.**

**Estimated percentage cost to develop a pesticide.**

| Cost application | % Cost |
|---|---|
| 1. Synthesis and screening | 25 |
| 2. Field testing and preliminary field research | 25 |
| 3. Toxicology and enviromnetal studies | 20 |
| 4. Formulation and process | 20 |
| 5. Registration and patent | 10 |

Table 1 illustrates an approximate division of the cost involved in presenting a new compound to the grower. Excluding synthesis, screening and patent registration, the remaining costs can all be attributed to the effect of the material on the environment.

Appreciable research effort is currently being directed towards improving the application of pesticides. The research, by Chemical Companies, Research Institutes, and to a lesser extent Equipment Manufacturers, has two main objectives. Firstly, modifying and improving the application techniques already in use, and secondly, addressing new methods of pesticide application being evaluated in anticipation of commercial introduction.

Many of the new systems and techniques have contributions to make towards improved pesticide application but are unlikely to be accepted as panaceas. Conventional spraying systems, using hydraulic nozzles to effect liquid break-up, will remain the preferred application method for a long time. However, a survey undertaken by Tisler and Kohsiek in West Germany (9) back in 1973 evaluated 510 farm sprayers and clearly illustrated the lack of maintenance and adjustment they received (Fig.1)

A Ministry of Agriculture survey in the UK in 1976 (1) found on average a 9% coefficient of variation between the calibrated and actual field applications of 91 farm sprayers surveyed. The highest coefficient of variation reached a 44% overdose situation. The survey also served to highlight the inadequacy of the instruction books issued with application equipment, pointing out that only 57% of the spray operatives checked had received any training on pesticides and their application.

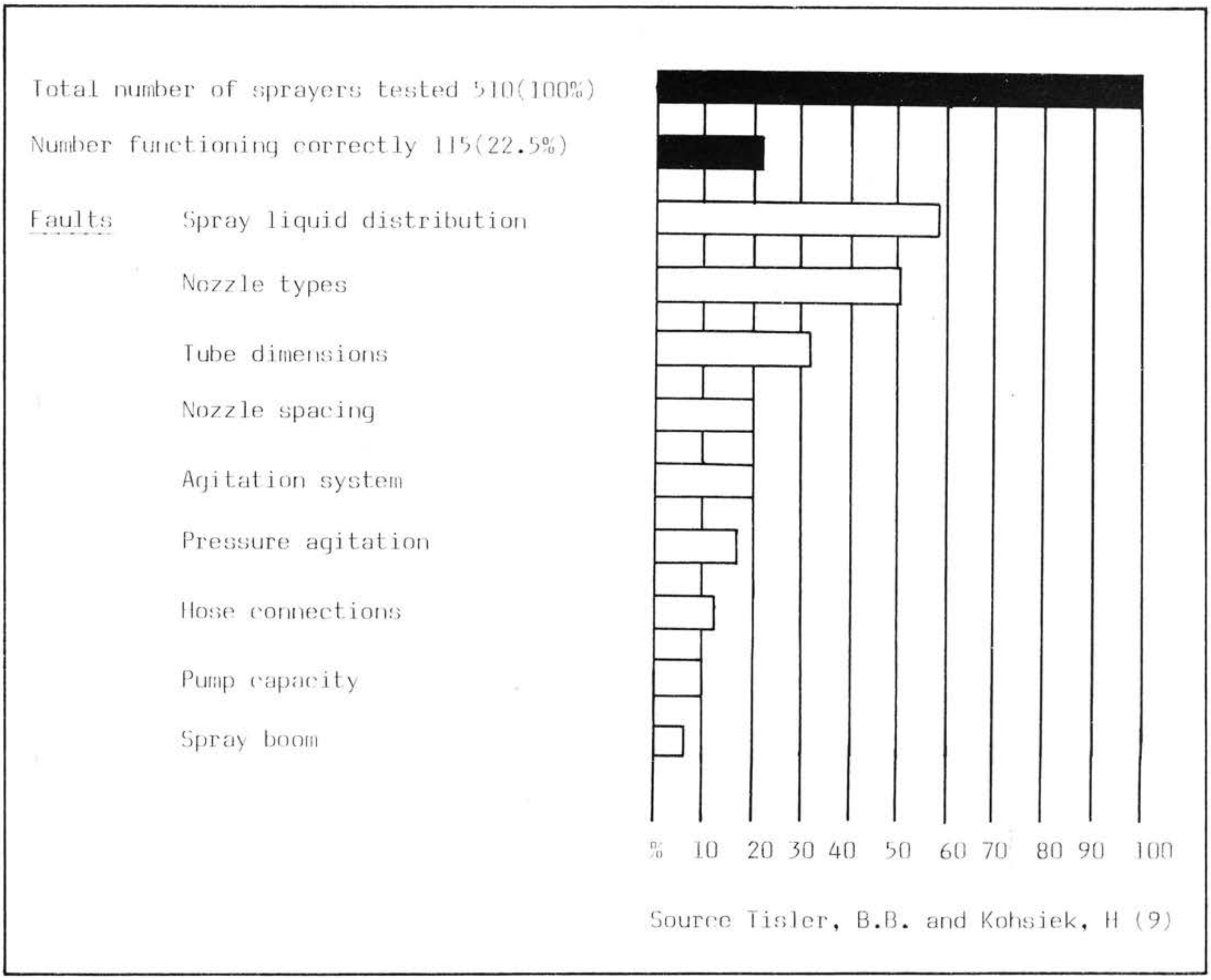


**Fig. 1** An analysis of faults found in a survey of spraying machinery on farms in West Germany.

Clearly application technology is advancing, but if the advance is to be beneficial it must be accompanied by an improved dissemination of information and the establishment of an ongoing dialogue between all interested parties.

Until fairly recently we have had only limited control over certain factors affecting application efficiency. However, methods of controlling drop size are being perfected while new methods of application are being included in the formulation design model.

It is the intention of this paper to discuss some of the parameters to be considered and modified in order to optimise pesticide use.

Firstly we must accept and realise that crop protection can only contribute to the full realisation of crop potential if the crop is well established in the first instance. Secondly the factors affecting chemical efficiency must be divided into those over which we exercise some control as opposed to those over which we have no control (Table 2).

**Table 2. Factors affecting pesticide efficiency.**

| Controllable | Uncontrollable |
|---|---|
| Droplet size | Crop morphology |
| Droplet trajectory | Extent of pest |
| Applied volume | Meteorological conditions |
| Formulation design | |
| Application timing | |

Obviously we have no control over the crop morphology or indeed the pest position within the crop canopy but an improved understanding of meteorogical conditions, particularly for aerial application, could be beneficial. The technology for controlling spray drop size is developing, as is the logistic approach to efficient spray timing, but the amount of inert diluent being used to transport and distribute the active material is still far from clearly understood. For example citrus is still being sprayed with 11 tonnes of water per hectare in Cyprus while in Indonesia the small farmer is treating one hectare of cotton with 1 litre of undiluted product, when applied by hand held ultra low volume applicator.

## Methods Of Liquid Break-Up

### 1. Hydraulic Nozzles

The nozzle is the most important part of the sprayer, yet usually the most neglected. During use, chemical abrasion and erosion will gradually increase the nozzle size, and correspondingly the nominal output. Table 3 lists the approximate coefficients of wear for materials used in nozzle production, based on the wear rate for brass being 1.

**Table 3. Nozzle wear.**

| | Coefficient wear rates |
|---|---|
| Brass | 1 |
| PVC | 3 |
| Stainless steel | 14 |
| Sintered alumina | 250 |

Using hydraulic nozzles is still the most common way of producing a spray. Nozzle tips are machined from brass or stainless steel, extruded in plastic or fitted with cintered alumina orifice inserts. The tendency is to move away from brass towards reinforced polypropylene which offers good resistance to erosion and proves less expensive. Complete nozzle bodies are now being moulded which incorporate the diaphragm check valves, and offer a quick release colour-coded tip holder for rapid changing.

Tips have been developed to produce coarse droplets at low operating pressure (100 kPa) applying between 50 and 100 litres/ha. In the case of the cone nozzle for insecticide and fungicide application, an additional swirl chamber and outlet orifice has been added to produce large droplets (Delevan 'Raindrop' nozzle) in an attempt to reduce drift.

Although versatile, the hydraulic nozzle produces a very wide droplet spectrum which may not provide adequate cover for specific targets. Work in the UK applying a wild oat herbicide to winter wheat suggests as much as 75% of the spray did not impact on the target.

### 2. Centrifugal Energy Nozzles (Spinning Discs)

For the small farmer in the tropics where water may be scarce, the introduction of the spinning disc to apply an undiluted formulation to cotton has enabled one hectare to be treated in 40 minutes applying 3 litres/ha. This development has necessitated the design of a specific unltra-low-volume formulation (ULV) which may contain up to 50% non-volatile ingredients.

The spinning disc gives a degree of control of droplet size, where size is inversely proportional to disc speed. Early hand-carried units were fitted with twin disc heads which attempted to displace surrounding air while spraying. This design is being slowly supeseded by disc units fitted with single cupped discs which require less power to operate.

In many countries the reliability of locally manufactured batteries, required to drive the spinning disc head motors, has proved unsatisfactory, while the adaption of solar energy to power the motor has proved extremely expensive.

Hand held ULV (already defined above) spraying utilises the wind to transport, distribute and assist droplet impaction, where wind speeds of between 7 and 14 kph are required, blowing at right angles to the direction of the treated rows. Meteorological studies in some countries have been used to determine the direction crop rows have to be planted to facilitate drift spraying (8).

Early work, using spinning disc atomisers for vector control, utilised small droplets with poor sedimentation characteristics. Discs, spinning at approximately 8500 rpm, produced small droplets (70 micrometers volume median diameter) for insecticide application but herbicide treatments posed different considerations.

The first disc herbicide applicators were hand-carried units applying between 10 and 14 litres/ha. The atomiser was governed at approximately 2500 rpm, producing 250 u micrometers vmd droplets. A 250 micrometer droplet possesses enough kinetic energy to give a predictable sedimentation rate when spraying a 1.2 m swath. However, the 8 cm diameter disc could handle only a limited liquid flow before true rotary atomisation ceased.

Development of a tractor-mounted unit used multiple stacked disc heads to increase the application rate. Discs were partly shrouded to produce a spray pattern similar to that of a flat fan nozzle.

The second generation of CDA (Controlled Droplet Applicators) are being fitted with larger single cupped disc units, while the Tecnoma (France) machine uses vertical discs which are shrouded to produce a 110 degree included angle spray pattern.

This interesting innovation directs the spray droplets into the crop canopy where targets may be more difficult to contact. Early field experience with tractor-mounted spinning discs generally gave poorer weed control when compared with treatments applied by hydraulic nozzles. (4)

### 3. Electrodynamic Spraying

Pierre Hampe, A French engineer, demonstrated an electrostatic crop dusting machine way back in 1940, but the machine proved unreliable. However, Coffee (3) simplified and improved electrostatic dust application and directed his efforts towards charging and atomising liquids.

Considerable research into electrostatic crop spraying is currently being undertaken, and Table 4 attempts to summarise todays position. Although the table does not claim to be exhaustive, it is significant to note that the equipment manufacturers do not feature dominantly in the sponsor and development list.

Early field work so far has been completed with cypermethrin, a contact insecticide, applied to cotton where a good spray distribution is essential.

Applications to crops grown in rows have proved successful at 0.5 1/ha but treatments applied to broadcast field crops have proved disappointing. The fact that charged droplets do not coalesce during flight or on impact, and that they give abaxial cover, makes electrostatic crop spraying an interesting innovation, and an efficient controlled droplet generator. Charged droplets, however, do not readily penetrate dense crop canopies and work is in hand to make the droplets air-assisted to improve penetration.

## Conventional Sprayer Design

The development of the conventional boom and nozzle sprayer as we know it today has been arrived at fortuitously rather than by an understanding of crop protection and the physics of spray-cloud behaviour. In order to increase the actual field spray time, machines have increased in size, while some sprayers are now manufactured as self-propelled units. Certain machines on view at this year's «Sprayers in Action» in the UK were fitted with 3500 litre tanks and 40 m booms. As long as we associate pesticide application with high applied volumes there will be a demand for high-capacity equipment, but if we can obtain biological efficiency from low-volume application we do not have to associate spraying with the tractor, and its accompanying weight factor.

**Table 4. Electrostacid spraying : estimated status, July 1982.**

| Sponsor | Machine type | Advantages | Current position |
|---|---|---|---|
| 1. Rothamstead NRDC-ARC (APE-80) | Spinning disc, hand-held and tractor mounted. Spray charged on leaving disc. | Handle aqueous based solutions, kit form to be fitted to existing sprayers | NRDC support withdrawn Manufacturers investigating Commercial production |
| 2. Laws/Device | Bi-fluid nozzle-spray charged on leaving nozzle, then fan assisted. High energy requirement apparently overcome | Apply aqueous based solutions. Improved crop canopy penetration. | FMC withdrawn support 81. Following disappointing field results[1]. |
| 3. ICI electrodyn | Hand-held device introduced in 3 countries in 1981. Tractor mounted machine and air blast units being developed. System product linked. | Low energy requirements. No working parts. Sealed system using special formulation. | Commercial introd. Hand-held devices taking place. Limited formulation range available. |
| 4. Dekinkellder (Marweld) | Air-carried spray charged when leaving nozzle. Marweld conversion on Kinkellder fan sprayer for orchard/top fruit work. | Handle aqueous based solutions. Improved crop canopy penetration for top fruits. | Commercially available in USA and Canada. |
| 5. Weed Research Organization (ARC) | Research machine for herbicides. Pulse jet liquid break-up. | Can handle all formulations. Droplets enter crop at high velocity. | Looking for commercial holding. |
| 6. National Institute of Agricultural Engineering (ARC) | Charged sprays from conventional nozzles, plus research work on other linear nozzle types. | Non-formulation selective. Devices could be fitted to existing spray equipment. | Research programme with manufacturers interested in production licence. |

1. A major US manufacturer is about to start production.

The main advances made with conventional spray equipment are due to improved construction materials and better boom design and suspension systems, with the major considerations aimed at improving the overall logisticis of spraying.

## Electronic Monitor And Control System

As applied volumes are reduced and application speeds increase, the demand for accurate control systems arises, an important consideration since a sprayer's performance cannot be assessed at the time of use.

The development of economically priced reliable electronic components has led to the introduction of solid-state technology to pesticide application equipment. (2)

The relationship between a tractor's forward speed and the applied volume can now be monitored and adjusted. Tractor speed, which varies with the shear between the driven wheel tread and the soil surface, can now be accurately assessed by a radar system servicing a console which integrates the effective working spray pressure, and compares the actual applied volume with the theoretically selected volume. Providing a spray operator with electronic monitoring and control equipment will be beneficial only if the operator is capable of interpreting the information supplied, and acting accordingly.

## Lightweight Vehicles (LGPV)

In Europe the increased use of autumn-applied pre-emergence weedkillers has increased the demand for high speed, low ground pressure vehicles to apply granular material and pesticides.

The all-terrain vehicle has been adapted from dual-purpose military use, but unfortunately has not considered pesticide application as a first consideration. Although there is no market leader, in the UK 30 companies are offering vehicles exerting less than 0.28 kg/cm² onto the soil, which militates against the use of heavy equipment. (5)

Rather than invest in a specialist spray vehicle, the UK farmer has recently gained access to the Goodyear Terra-Tyre which can be fitted to rims designed for the modern tractor. A 40 kW (55 HP) tractor can be quickly modified, at a cost of £4000 sterling, into a low ground pressure vehicle.

If reduced volume application proves biologically acceptable under field assessment the interest in tool-bar frames, and lightweight vehicles will obviously increase.

## Aerial Spraying

Although aircraft performance and safety have improved considerably attention to spray recovery from aerial application is still neglected.

It has been estimated that aerial spraying is seven or eight times more energy efficient than ground spraying, but unlike terrestrial application, where uniform coverage is relatively easy, aerial application presents far more complex problems.

The majority of aircraft are fitted with hydraulic nozzles which, although producing a wide droplet spec-

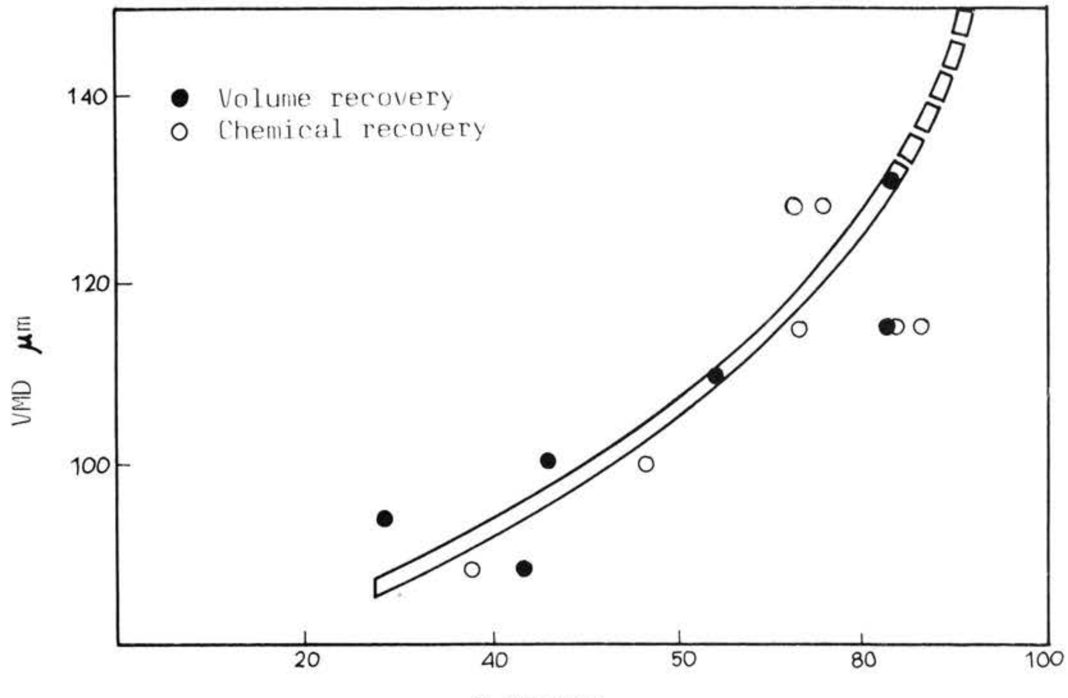


**Fig. 2.** The percentage recovery on cotton leaves related to VMD

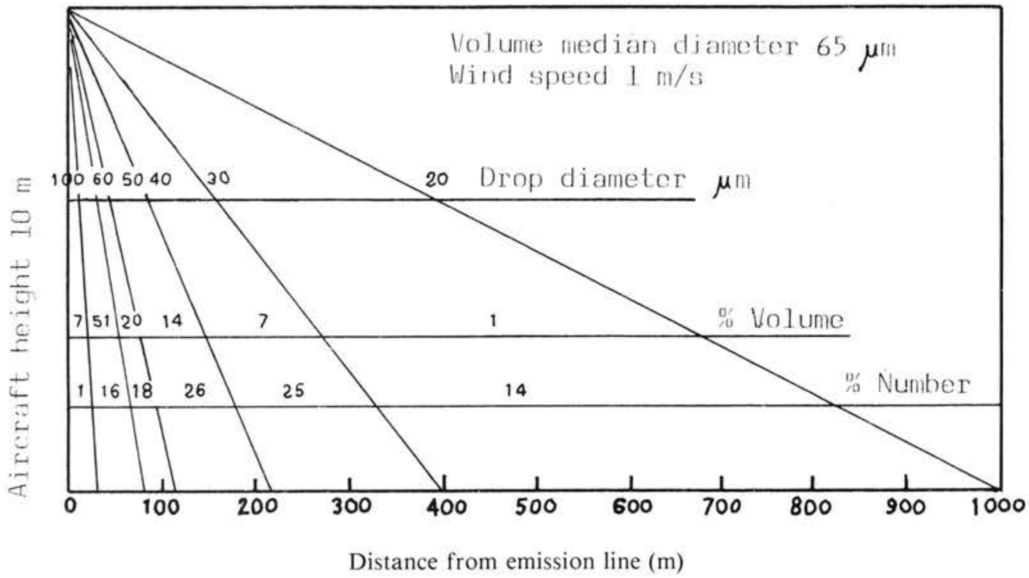


**Fig. 3.** Theoretical distribution of spray droplets released at a height of 10m and falling at their terminal velocity under stable meteorological conditions.

trum, are used extensively for conventional application (20 l/ha). Ultra-low-volume application (ULV), where the product is applied undiluted at rates below 5 l/ha, requires an atomiser capable of restricting the droplet spectrum. The Micronair Au 3000 is still the favoured rotary atomiser although its use increases wing drag and fuel use. The recently introduced Mini-Micronair is less expensive to purchase but still offers droplet size control.

Studies of droplet size in relation to the target have been numerous, and from our own work in the Sudan Fig. 2 indicates the increase in spray recovery when the droplet size was increased from 80 vmd $\mu$m to 140 $\mu$m vmd, when applying a systemic insecticide.

Aircraft application is invariably associated with drift, but by utilising the meteorological factors and control-

**Table 5. Use of ag-aviation in selected countries with aerial applications in agriculture.**

| Country | Number of aircrafts | Area treated by ag-aviation thousand ha | Total area of crops and pastures, thousand ha | % total area treated by ag-aviation |
|---|---|---|---|---|
| Argentina | 538 | 5000 | 172168 | 2.9 |
| Australia | 247 | - | - | |
| Columbia | 208 | 2563 | 20195 | 12.7 |
| Cuba | 148 | 5152 | 6000 | 85.9 |
| Czechoslovakia | 200 | 2994 | 10585 | 28.3 |
| Hungary | 150 | 4627 | 13726.5 | 33.7 |
| German Democratic Republic | 185 | 3860 | 6200 | 62.3 |
| Japan | 179 | 2544 | 6593 | 38.6 |
| Mexico | 759 | 2750 | 102965 | 2.7 |
| New Zealand | 451 | 5854 | 13570 | 43.1 |
| Poland | 274 | 2943 | 15516 | 19.0 |
| Spain | 161 | 1143 | 36396 | 3.1 |
| Uruguay | 40 | 1100 | 10363 | 10.6 |
| United Kingdom | 143 | 584 | - | - |
| United States | 8649 | 72800 | 435400 | 16.7 |
| USSR | 10000 | 95648 | 609340 | 15.7 |
| Yuguslavia | 46 | 873 | 12916 | 6.8 |

**Source :** Data collected by Instytut Lotnictw (Aviation Institute), Warsaw.

ling droplet size, drift can be kept to a minimum, but will never be totally eliminated.

Fig. 3 shows the theoretical distribution of spray drops released from a height of 10 m under stable meteorological conditions, clearly illustrating the effect of drop size on terminal velocity. However, as the wind velocity increases, so the turbulent eddies increase at ground level, which can increase the recovery from ULV spraying.

The use of aircraft, both fixed and rotary wing, for pesticide application is actually increasing although in certain areas the aircraft population is falling; the current estimation gives a world spray aircraft population of 22,000 treating 315 million hectares per year (6). Table 5 illustrates selected countries, listing the spray aircraft population and the areas treated.

## Over Crop Application

### a) Wicks and Wipers

Post-emergence applications have been developed to apply non-selective weedkillers to weeds growing above crop level. Rope wicks or absorbent rollers are impregnated with herbicide and carried above the crop. Chemical waste is reduced, and the drift hazard eliminted by this method of application.

The herbicide is contained in a PVC or stainless steel pipe which feeds the chemical by capillary action to overlapping sections of braided nylon rope. The rope must be kept moist but the liquid flow must not be excessive.

The wick is slow in heavy weed growth where control is usually inferior to that achieved by the wiper, which contra rotates to the direction of travel and can work at higher speeds giving a better coverage.

### b) Recirculating Sprayers

Similar to wick application the recirculating sprayer treats weeds above the crop canopy. Solid jet streams spray into traps which recover between 70 and 90% of the spray volume not intercepted. With prolonged use detritus accumulates in the spray traps which can block nozzles and reduce herbicidal activity.

Research workers in the UK have also used high-voltage charges to scorch weeds growing above a crop but safety considerations have limited further development.

## Seed Dressing

Seed dressing and coating must be an area where improved chemical distribution, coupled with formulation development could contribute substantially to time and energy savings.

Seed dressing in many countries is carried out by the seed merchant, who, in the UK, is estimated to be treating up to 95% of the cereal seed with a fungicide. Powder treatments are still the most common in the UK although powder does not adhere readily to the grain, leaving treated seed deficient in chemical protection. Surveys of commercially treated seed in the UK showed 5 out of 33 samples achieved an average loading greater than 50% of the target dose, with one of these five samples retaining 70% of the target dose. Liquid formulations gave better seed loading than powder. (7)

Today's seed dressing machine must be capable of applying all types of formulation to seeds of different shapes. Application rates may vary between 1 and 20 ml of product per kilo of grain, where the treatment has to be evenly distributed over approximately 20,000 grains per kg. Early volatile formulations carried on working while the grain was in store but today's small dose rates require accurate application.

## Formulation

Formulation design and packing is now seen as a major contributor towards operator safety. Toxic material can be handled by sealed systems, while in some countries chemical has been packed in water-soluble sachets which dissolve in the spray tank when agitation is started. These systems avoid the possible hazard of dermal contamination when mixing and pouring the formulation.

Water-dispersible granules have recently been introduced in Europe where the formulation is put directly into the spray tank, thus avoiding pre-mixing.

'Tank-mixing' has become so important in the UK that chemical manufacturers have been obliged to produce label recommendations in order to reduce the ad-hoc mixtures concocted by the farmers. Mixtures including as many as seven ingredients have been used by farmers in the UK but the accompanying problems of settling out have reduced the practice, and encouraged the farmer to pay more attention to label recommendations.

Granule application equipment has been used to apply slow release pesticides but hollow fibres and laminated strips for phermomones require special application equipment.

## Chemigation

Chemigation refers to the technique of applying pesticide through an irrigation system.

Applying chemical treatments in the irrigation water has been shown to be practicable when using gravity flow irrigation, centre pivot sprinklers, side roil systems, and rain-guns.

However, not all formulations are suited for chemigation; for example, some herbicides may be diluted too much to prove effective, while others which are readily absorbed by soil particles, may not be incorporated deeply enough. Capital outlay for chemigation is low as only a metering device is really required.

## Operator Safety

During Pesticide application, the main hazard to the operator is dermal exposure to the spray. With ULV application, because of the small size of the spray droplets, there is the additional hazard of inhalation. However, handling formulations and transfer and mixing operations during which the operator is potentially exposed to concentrated products often present the greatest hazard.

Safety concerns the precautions that need to be taken to reduce exposure to levels that will not adversely affect the health of the operator. Precautions are largely a matter of common sense, for example, avoiding exposure of the spray, taking care when preparing spray dilutions, paying attention to personal hygiene and minimising spray drift. In some instances, depending on the toxicity of the pesticide involved and type of application, special precautions involving the use of protective clothing or equipment may be needed. Legislation in countries which have pesticide registration schemes often requires that certain precautions are observed, but in any event, the authorities in such countries will need to review label directions and to satisfy themselves that the pesticide can be handled and applied safely.

The subjects of operator safety and use of protective clothing are far from new, but unfortunately often neglected. Protective clothing and equipment is often cumbersome and uncomfortable to wear, particularly in hot climates. It is vital therefore that precautions are realistic, acceptable to the operator and practical.

## General Development

The acceptance of reduced volume pesticide application under less than ideal conditions has led to a variety of unconventional vehicles being assessed as suitable for pesticide application. The hovercraft has been presented as a suitable carrying vehicle but the lack of the correct spraying equipment coupled with the hovercraft's poor field performance has led to a decline in agricultural interest.

Spray equipment mounted on a high clearance gantry supported by wheels at each end proved a versatile application vehicle avoiding boom bounce and yawl. Large flat areas would be required to fully utilise this approach, but the concept is interesting.

The development of the control line kite has renewed interest in the kite as a vehicle to carry ULV spray heads. The lack of steady breeze conditions close to ground level suggests that the kite is better suited to bird scaring where it has found a ready market.

The remotely piloted aircraft has been assessed as a spray vehicle working at ULV rates, but payload limitations, the difficulty of precise control and vision horizon, plus the high depreciation costs have militated against further development. The powered hand glider (Microlite) offers an interesting spray vehicle but its use in the UK has been restricted by the Civil Aviation Authorities as there are no ULV formulation registered for aerial application which the Microlite could utilise.

The powered hand glider has been used successfully to apply insecticide to afforested areas in France and is worthy of evaluation when working over field crops, where air turbulence could prove difficult.

This modest discussion paper has briefly reviewed the current developments in pesticide application, but does not claim to cover all of the work in hand.

In a world where 350 million families are involved in agricultural production, over 60% still rely on wooden hoes and ploughs to cultivate and weed their crops. For many peasant farmers the introduction of crop protection chemicals applied by knapsack sprayer has meant the difference between adequate food and starvation. In order to feed the increasing world population, food production between 1980 and the year 2000 must increase by 112%.

A comprehensive range of crop-protection chemicals is available but if recent changes and developments are to prove beneficial we must accurately target our spray treatments.

A continued effort by Chemical Companies, Application Equipment Manufacturers and Researchers, together with improved training, will ensure the optimum utilisation of today's agrochemicals, when used for food and fibre production.

## الملخص

ان تطور انتاج المحاصيل في المستقبل المنظور وربما البعيد سيبقى معتمدا على المعالجة الكيماوية لمكافحة الامراض والحشرات والاعشاب ان قبول تكنولوجيا المبيدات في كل من البلدان المتقدمة والنامية زراعياً في كل انحاء العالم لعب دورا اساسيا في تحسين الانتاج. وبالرغم من ان التقدم الذي احرزه الباحثين في زيادة الانتاج الزراعي كان مهما، الا انه كان هناك تقصير بالنسبة لتصميم اجهزة رش المبيدات التي تتميز بدقة توزيع المبيد على منطقة الهدف، وكذلك لم يواكب التقدم في صنع ادوات الرش التقدم الذي حصل في تطوير المبيدات الجديدة. ان المبيدات الكيماوية التي كانت تستعمل منذ مدة لم تتأثر كثيرا عند عدم استعمال الاجهزة المناسبة، ونسبة لتدني اسعارها كان من الممكن ان يحصل المزارع على مكافحة جيدة. ولقد اظهر ان استعمال المبيدات هو فن اكثر من انه علم دقيق. وفي يومنا هذا يمكن اعتبار طرق رش المبيدات هو حل اقتضته متطلبات المبيدات الحديثة. ومع ان كثير من المبيدات اليوم تباع على انها مركبات فعالة، الا ان النتائج الغير مرضية التي تحصل عليها في كثير من الاحيان تكون نتيجة الرش الغير جيد. لذلك كان استعمال طرق الرش المناسبة هي الكفيلة للوصول الى افضل النتائج التي يمكن ان تعطيها المبيدات.


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