cessful. Some hardier species do not need mist. The "tanks" of funnel shaped bromeliads must be filled with water.

SUMMARY

The large number of bromeliad species (over 1400 from 60 genera) and their wide growing adaption to various climatic areas and growing situations makes it very difficult to give an authoritative account on the culture and propagation of these plants. To add to this list of species are the many hundreds of hybrids that have been raised. This is only an introduction to this wide and interesting group of plants. Bromeliads are easily cared for and should be grown more by the horticultural industry.

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NEW DEVELOPMENTS IN SPRAY APPLICATION TECHNOLOGY

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ABSTRACT. The basic principles of controlled droplet application (CDA) spraying and electrostatic spraying are reviewed, with particular reference to how these techniques can increase the efficiency of spray application

The introduction of these techniques and their acceptance in New Zealand is discussed

1. INTRODUCTION

The sole reason for applying pesticides (including herbicides) is to protect crop yield potential. To do this, one must transmit an appropriate quantity of active ingredient to a population of specific targets such that the organism or weed endangering the yield may collect it and be killed.

Whilst present spray application techniques may, on the whole, be effective they are inefficient. New developments in spray application techniques are directed at improving this efficiency, whilst maintaining or improving effectiveness.

This paper reviews two of the most important of these new techniques; controlled droplet application (CDA) spraying and electrostatic spraying. There is, however, one other development which, although technically cannot be described as spray application, is important. Much of the inefficiency in present spray application techniques can be attributed to drift of spray droplets out of the target area. The development of herbicides such as Glyphosate has given rise to equipment which applies the chemical directly to the target plant — there is no spray drift because there are no spray droplets. Instead the chemical is wiped onto the plant — complete coverage is not necessary because the chemical is translocated throughout the plant. The example is interesting because the application technique and appropriate equipment followed on from the development of the chemical. It also illustrates the importance of chemical mode of action and formulation in relation to the equipment being used to apply the chemical.

One result of the "weed-wiping" technique and of CDA and electrostatic spraying is greatly reduced application rates — both total volume and chemical rate. With CDA spraying, the achievement of reduced rates involves the use of smaller sized droplets to maintain coverage. This conflicts with the need to control drift and has, to some extent, led to the next step — the need to give a definite guidance to the spray droplets in their travel from nozzle to target. Electrostatic charging of the spray droplets provides such guidance.

What follows is a review of the important concepts in CDA spraying and the developments taking place in the electrostatic charging of spray droplets. The introduction of these techniques in New Zealand is also discussed.

2. CONTROLLED DROPLET APPLICATION (CDA)

A logical extension of the ULV (Ultra Low Volume) concept, the objective of which is to apply the minimum volume compatible with achieving economic control, is CDA spraying. CDA emphasises not only the importance of applying the correct size of droplets for a given target, but also the uniformity of droplet size, to optimise use of the minimum volume and dose to achieve effective control.

There are four important aspects of CDA spraying:

2.1 **The Target.** Precise definition of the target is vital if pesticides are to be used more efficiently. In horticulture for example, the target for insecticides and fungicides has been regarded as the crop itself, with no regard for where the pest might be in that crop. Also, insecticide applications may be more effective if applied in the evening, when conditions are more stable, and many pest species are more active. The importance of understanding the target was perhaps best illustrated by Himel and Moore (4). By using the fluorescent particle droplet sizing technique, he showed that droplets collected (impacting on) insects were never bigger than 50 μm (1000 μm = 1 mm). In contrast, over 99 percent of the spray volume commonly used was in droplets bigger than this.

2.2 **Droplet Size.** From work by Himel and others, it is clear that maximum control of a pest, with minimum use of chemical and minimum contamination of the environment, can be achieved when droplets of optimum size are used. If droplets much larger than the optimum are used, the amount of chemical wasted rapidly increases — a droplet of 200 μm has a volume 1 000 x greater than a 20 μm droplet.

Optimum droplet size will vary with different targets. It is possible to choose droplets small enough to follow the airflow around an obstacle such as a stem, yet large enough to impact on insects resting on it.

Larger droplets ($>$ 250 μm) are needed when settling of droplets onto horizontal surfaces with minimum downwind drift is required. Drift is accentuated when sprays are used under hot, dry convective conditions, because of the rapid decrease in droplet size due to evaporation. The smaller the initial droplet size, the more rapid the further decrease in size from evaporation, so with droplets smaller than 100 μm, oil based formulations should be used.

CDA spraying also implies a limited droplet size range. The volume median diameter (VMD) is defined as the drop diameter having half the volume of the spray in smaller drops, and half the volume in larger drops. The number median diameter (NMD) is defined as the drop diameter which divides the total number of drops into two equal groups, half (by number) the drops being smaller than then NMD, and half larger.

If all the droplets in the spray volume were exactly the same size, then:

$$\text{VMD} = \text{NMD},$$
$$\text{or VMD/NMD} = 1.$$

The closer the VMD/NMD ratio is to one, the more uniform the droplet size range. Ideally, for CDA the VMD/NMD ratio should be less than 1.4 (when sampling droplets on magnesium oxide coated slides) (10).

2.3 **Droplet Density.** The required number of drops/unit area will vary depending on the mobility of the pest, the characteristic of the active ingredient, and redistribution of the active ingredient over the target.

The theoretical droplet density obtained if uniform sized droplets were distributed evenly over a flat surface is given in Table 1.

Table 1: Theoretical droplet density when spraying 1 litre evenly over 1 Ha

Droplet Diameter (μm)	No of Droplets/cm²
10	19,099
20	2,387
50	153
100	19
200	2 4
400	0 298

2.4 **Spray Concentration.** The basic measurement of acute toxicity of a chemical is the Lethal Dose, or LD. The dosage, in mg of active ingredient per kg of body weight of the test organism (mg/kg) which kills 50 percent of those organisms is described as the LD_{50} If the LD_{50} contained in a single droplet can be determined, the concentration of the spray required in controlled droplet application can also be calculated. When a high proportion of the spray reaches the target, a reduction in the total dosage compared with recommended dosages per unit of ground area may be possible. The application of 1 kg/ha is equivalent to 100 nanograms/mm^2 (1 nanogram = 10^{-9} gm). The lethal dose for some insects may be as little as 1.0 nanogram of certain insecticides, so in some circumstances, there could be 100 times overkill.

3. THE PRODUCTION OF NARROW DROPLET SPECTRA

One of the most promising methods of controlling size of droplets within fairly narrow limits is by using centrifugal force and various spinning discs, cups and cages have been designed. With spinning discs, the three most important parameters (apart from disc shape), are:

(i) Disc diameter
(ii) Disc rotational speed
(iii) Flow rate onto disc.

Liquid is fed near the centre of a rotating surface so that centrifugal force spreads the liquid to the edge at or near which the droplets are formed. Three methods of droplet formation, for increasing liquid flow rates, have been defined.

These are:

(i) Single droplets leave directly from the nozzle at low flow rates.
(ii) Liquid leaves the nozzle in the form of long curved threads or ligaments which break down into droplets.
(iii) At still greater flow rates, liquid leaves the nozzle in the form of a sheet which disintegrates — fragments of the sheet break up into ligaments and subsequently droplets. Sheet formation occurs when the

rotating surface is flooded; droplet formation is similar to that of hydraulic nozzles, and a wide range of droplet sizes is produced.

For VMD/NMD ratios of 1.4 or less, the total liquid flow rate onto a rotating surface should be such that droplet formation is by methods (i) or (ii) above. If larger flow rates are required for a given disc speed and diameter, a stack of discs can be used.

The other main type of rotary atomiser is the spinning cage. With this, the liquid is introduced through a central hollow spindle, then via a deflector, onto a rotating gauze, which completes the final atomization. The speed of rotation determines droplet size. The droplet spectra produced by rotating cage atomisers is not as narrow as that produced by spinning discs, with VMD/NMD ratios typically around 3.0.

As the name implies, CDA spraying emphasises the importance of the individual spray droplet. CDA sprayers are machines which exhibit a degree of control over both the droplet size and size range produced. Some equipment, notably the hand held spinning disc applicators, are intended to be used as drift sprayers. That is, use is made of prevailing winds to carry the pesticide (normally a fungicide or insecticide) to the target. This is a very important concept, as this type of sprayer produces a narrow size range of small droplets ($<100\mu m$) and if the correct procedure is not followed in their use, results will be poor. It is the promise of more positive control of the spray droplets in directing them to the target which makes electrostatic spraying attractive.

4. ELECTROSTATIC SPRAYING

As droplet size becomes smaller, deposition of these droplets by inertial or gravitational forces alone becomes more uncertain and they are prone to air borne drift. Droplet charging and electrostatic deposition technology has been proposed and investigated by a number of workers as a possible means of reducing drift and improving depostion (2,8). Figure 1 illustrates the effect of electrical propulsion.

The particles to be deposited are given a unipolar charge, q, as they leave the spray nozzle. The charge acquired by the particles is of the same polarity as the electrode, so that they are then electrically propelled away from it immediately they acquire charge. The force of propulsion, F_e, on each particle is qE, where E is the electric field strength. In some cases, the electrode may form an integral part of the spray nozzle.

Both electrostatic considerations, and efficient liquid use for adequate target coverage at low application rates dictates

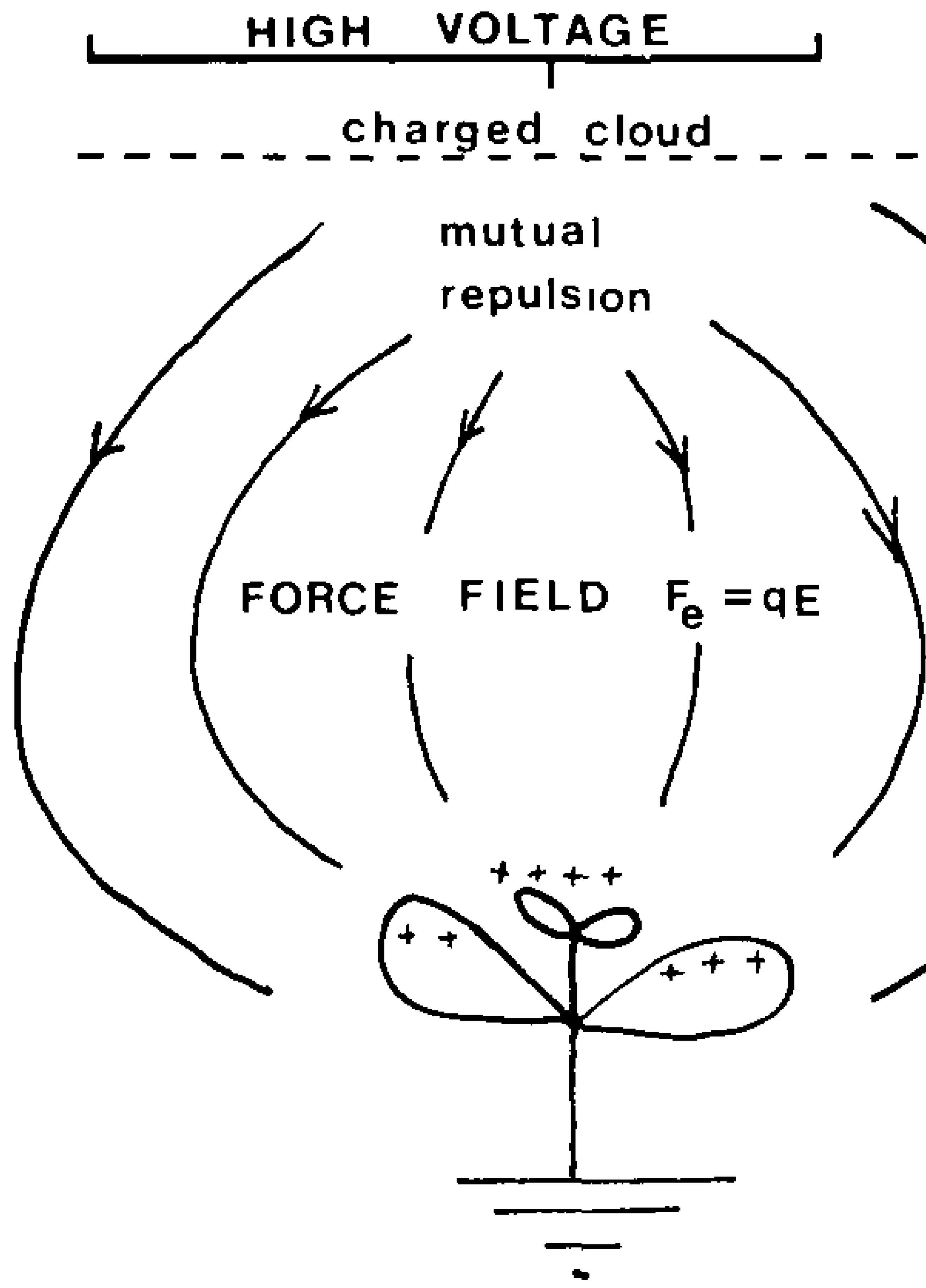

Figure 1: When particles are charged and ejected into a powerful electrical field, they experience a force F_e in the direction of the field

using droplets with diameters generally under 50 μm (7). Since the electrostatic charge resides on the particle surface, the electrostatic forces are proportional to the square of the diameter. The smaller the droplet, the greater the charge/mass ratio, and the greater the electrical force acting on the droplet.

One could expect more even deposition of spray droplets because of the mutual repulsion that occurs between like charged particles. Also, the travel path of droplets from nozzle to target will tend to follow the curved electrical flux lines

Table 2. A summary of the three main lines of work in the development of commercially available electrostatic sprayers

	Law	Arnold	Coffee
Droplet Production	Air Shear	Centrifugal	Electrodynamic
Droplet Charging	Induction	Ion Injection	Electrodynamic
Droplet Size (VMD)	30 - 50 μm	30 - 250 μm (adjustable)	40 - 200 μm (adjustable)
Application Rate	5 - 15 l/ha	0 5 - 20 l/ha	<1 5 l/ha
Formulation	Water Based	Oil and Water Based	Oil Based
Energy Requirement	750 w	7 - 10 w	0 1 w
Moving Parts	Compressor	Motor/Spinning Disc	None

that envelop the earthed target, rather than the straight line of sight (Figure 1). This would tend to give better coverage on the underside of leaves.

The principles of electrostatics are not new, but it is the development of suitable high voltage generators that largely has given impetus to the commercial exploitation of these principles. There are presently three main development areas being worked on, and these are summarised in Table 2 (1,3,7).

Comparisons of charged droplets with uncharged droplets drift sprayed onto cotton showed up to nine times greater recovery from the charged spray (2).

5. NEW PESTICIDE APPLICATION TECHNIQUES IN NEW ZEALAND

With the dramatic increase in horticulture over recent years, there has been a corresponding increase in awareness of the need for more efficient spray applications. The establishment of new crops such as kiwifruit, with their strict quality and chemical residue standards, places stringent requirements on spray application techniques. The success of CDA techniques in other cropping situations has led to the development of a CDA/airblast sprayer for kiwifruit. The first full field trials of this machine are being carried out by the Agricultural Engineering Institute this season. The treatments include the full Ministry of Agriculture and Fisheries export schedule spray programme, except that the active ingredient will be applied in a total of approximately 60l/ha instead of the usual 2,250 l/ha. A second treatment involves applying half the recommended of active ingredient again at an approximate total application rate of 60 l/ha. The machine, illustrated in Figure 2, uses spinning disc rotary atomisers with a modified plumbing and agitation system to handle the greatly increased liquid concentrations (almost all of the chemicals used in the kiwifruit spray programme are wettable power formulations).

A second example of the interest in greater application efficiency is the importation into New Zealand of the first commercially available electrostatic sprayer. The machine, a low volume airblast sprayer with a radial flow fan, uses air shear atomisers, with induction charging of the droplets.

In an evaluation of this sprayer, Inculet et al. (5) showed that, by using electrostatically charged liquid pesticide droplets, one can achieve a substantially enhanced leaf coverage in an orchard. They found a markedly improved deposition in the upper tree canopy with better uniformity of deposition.

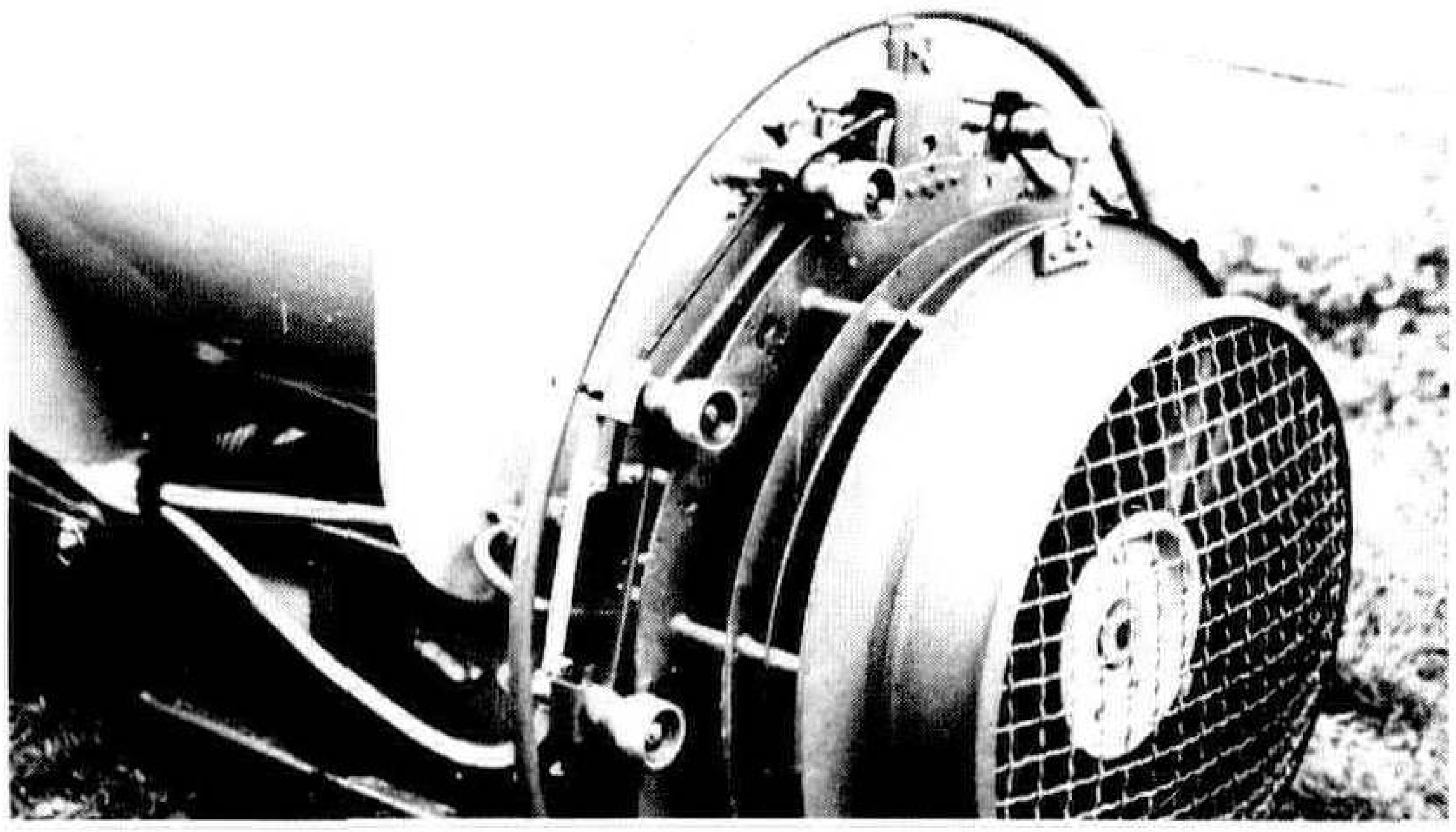

Figure 2: The CDA/Airblast sprayer being developed for kiwifruit, by the NZ Agricultural Engineering Institute.

6. SUMMARY AND CONCLUSIONS

The new techniques in spray application are exciting and offer real promise of greatly reduced total application rates and chemical rates. The path to achieving these objectives is not without potholes however. The underlying principles of CDA spraying have been set out clearly in many publications (e.g. 9); and reports of successful trial work demonstrating the advantages of the technique continue to be published. The drift spraying technique demands perhaps a greater operator understanding for success. He must, for example, learn to use the prevailing wind to direct the spray to the target. A number of parallel developments must occur for the successful implementation of the CDA technique. For example, the availability of suitably formulated chemicals currently lags behind the availability of application equipment. Again, widespread implementation of electrostatic spraying is unlikely within the next five years as there are many aspects still needing work — for example, drought stress on a target plant adversely affecting the deposition process by reducing the plant's ability to transfer charge (6).

While these developments are exciting it is perhaps appropriate to observe that to a large extent current spraying techniques and equipment used in New Zealand are effective. To make the most immediate impact in improving efficiency, the value of correct calibration and use of existing equipment should not be lost sight of.

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GRAFTING NUT TREES IN A COLD CLIMATE

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Until five years ago, grafted walnut trees could not be bought in New Zealand No nurseryman could offer them, yet in California alone, there are 200,000 acres of grafted walnuts in orchards, and we were told again and again that they were all grafted outside and there was no special trick about achieving good results.

The breakthrough came when we realised that the limiting factor was our low average temperature, thanks to our equitable maritime climate. Walnuts need a temperature of around 80°F for a period of three weeks to make a strong graft union and as you know, we seldom have a spell of weather as hot as this — thank heavens! California has a Mediterranean climate with moderate winters and very hot summers in the interior valleys, as does southern France where walnuts are grafted in the field as a matter of course. However, walnuts have the ability to callus in winter even though dormant and our grafting methods are based on this.

We like to use two-year-old black walnut (*Juglans nigra*) as the rootstock, it will grow a metre a year in the garden, but we need to do work on choosing more suitable rootstocks. *Juglans hindsii* is a possibility, as is the Manregian strain of the