MULTI-PURPOSE CDA SPRAYER DEVELOPMENT

BY

MAIWADA LIMAN SULEIMAN

Department of Agricultural Engineering

Faculty of Engineering

Ahmadu Bello University, Zaria

A Dissertation Submitted to the

Postgraduate School,

in fulfillment of the requirements

for the degree of Doctor of Philisophy of

Ahmadu Bello University,

Z a r i a

September, 1994

DECLARATION

I hereby declare that the whole of this work now being submitted as a thesis for the degree of Doctor of Philosophy (Ph.D) of Ahmadu Bello University is the result of my own investigation. The work embodied in this thesis has not been submitted already in substance in candidature for any other degree.

Candidate _____

Date 15/10/94

The above declaration is confirmed by:-

_____

Professor R.N. Kaul
Major Supervisor

CERTIFICATION

This Project thesis entitled "MULTI-PURPOSE CDA SPRAYER DEVELOPMENT by Maiwada Liman Suleiman meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

October 15, 94
Date

Professor R.N. Kaul
Chairman, Supervisory Committee

15/10/94
Date

Member, Supervisory Committee

15/10/94
Date

Dr. O.J. Mudiare
Head of Department

02/09/99
Date

Dean, Post Graduate School

D E D I C A T I O N

This thesis is dedicated to my Parents: Hafsatu Umaru Aliyu and Suleiman Thabitu who have contributed immensely to my present achievements.

A C K N O W L E D G E M E N T

The author expressses profound appreciation to his supervisors for scholarly advice and interest throughout the period of the project. Grateful acknowledgement is given to the Head of Department also for his encouragement and interest whose together with the supervisors inputs made this thesis a reality.

Profound appreciation is expressed to Alhaji Abdullahi El-Okene for playing an outstanding support role to see to the success of this work. He remained solenly and solidly behind me at this work. "When the going went tough! only Abdullahi kept going in support of the gower". May Allah bless him and his family in this world and here after.

The author is thankfully indebted to the agricultural Mechanization Research Programme of the Institute for Agricultural Research for their financial assistance. Also part of the study forms part of the Research project of the latter. The author is therefore thankful to Prof. L.B. Olugbemi, the Director IAR not only for permission to use the data for this thesis but also for unique role he and Dr Mudiare played to see the success of this work.

Appreciation is also expressed to Dr.S.S. Okatahi, and Dr. Y. Yiljep both of NAERLS ABU for their valuable advice, Malam Musa Onogu, Malam Dikko Samaru, Iro Sule, and Malam Abdullahi Adamu Damo of the IAR for their encourgament and moral support during the period of this work.

Numerous senior and junior colleagues of the Department, friends and relations too many to be mentioned individually, supported in prayer and encouragement. To all of you the author is grateful.

Finally the author expresses deep appreciation to members of his family, Khadijatu, Hauwa, Hafsatu, Aminatu, Maryama, Muhammad Awwal, Muhammad Sani, Zainab and A'ishatu for their encouragement and sacrifice throughout the period of the study. Above all, praise be to Allah the cherisher and sustainer of the worlds, for granting me the previledge, health and wisdom to achieve this.

A B S T R A C T

A multi-purpose spinning disc controlled droplet applicator (CDA) has been developed. The sprayer takes care of spraying applications for different needs such as: Insecticide/fungicide spraying, Herbicide spraying and even tree crop spraying eliminating the need for having different spraying machines.

The machine was developed by modifying the conventional (CDA) sprayer to produce different sizes of droplets achieved by change of sprayer motor voltage and the change of sprayer configuration to provide for adjustment for tree crop spraying. An alternate power source was also identified as being more superior to conventional U2 batteries.

Laboratory evaluation of the prototype revealed that the sprayer was capable of producing insecticide/fungicide droplets of 82 micron volume median diameter (vmd) at 600 rpm disc speed when the input voltage was set at: 12V and Herbicide droplets of 285 micron vmd at 2500 rpm when set at 6v. Spray volume distribution pattern tests revealed a decrease in the Coefficient of variation of spray with decrease in input voltage. The dispersion ratio range between 1.22-1-30 which are within acceptable limits for cda spraying.

Field tests revealed an application rate of 7.2 L/ha for insecticide/fungicide and 24 L/ha for herbicide sprayings with spray droplet densities Of 236 and 19 droplets per square centimeter respectively. The maximum vertical height reached by droplets during tree Crop Spraying was 8 metres.

Power consumption tests revealed an average consumption of 16.1 watt at 12 volt during Insecticide spraying and A.6 watt at 6 volt during Herbicide application. Annual spraying operating power cost with the modified power source was below 20% of that when conventional U2 batteries were used. The above in addition to higher field capacity, versatility, and better spray droplet spectra due to relatively constant operating voltages were some of the merits of the new prototype sprayer design.

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Abreviations, Definations, Units and Symbols

Abreviations and Symbols

A	Area or ammetre
ai	Active ingredient
CDA	Controlled droplet application
CV	Co-efficient of variation
D	Diameter of centrifugal energy nozzle (disc)
d	Diameter of Spray droplet
dm	Droplet mean diameter
dm^3	Cube of mean diameter
f	Frequency of droplet production for one ligament
GMSD	Ground metred shrouded disc
HV	High volume
IGMSD	Improved ground metred shrouded disc
LV	Low volume
M	Spinning disc delectric motor
Mgo	Magnesium oxide
N	Number of droplets in a class or rotational speed
Nmd	Number median diameter
n	Number of ligaments, or droplet density
Q	Application rate (L/ha)
q	Volume flow rate along one ligament
RPM	Revolutions per minute

r	Dispersion ratio
SD	Standard deviation
SF	Spread factor
ULVA	Ultra low volume
V	Voltametre, or volume of droplet
VMD	Volume median diameter
VLV	Very low volume
$\bar{x}$	Mean
$<$	Less than
$\leq$	Less than or equal to
$>$	Greater than
ρ	Density of liquid
γ	Surface tension
W	Angular velocity
K	Constant
	Liquid spray viscosity
E%	Cumulative percentage.

Units

A	Ampere
cm	Centimetre
dB	Decibels
g	Acceleration due to gravity (9.8 m/sec^{-2})
ha	Hectare

Kg	Kilogram
Kv	Kilo volt
L	Litre
m	metre
μ_m	Micrometre (10^{-6} metre)
μ_p	Micro poise
P	Poise
Sec	Second
v	Volt
W	Watt

Definations

Volume Median diameter (Vmd)

This is the diameter of a droplet in a representative sample of spray such that when divided into two equal parts one half contains droplets which diameters are smaller than the vmd and the other half of the volume contains droplets which diameters are larger than the vmd.

Number median diameter (Nmd)

This is the numerical average droplet size without any reference to volume.

Dispersion Ratio (r)

This is the ratio of the volume median diameter (vmd) to the number median diameter (nmd). The closer this ratio is to unity the more uniform the spray droplets are. For satisfactory and acceptable CDA spraying the dispersion ratio should be less than 1.4 ($r < 1.4$).

Spraying efficiency

This is the ratio of the minimum spray volume required for a particular target to the actual spray volume applied.

Droplet density (n)

This is the number of droplets per square centimetre of sprayed surface e.g:- 5-10 droplets/ cm^2 for Translocated herbicide, 20 droplets/cm^2 for most insecticides and systemic fungicides and 50-70 droplets/cm^2 for non systemic fungicides, serve as a general guideline.

Droplet spectrum

This is a wide range or sequence of spray droplets emitted from a sprayer nozzle. Droplet spectrum emphasises not only on droplet sizes but also on droplet uniformity and distribution.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Pesticides will continue to play a great role in the rapid development of agricultural crop production. As Smith (1980) pointed out pesticides remain our most powerful tool in pest management in spite of recent popular pressure to have their use curtailed and despite intensive research into alternative methods. Higher standards of living by an ever increasing human population will undoubtedly mean increased use of pesticides. (Table 1.1)

Table 1.1 Increase in use of pesticides throughout the world as indicated by annual expenditure (After Farm chemicals 1975 and Farm chemicals international 1993).

Pesticide	Expenditure (Millions of US Dollars)			
	1971	1974	1980	1991
Herbicides	1,100	2,200	3,500	11,000
Insecticides	800	1,800	2,500	6,900
Fungicides	300	1,000	1,300	4,500
Soil fumigants	20	70	100	-
Others (growth regulators)etc.	50	100	150	1,400
Total	2,270	5,170	7,550	23,800

The trend especially in developing countries is towards large scaled farming, as such the use of pesticides is likely to continue to increase backed with increase in manual labour cost. This necessiates wiser and more careful use of pesticides. If environmental contermination and resides in foods are to be minimised (Southwood, 1977). This calls for better design and development of pesticides application machinery of cheap and diversified nature.

1.1.1 General classification of present day pesticide application machinery.

Pesticide applicators could be classified into the following groups and sub groups as shown in Fig. 1.1.

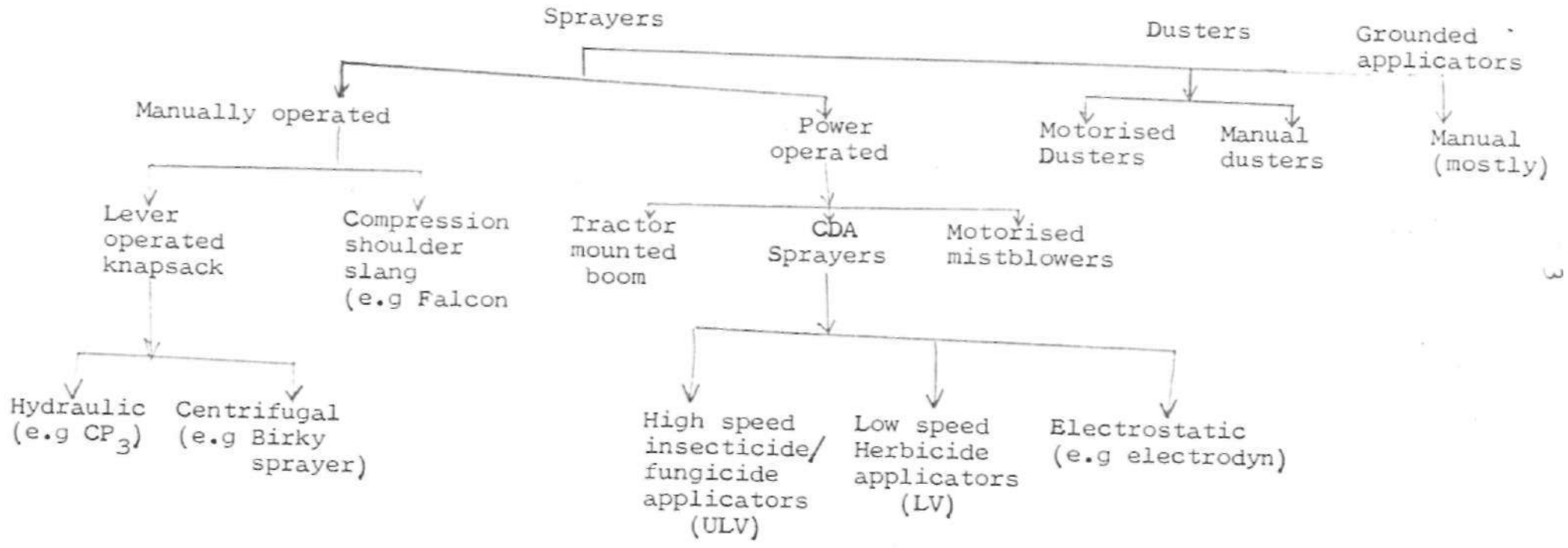


Fig. 1.1 Classifications of pesticide Applicators.

From the above figure it could be observed that sprayers could be classified into six main groups according to the type of energy used for droplet atomization at the nozzle viz:-

1. Hydraulic energy sprayers

   These are sprayers that use hydraulic pressure energy to break spray liquid into droplets of a wide range of sizes. Examples are knapsack lever operated or compression sprayers and tractor mounted or self propelled sprayers. (Figs. 1.2 - 1.4).

2. Gaseous energy sprayers

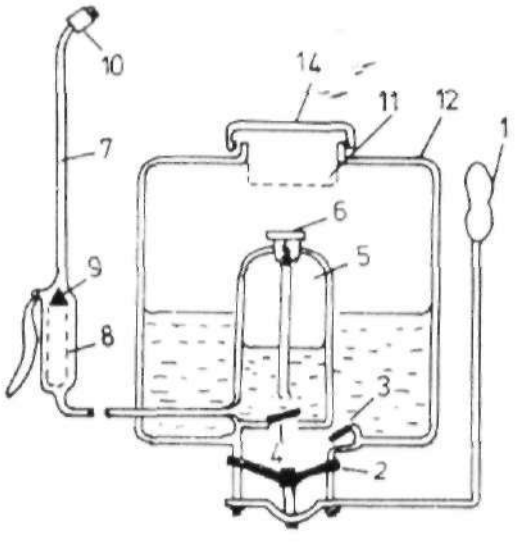
   These sprayers use high velocity air to shear liquid flowing into its stream into fine droplets. Examples are the motorised knapsack Mistblowers. (Fig. 1.5) (Clayphon 1971).

3. Centrifugal energy sprayers

   These sprayers use spinning action of a disc to disc to atomize liquid into droplets falling on to it using centrifugal energy from the disc. Examples are the Ultra low and low volume sprayers (Figs 1.6 and 1.7) (Matthews, 1990).

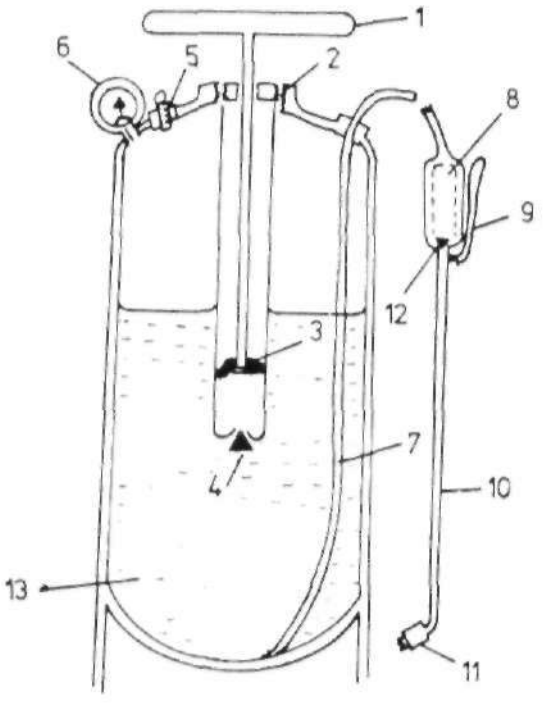
4. Thermal energy sprayers

   These sprayers use oil containing an active ingredient to be injected into a stream of hot gas which vaporises it and produces dense fog formed by the condensation of the oil when emitted into the



1. Operating lever
2. Diaghragm
3. Inlet valve
4. Outlet valve
5. Pressure chamber
6. Pressure lelief valve
7. Lance
8. Filter
9. Control valve
10. Nozzle
11. Filter
12. Spray tank
13. Trigger
14. Filler cap

Fig. 1.2 Lever operated knapsack sprayer (After Kaul and Suleman 1990



1. Handle
2. Filler opening
3. Piston
4. Valve
5. Pressure relief valve
6. Pressure gauge
7. Dip tube
8. Filter
9. Trigger
10. Lance
11. Nozzle
12. Trigger control valve
13. Spray tank

Fig 1.3 Knapsack sprayer (compression type). After Kaul and

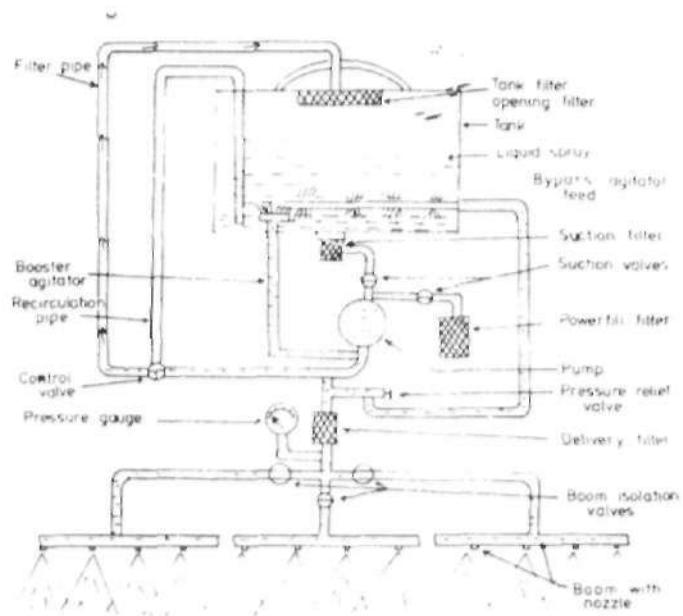


Fig. 1·4 Schematic diagram showing the lay out of tractor mounted sprayer (during spraying). (After Kaul and Sulaiman 1990)

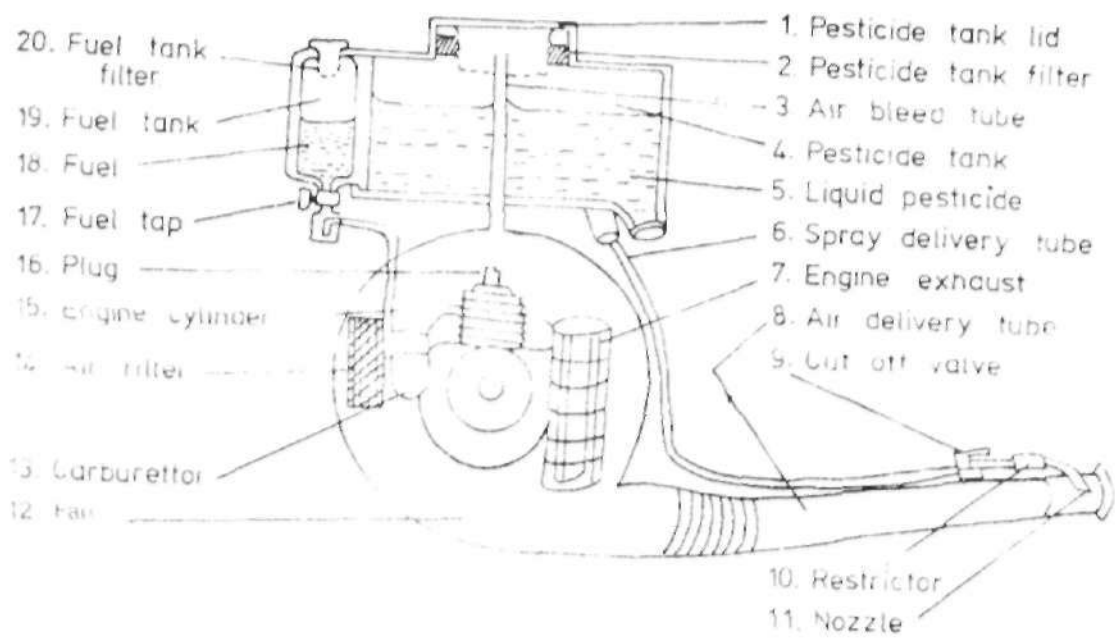
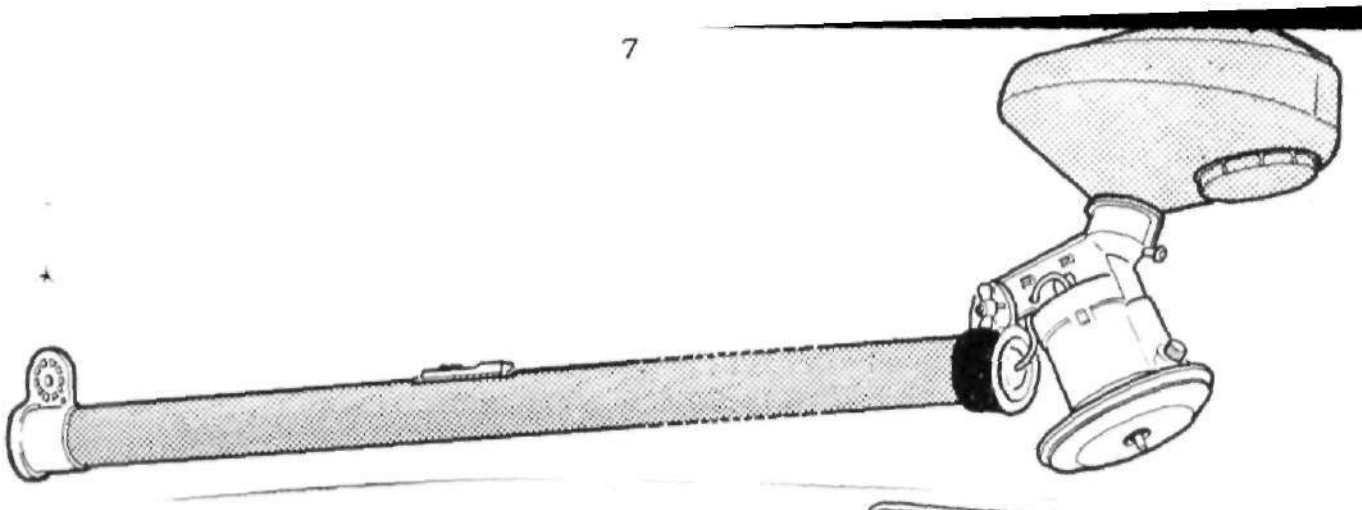


Fig 1·5 Motorised Knapsack Mistblower (After Kaul and Sulaiman 1990)



1. Spinning disc
2. Thrower plate
3. Backing plate
4. Electric motor
5. Battery
6. Restrictor
7. Pesticide tank

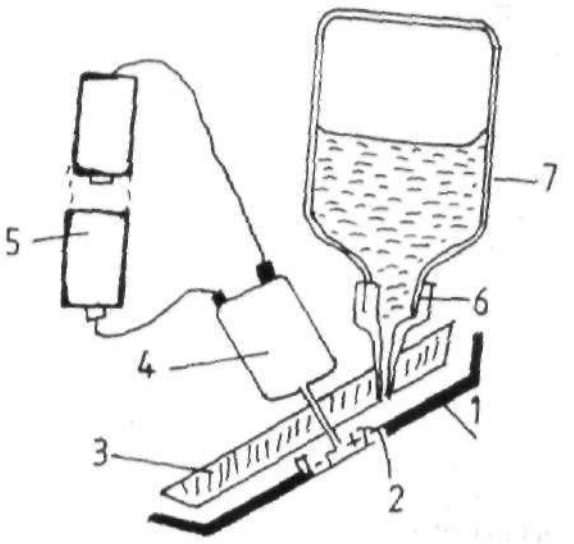


Fig. 1.6 Constructional features of a spinning disc insecticide/fungicide CDA sprayer. After: Kaul and Suleman 1990)

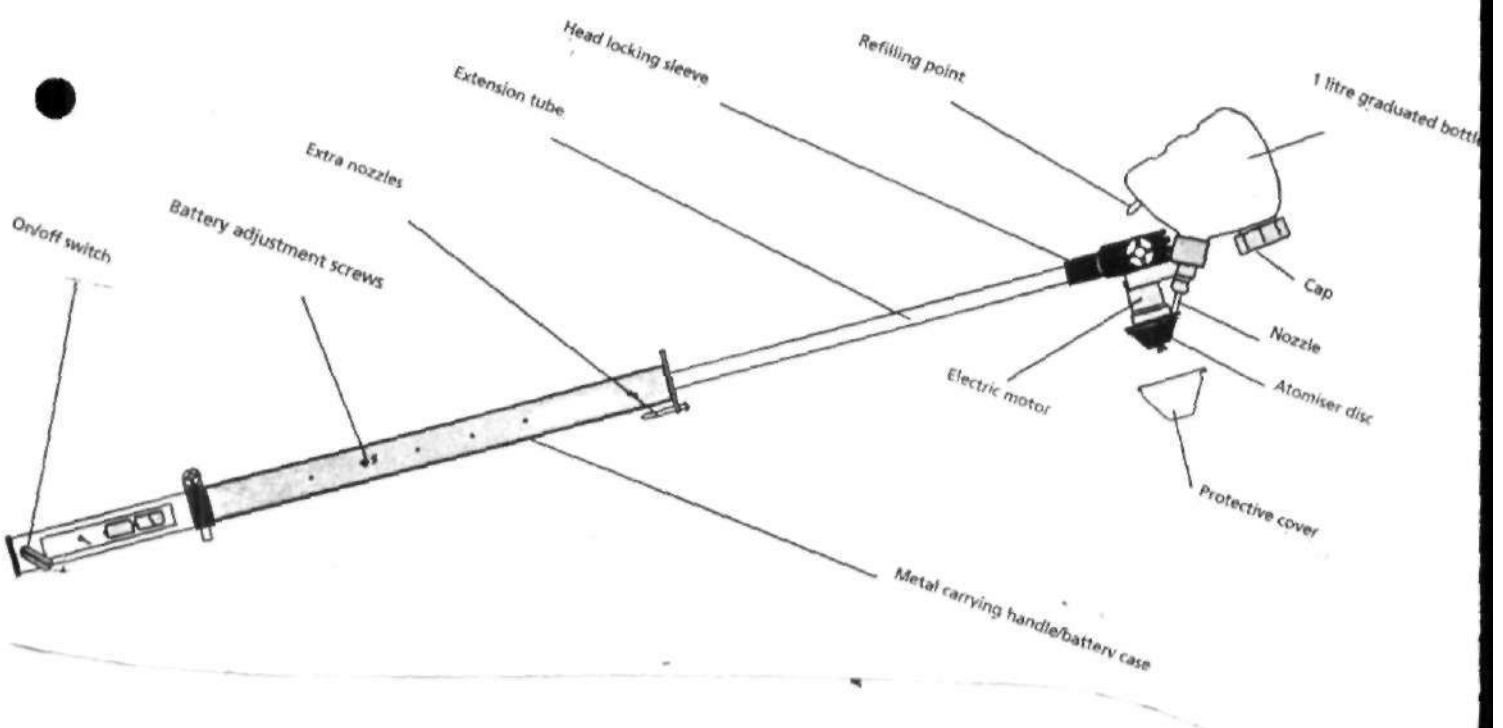


Fig. 1.7 Constructional features of a CDA Herbicide Applicator.

atmosphere. Example as in fogging machine. (Munthali, 1976).

5. Kinetic energy sprayers

In these sprayers, drops of spray liquid are formed by feeding liquid by gravity through a small hole as in a simple dribble bar. (Clyphon and Thornhill, 1974a).

6. Electrical energy sprayers

In these sprayers, charged droplets are produced at the nozzle by passing spray liquid through a strong electric field formed by a high voltage generator (Nyambo, 1989). Example as in the ICI Electrodyn sprayer (Fig. 1.8).

Other pesticide applicators include:-

Dusters

Dusters are used for applying solid, powdered chemical pesticides in the form of dusts using some form of air for particle distribution. They could be either manual using simple bellow type devices or motorized using high velocity air generated by an engine similar to that of a mistblower. (Fig. 1.9)

Granule applicators

Granule applicators deliver much larger solid particles to the forget than of dusters. They are usually used for spot treatments (Farmery 1986).

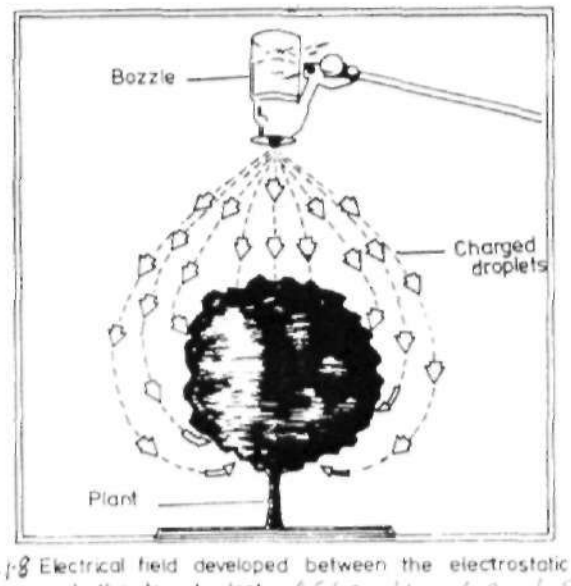


Fig. 1·8 Electrical field developed between the electrostatic sprayer and the target plant. After Kaul and Sulaiman 1990)

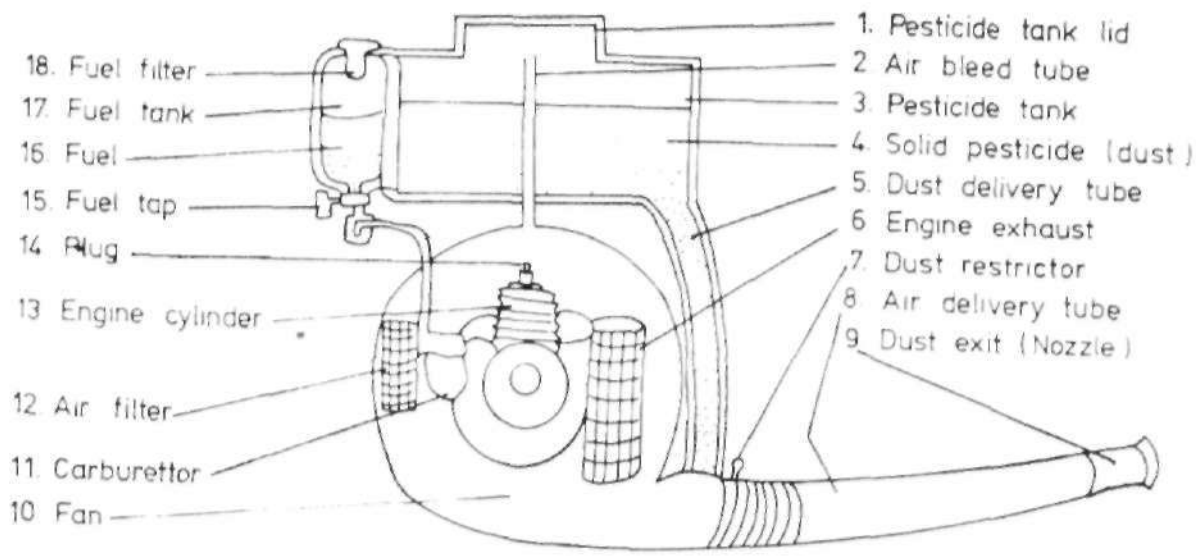


Fig. 1·9 Motorised knapsack duster. After: Kaul and Sulaiman 1990)

1.1.2 Design purpose and limitations of existing pesticides applicators

Among the various uses of the various types of pesticide application equipment are the following:-

(a) Application of insecticide sprays to control flying or crawing insects on plants.

(b) Application of fungicide sprays to control plant diseases.

(c) Application of herbicides to kill weeds, either indiscriminately or selectively and either at pre- or post emergence stage.

(d) Application of Dusts particles for control of insects on the fields or in stores and wire houses.

(e) Application of granular pesticides mainly for spot treatments at the base of individual plants.

(f) Application of pre-harvest sprays to defoliate or condition crops such as cotton for mechanical harvesting.

(g) Application of hormones (growth regulators) to increase fruit set or prevent early droping of the fruit.

(h) Application of biological materials such as viruses and bacteria, in sprays to control insect pests (Non-Chemical methods of pest control).

Various pesticide application machines are therefore designed to accomplish the above mentioned tasks. Earlier designs of pesticide applicators especially sprayers were made as 'multipurposed', Hydraulic energy sprayers for instance are used to apply both insecticides fungicides and herbicides with same machine.

Later studies and developments in pesticide application technology revealed that different droplet sizes and distribution (droplet spectra) are required for different pest situations. Hydraulic sprayers for example produce very wide range of droplet sizes (Matthews, 1979) and as such not suitable for specialized pest situations, hence the need for an alternative nozzle has been long recognised (Fraser, 1957). The use of high volume (> 600 L/ha) for field crops (Suleiman, 1986) for hydraulic nozzle sprayers also is another basic limitation especially in areas where water is scarse, availability of diluent is thus very critical here.

The use of narrow swath per nozzle and the need for alot of mixing of chemical during spraying to avoid settlement below tanks are other limitations of these existing devices. Especially with knapsack sprayers much more time is needed per hactare treatment then

with other designs.

Large droplets produced (about 500 micron volume median diameter-vmd) may some times become unstable resulting in possible run off causing chemical loss and hence environmental pollution resulting in major changes in population of non-target organisms such as earth worms (Cooke et al, 1984).

Poor bush penetration and high capital investiment especially for tractor mounted trailed or self propelled hydraulic boom sprayer represent other limitations. Even though less critical during spraying, operators safety is critical during formulation handling. Operator is likely to make more contact with chemical at this stage.

An attempt to correct the above mentioned limitation let to the development of an improved nozzle capable producing narrower spectrum of droplets and of specific sizes for the desired pest situations.

1.1.3 Development of Controlled Droplet Applicators (CDA)

Controlled droplet application emphasises the importance of applying correct droplet size for a given target and also the uniformity of droplet size

to optimise the use of minimum volume and dose to achieve effective control of the pest. It is therefore an extension of the Ultra low Volume (ULV) concept which objective is to apply the minimum volume of spray compartible with achieving economic control of pest.

A most promising method of controlling sizes of droplets within fairly narrow limits is by the use of centrifugal energy nozzles with which droplets can be adjusted to some required size by restricting their rotational speeds within certain range. Various types of cda sprayers have hence been designed and developed for production of different droplet spectra required for different pest situations needed.

A hand-held spinning disc ulv sprayer usually has a plastic spray head with a small electric motor which drives a rotating disc (Fig. 1.7). Liquid is fed from a litre capacity tank through a restrictor into the surface of the rotating disc by gravity, so that the centrifugal force spreads the liquid to the edge of the disc where droplets are formed.

Controlled droplet applicators have an age over and above other classes of conventional spraying machines due to the following basic advantages viz:-

(i) Cda sprayers use very low (20-30 L/ha), to Ultra low ($\leq$ 5 L/ha) down to Ultra-Ultra low (0.5 L/ha) amount of spray liquid per unit area, thus proving very advantageous in drier areas of the world including Northern parts of Nigeria where availability of diluent is scarce. (Compare with 200-500 L/ha for High volume sprayers). Despite the decrease from 200 litres of spray from conventional hydraulic sprayer to about 2.5 litres/ha, with cda sprayer on fully grown cotton, yields were similar (Matthews, 1990).

(ii) They produce the narrowest spectrum of droplets which is most desirable since specific sizes of droplets are required for specific pest situations (e.g 80 μm vmd for insect and 200 um for weed control etc).

(iii) They produce higher concentration of droplets per unit amount of diluent used (e.g $4x10^9$ droplets per litre compared with 16×10^6 for high volume sprayers (Suleiman, 1986). This is highly advantageous since an even coverage over the whole plant may be desirable when applying fungicide (Hadfield, 1987).

(iv) Their use with oil based sprays not liable to evaporation facilitates greater spraying efficiency; compared to water based sprays with high volume sprayers liable to evaporation.

(v) Wider swath widths, better penetration and retention of droplets makes spray operation faster with cda them with conventional sprayers.

(vi) Lower initial capital investiment, least environmental pollution possibilities and least labour requirements are other added advantages of hand-held cda sprayers over other classes of spraying machines. (Swiss, 1993).

1.2 Statement of the problem

Based on the comparison of their features and per for mance characteristics with those of other conventional sprayers it could be clearly observed that the controlled droplet applicators have in totality shown clear obvious advantages over and above other conventional high volume hydraulic sprayers, as outlined in section 1.4. It could therefore be said that the controlled droplet application (Cda) principle as a pesticide application technique can stay.

However, in spite of their obvious merits as already outlined and despite the fact that controlled droplet applicators came into prominence well over 15 years ago (Matthews, 1977) they are still to be fully established and accepted as a better alternative to conventional pesticide spraying devices in many parts of Nigeria. Farmers still prefer to use the conventional knapsack lever operated or compression sprayers with high volumetric outputs even in the drier parts of Nigeria despite their obvious limitations. One would have expected by now, an almost total replacement of the conventional spraying techniques that are not only drudgerous but in-efficient with the more modern light weight controlled droplet applicators.

The bases for continued preference of the conventional high volume hydraulic sprayers are as follows:-

i) Power (battery) consumption of cda sprayer.

The power consumed by many of the cda sprayers is generally high with some makes consuming as high as about 23 Watt (Suleiman, 1991) thus resulting in very frequent battery replacements some of which last only a few hours (Suleiman and Kaul 1990, and Yusuf 1993). About N80 is required to load an Ulva sprayer taking 8 pairs of batteries. This results in high operating cost of such sprayers and consequently high spraying costs.

ii) Spraying type limitation of cda sprayers

An existing cda battery oprated sprayer can only be used for a particular type of spraying operation, e.g. Insecticide or fungicide application only and that a user requires another type of cda sprayer for herbicide application, thereby requiring a user to own two different types of cda sprayers for normal ground crop spraying. The HV sprayer on the other hand (Wheather lever operated or compression type) could be used for a variety of spraying operatin e.g. Insecticide/fungicide and as well as herbicide spraying.

iii) Tree Crop Spraying

The HV sprayer could to some extent also be used for small tree crop spraying in addition to ground crop. Crops such as citrus could be sprayed as droplets are to some extent projected high up as a result of pressurisation of liquid spray from tank before emission into droplets.

It has however been pointed out in 1.1.2 that the conventional high volume hydraulic sprayers possesSvarious limitations such as excessively high volumetric out puts (making it very unsuitable in areas where water is a constraint), Wide range of droplet sizes (making it unsuitable for specific type of spraying), Narrow swath, poor bush pemetration etc thus justifying the development of an alternative sprayer.

1.3 Objectives of the Study

Based on the above, it could therefore be seen clearly that there is the need to evolve an alternative sprayer that is multipurpose in function which would combine the performance advantages of hydraulic, mistblower and controlled droplet application sprayer concepts. This is disirable so that those advantages possessed and demonstrated by cda sprayers are retained and additional ones that are attributable only to hydraulic and gaseous energy sprayers are also encoporated.

The specific objectives of the thesis are:-

1) To evolve a controlled droplet applicator prototype that is:-

i) Capable of producing droplets suitable for insecticide/fungicide application (as in one class of existing cda sprayers and some hydraulic sprayers).

ii) Capable of producing droplets that are suitable for herbicide application (as in another class of cda sprayers).

iii) Capable of Projecting the droplets to longer distances such as trees than conventional cda or hydraulic sprayers (i.e similar to mistblowers).

iv) Of improved operating power utilisation than Currently available thus reducing sprayer operating costs presently responsible for slow adoption of present day cda sprayers.

2) To evaluate the prototype sprayer with characteristics outlined on 1 (i) - (iv) above in the laboratory and in the field.

3) To make appropriate recommendations with regards to further developmental work in the concept if and where necessary.

1.4 Significance of the Study

Research and development in pesticide application technology is globally geared towards achieving an effective pest control not only by using the minimum volume and amount of pesticide but also with an efficient equipment of minimal capital and operating costs. This is not only to reduce expenses attributed to ever rising costs of pesticides and application machinery but also to minimise environmental pollution posing threats to both the operator, the atomsphere and the soil fauna. In Nigeria and indeed in many other developing countries where almost all spraying machines used are imported care during selection for import or local purchase and during operation is highly important.

The information to be gained from this study would serve as a pointer to manufacturers of conventional controlled droplet applicators not only to improve upon

designs of existing makes and models of spinning disc cda machines but also to develope new ones to meet the present day user requirements, considering high costs of owning and operating more than one machine for spraying operation.

U2 dry cell battery manufacturers could use information from this study to evolve more economically suitable battery makes for use with cda spinning disc sprayers that would produce not only improved droplet spectra but also performance in general.

In summary, this study may lead to the production of an improved controlled droplet applicator of greater versatility and more economical power use.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Fundermental Concept

Thirty six years ago, Fraser (1957) stated; 'An atomizing device to give control and adjustable drop size within narrow limits is universally required'. Later, Bals (1969) pointed out that 'the efficiency of a spraying machine is inversely proportional to the range of droplets it emits, whilst the suitability for a specific problem depends on the actual size of the droplets emitted'. The concept of controlled droplet application (cda) is not new, although the term was only coined in 1975 by J. Fryer, Director of the UK's Weed Research Organization during discussions on the application of herbicide and through the encouragement of whom the technique came into prominence Matthews (1977).

Centrifugal energy nozzles have proved valuable in the laboratory as a means of obtaining a narrow spectrum and hence controlled droplets, but early attempts in the field were not successful since they were operated under flooded conditions in an attempt to apply the same volumes of liquid as used with hydraulic nozzles.

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. Fraser, Dombrowski and Routley (1963) have defined three methods of droplet formation as the liquid flowrate is in creased. These are:-

(i) Single droplet formation

(ii) Ligament formation

(iii) Sheet formation

Single droplet formation

In this case single droplets leave directly from the nozzle at low flow rates. The diameter of droplets produced singly by a rotary nozzle can be approximately calculated from the following equation (Walton and Prewett 1949).

$$d = K \frac{1}{W} \sqrt{\frac{\gamma}{D\,\rho}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where

d = diameter of droplet (μm)

w = angular velocity (rad/sec)

D = diameter of disc or cup (mm)

γ = surface tension of liquid (mN/m)

ρ = density of liquid (g/cm^3)

K = constant which has been found experimentally to average 3.76 (Fraser, 1957).

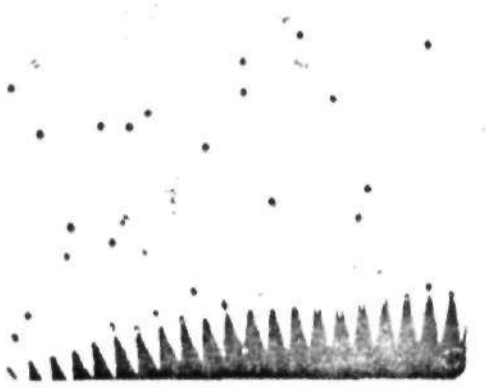


Fig. 2.1 Sattellite Droplets from a Rotating Disc.
After (Fraser et al (1963

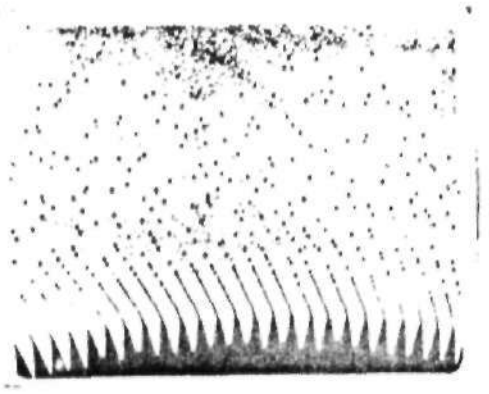


Fig. 2.2 Ligament formation from a Rotating Disc.
(After Fraser et al (1963

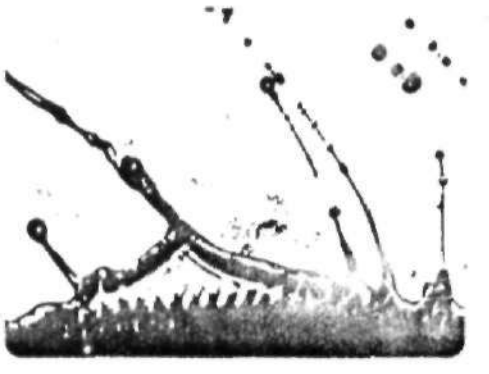


Fig. 2.3 Sheet formation from a Rotating Disc
(After Fraser et al (1963)

These single droplets are called satellite droplets and are very unifrom. Ideally these are the types of droplets required in controlled droplet application. However, these types of droplets could only be formed at very low flow rate about 60 ml/min (Dombrowski and Lloyd 1974). Their sizes depends on such factors like the disc angular velocity, size of disc, surface tension and density of spray liquid. (Fig.2.1)

Ligament formation

In this case liquid spray leave the spinning disc in the form of long curved threads or ligaments and subsequently break down into droplets. This happen at flow rates that are higher than those in which satellite droplets are formed. In the transition from single to ligament droplet formation, the size and number of satellite droplets increases causing a decrease in mean diameter. The spray droplets produced in this stage are therefore not as uniform as the satellite or individual droplets. They are formed at flow rates of about 100 ml/min (Frost 1978). Fig. 2.2

Sheet formation

In this case liquid leaves the nozzle in the form of an attenuating sheet which dis-integrates - mostly caused by aerodynamic waves of increasing amplitude so that fragments of the sheet break up into ligaments and subsequently into droplets

(Bals, 1970). Sheet formation occurs when the rotating surface is flooded. This occurs at flow rates higher than those at which ligaments only are formed. Droplet formation at this stage is similar to that with hydraulic nozzles and a wide range of droplet sizes is produced. It occurs at flow rates of about 800 ml/min. (Fig. 2.3).

The transition between satellite droplets and ligaments and between ligaments and sheet formation occurs over a range of flow rates when droplets are formed by both mechanisms. (Frost, 1974).

At a constant flow rate which is as low as possible, as close to 60 ml/min (1 ml/sec) as possible but obviously lower than 100 ml/min and at a constant spinning disc rotational speed a spinning disc cda sprayer is therefore expected to produce constant droplet spectrum required for a particular pest situation. This is important because different pest situations require different spray droplet spectra.

2.2 Review of CDA Sprayer Development and general performance studies

Almost all of conventional high volume hydraulic sprayers currently being used in Nigeria are imported let alone the more modern controlled droplet applicators.

As such very little work was done in the area of research and development of cda sprayers in this country. However, this is not the case globally as a number of attempts at various parts of the world were made in the fields of equipment design and modifications to control the droplet sizes and minimise spray volume rates yet achieving the desired pest control.

Young (1987) reported the use of a piezoelectrically driven single drop generator to produce specific size droplets, such that by varying the orifice size, pulse width and amplitude, control over a wide range of droplet size was achieved. The generator produced and accurately placed single droplets of four formulations with constant droplet size and impaction velocity, and applied them to the surface of wheat leaves in a controlled manner. Panneton and Roy (1990) reported the development of a mono disperse droplet generator which uses the principle of controlled break-up of liquid jets. Droplet coalescence was shown to be effectively controlled by emitting the jets from a rotating cylinder. Droplet sizes of range 120-220 µm were achieved with dispersion ratio 1.06. This is probably about one of the least value of dispersion ratios (most uniform spray droplet spectrum) produced so far within the present day literature on controlled droplet application. Similar work was reported by L'vor and

Shashora (1988) on a ground crop sprayer designed and developed in the USSR for spray application in low and ultra low volume conditions in forest plots. The atomizer rotational speed can be regulated accurately between 600 - 4500 rpm and can apply herbicide and arboricides on crops up to a height of 3 metres and on a slope up to 20^{o} with median drop sizes of 120 um (at 4500 rpm) and 650 µm (at 600 rpm).

Some of the work done in the area of cda sprayer developments were aimed at not only controlling sizes of droplets only to suit particular pest situation but for reduction of spray material volume rate also. Matthews et al (1992) reported trials with a wind tunnel sprayer which incorporates a rotary drum driven by a hydraulic motor which also drives a fan producing a moderated air blast ducted in acurtain shape by the design of the housing. The results indicated that the tunnel sprayer can minimize spray treatments allow spraying in wind conditions which would cause excessive drift with other equipment and re-cycle up to one third of spray and apply at lower volume than conventional spraying equipment. It has been proven that minimising the spray volume per unit area results in more effective pest control at least in herbicide application. Ugryumor et-al (1990) reported achieving 1.5-2.0 times effective herbicide spraying when Round-up (Glyphosate) was applied to sorghum, millet, pea and mustard at the rate

of 10L/ha as against 250 L/ha. Similar work aimed at reducing spray rate at IRRI, philiphines reported by Awadhwal et al (1992) described the development of a spinning brush (VLV) pesticide applicator. The applicator consists of a rotary brush atomizer mounted on the end of a shaft that passes through a pipe frame and rotated manually with a bevel gear. When the bristles of the wet brush a forcibly deflected and then a llowed to bounce back swiftly a spray of fine droplets is generated. Chemical flows by gravity at a reasonably constant rate and drips onto the brush bristles. A sheet metal deflector generates a spray when the brush is rotated. When the sprayer was evaluated comparatively with a Micro Ulva spinning disc sprayer, a CP 15; CP 16 and Tung Ho hydraulic knapsack sprayers in terms of spray droplet spectrum the results obtained are as given on the Table 2.1.

Table 2.1 Comparison of performance of Brush applicator with other conventional cda and hydraulic sprayers (after Awadhwal *et al.* (1992))

Equipment	Vmd (μm)	Nmd (μm)	r	Swath width (CM)	Droplet density Mean (NO/cm^2)	CV %
Brush applicator	187	90	2.07	100	43.1	30.2
Micro Ulva (Orange nozzle, 6 volt)	105	73	1.43	150	127.5	47.0
CP 15 (Hc 60)	90	70	1.28	60	32.9	60.1
CP 16 (Blue nozzle)	230	125	1.84	50	81.2	48.3
Tung Ho	200	70	2.85	50	35.5	41.0

The droplets from the brush applicator have vmd of 187 m, smaller than that of knapsack sprayers CP 16 and Tung Ho but bigger than that of CP 15 and Micro Ulva droplets. The dispersion ratio of the brush applicator was 2.07 Cf with 2.85 for Tung Ho indicating greater spray droplet uniformity from the brush applicator. With a mean droplet density of 43.1 droplets/cm^2 and CV of 30.2% it is adequate for pesticide application. The spraying operation using the applicator does not only require less effort than knapsack sprayer but requires only 12-15 litres and about 6 hours to cover 1 hectare as against 200 litres of water and 14 hours to cover a hectare with knapsack sprayers.

A more precise herbicide application technique developed and aimed at considerable reduction of spray material and minimising of environmental pollution was that reported by Felton et-al (1991). In his report, a reflectance based prototype weed detector and sprayer that could automatically activate each nozzle of a boom in order to spray only green vegetation was developed and tested in the field using a 37 nozzle, 18 m spray boom operating at a ground speed of 12km/hr and spray line pressure of 250 Kpa. With the sprayer, a total area of 2681 ha was treated giving a mean saving in area sprayed, relative to overall treatment of 90% with

considerable reduction in spray volume herbicide cost and time requirement. Even in less surphisticated cda spraying technique for weed control clear advantages were shown over and above hydraulic high volume spraying. Bisen and Devnan (1987) reported comparative performance of hand-held cda spinning disc sprayers and knapsack hydraulic sprayers using cone and fan nozzles in the application of herbicides in soya bean, at the rate of 2.0 L/ha. The results showed higher field capacity achieved with the cda compared to knapsack sprayers and resulted in higher benefit cost ratio of chemical treatment with 58-70% savings in labour requirement.

Due to large variability in spray deposition with little repeatability between runs obtained from the practice of applying pesticides to field crops using motorised knapsack mistblowers by using prevailing wind to drift a spray cloud on to the target area as reported by Alexander and Wills (1990) a number of air assisted nozzles were developed with the aim of improving spray droplet uniformity and improve canopy penetration. Bode (1988) reported the development of an air assist nozzle that uses pneumatic energy to atomize the spray liquid, such that by changing the air pressure, various droplet sizes can be produced without changing nozzle tip, producing more uniform droplets on both the over and under surfaces of the leaves.

Electrostatic charging of spray materials aimed at producing uniform droplets of controlled size and improving spray deposition efficiency is another revolutionary concept in pesticide spraying technology gaining popularity all over the world. The method is seen as an important development in the technique of controlled droplet application of pesticides.

Almekinders et-al (1991) investigated the deposit patterns of spray droplets relying primarily on electrostatic and gravitational forces for transportation and subsequent deposition in order to better understand the underlying processes governing the electro-deposition process. The deposits distribution of the charged spray cloud were measured in a wind tunnel and on artificial plants. The results indicated that electrostatic forces can be used to improve the deposit efficiency of spray droplets but an additional force is required to improve canopy penetration and reduce drift of air bone charged droplets. This improvement of spray deposition efficiency was confirmed by Gupta and Alamban (1991) in their development of a twin spinning disc electrostatic herbicide sprayer for low land rice tested under field condition in Thailand. The performance of the electrostatic sprayer was compared to an existing knapsack hydraulic sprayer. Using 50% of the herbicide manufacturer's recommended

dose, weeding efficiency and spray distribution uniformity of the electrostatic sprayer were 86% and 95% respectively compared to 74% and 57% for hydraulic sprayer. Most of the equipments already mentained in the review are still in prototype stages yet to be perfected. An example of a commercially available electrostatic cda sprayer is the 'Electrodyn', developed by the Imperial Chemical Industries (ICI) and first evaluated comparatively with other cda sprayers in this country in 1980 and reported in Raheja et-al (1984). The 'Electrodyn' differs from the popular Ulv applicators in that the small droplets (40-60 m vmd) are electrically charged and are consequently attracted to the earthed target, (the plant). Like the popular spinning disc sprayer the tubular 'handle' contains four U2 batteries from which a high voltage generator produces about 25,000 volt at the 'bozzle' (bottle + nozzle) end of the applicator. The bozzle is a plastic bottle containing the spray liquid which when the bottle is inverted flows into the nozzle comprising two tubes are inside the other. These tubes provide a narrow gap outlet (annulus). Built into the nozzle configuration are two electrodes; one charges the nozzle with high voltage, the other provides an earth potential in a ring collar which surrounds the nozzle. Spraying liquid of a specific viscosity and conductivity is gravity fed to a circular gap at the

nozzle tip. Air is bled into the bottle up the centre of the circular nozzle up the thread of a plastic screw. This screw and the annular nozzle gap regulate the flow rate which is only at the required rate when a constant stream of bubbles is rising from the air bleed screw. The conducting plastic nozzle contacts the high voltage out put from the generator which is housed in the main body of the stick. The atomisation process being extremely energy efficient requires a current of only 2-5 micro amps and therefore present no safety hazard to the operator. Am electric field is set up between the charged nozzle and the earthed ring surrounding the nozzle and it is this field which causes the liquid leaving the nozzle to form a series of fine ligaments. These ligaments subsequently breaks up into aessentially uniform sized droplets with a similar charge (+ ve) on each resulting in repulsion from the nozzle and each other, with subsequent attraction to the nearest earthed object. Any small satellite droplets produced carry a different charge to mass ratio and are consequently attracted to the earthed ring around the nozzle.

Unlike the conventional spinning disc cda sprayers a number of safety special safety precautions need to be observed while using the sprayer. It is necessary

for instance with this sprayer to ensure an adequate earth return for electrons leaving this nozzle on the droplets. If the earth lead does not contact plant or ground intermittently a charge will build up on the sprayer which could prevent the machine from operating correctly. Eventually this charge will reach a level where it will discharge usually through the operator, if insulated from the ground, giving a mild electic shock. If the operator is not insulated from the ground the charge will gradually leak through the operator without being noticed. After spraying the nozzle must be discharged by touching it against an earthed object before attempting to fit the bottle cap or removing the bottle. Failure to do this will result in a mild electric shock since a residual charge is held for an appreciable period after the high voltage generator is switched off.

2.1.1 Research at the Institute for Agricultural Research (IAR) Samaru

A prototype of the ICI 'Electrodyn' sprayer and a conventional spinning disc ultra low volume (ULV) Cda sprayer. Micron Ulva were compared at the IAR Samaru to assess relative merits and weaknesses in performance (Raheja et-al, 1984). Main focus was on flow rate of spraying liquid, spray droplet spectrum and power consumption. The summary of results are given on Tables 2.1 - 2.3.

Table 2.2 Change in droplet spectrum with varying voltage of an 'Electrodyn' Sprayer. (Raheja et-al 1984)

No of Batteries	Input Voltage	Output Voltage (Not spraying with bozzle)	Output Voltage Spraying	Droplet size (Micron)						Dispersion ratio
				Volume diameter			Number diameter			
	(V)	(KV)	(KV)	V16	Vmd	V84	N16	Nmd	N84	(r)
4	6.0	26.50	25.50	35.0	45.0	53.0	19.0	35.0	45.0	1.28
3	4.5	25.70	24.85	44.0	54.0	62.0	39.0	48.0	57.0	1.13
2	3.0	25.40	24.80	52.0	64.0	70.0	30.0	52.0	62.0	1.23
1	1.5	The Sprayer does not work with in put voltage below 3 volts								

Compared with conventional hydraulic energy (HV) sprayers with volumetric outputs of about 500 L/ha (Suleiman, 1986), controlled droplet applicators generally use much much lower volume application rate (diluent) but maintaining similar amount of active ingredient per ha. This tremendous saving of diluent is advantageous not only with respect to reduction in weight of application machinery but also in areas where water is a constraint especially in drier parts of Northern Nigeria.

The vmd for the ED sprayer was found to range from 45 to 64 micron (μm) in comparison to Ulva which was 96-102 m for red restrictor and 104-115 for the yellow restrictor. There was an increase in droplet size with decrease in the number of batteries in the battery compartment (input voltage), the ED sprayer did not work at an input voltage of less than 3 volts (Table 2.2). The recommended droplet size for normal crop spraying using Ulv machines is 60-120 um with 80 um as being the optimum.= The smaller droplets (80 μm) though desirable in insecticides application are very drift prone and may never settle on the target. The point of deposition down wind presuming a cross wind speed of 1m/sec and a height of release of 1m is 22m for 40 um droplets; 10m for 60 um droplets; 6m for 80 um droplets and 3m for 120 um droplets. The smaller droplets produced by the 'ED' sprayer (40-60 um) are not affected by the wind velocity as being electrically charged they are attracted by the target crop. This system therefore has an

Table 2.1 Comparison of flow and application rates of 'Electrodyn' Sprayer with 'Micron Ulva' Cda Sprayer (After Raheja et-al 1984)

Sprayer	Nominal Flow rate ($Cm^3 min^{-1}$)	Measured Flow rate ($Cm^3 min^{-1}$)	Volume Application rate (L/ha)*	Active Ingredient (ai) g/ha
Electrodyn (ED)	3.00	3.10	0.52 (1m swath)	12.00
			0.26 (2m swath)	6.00
ULVA spinning disc (yellow restrictor)	30.00	20.00	1.11 (3m swath)	19.00
ULVA spinning disc (Red restrictor)	60.00	83.00	2.31 (6m swath)	41.50

* Based on a walking speed of 1.0 m/sec.

advantage of allowing spraying at the wind speeds where normal ULV spinning disc spraying would be risky. Even though the ED sprayer has the merit of not being dependent upon wind to ensure appropriate spray cloud dispersion it however has a limitation of restricted swath width to just the width of a single crop canopy due to the nature of motion of charged droplets.

The droplet spectrum for the 'ED' sprayer is very narrow compared with that of the normal spinning disc Ulva sprayer such as the ULVA machine but droplet distribution is slightly bimodal similar to that of the ULVA. This means that the droplet distribution does not show appreciable advantage over ULVA machine.

So far, the above review at the IAR was focusses on insecticide/fungicide cda application only, using small droplets of oil based sprays. Some work was however carried out at the Institude on spinnig disc cda herbicide applicator performance.

Kaul *et al* (1981) evaluating comparatively the performance of four spinning disc cda herbicide applicators viz:- Micron Herbi, FW, Handy, Berthond C2 and Turbair weeder, points out that there is some indication of change in flow rates as the sprayer bottles empty with flow rates increasing as the bottles are about to empty in some makes. While the

machines show a rather close range in their swaths widths (1.42-1.5m) (Table 2.3), they however show volume distribution patterns of varying degrees. Comparative evaluation of the four spinning disc herbicide applicators in terms of spray droplet spetrum revealed that even though the machines operate on same principles is shown on indication of differences in spray droplet spectra Table 2.4.

The Micron Herbi gave the best droplet formation among the machines showing the narrowest spectrum. However, droplets of sizes closer to that recommended for normal herbicides application (about 200-250 micron vmd) are obtained when the machine is operated at around the lower voltage limits (about 6v). This is also the case with Berthoud C2 machine.

The FW Handy on the other hand produces droplets closest to the recommended size but with the most irregular number distribution showing a bi-modality in the spectrum obtained.

Turbair weeder produces droplets that are rather too small for herbicide application (125-140 um vmd) for all the three restrictors and at the recommended voltage (6V) most likely due to low flow rates and a bit higher rotational speeds. The droplets are however relatively more uniform with the least dispersion ratio (1.2 - 1.3).

Table 2.3 Flow rates and Swaths of four makes of spinning disc LV Cda herbicide applicators using different restrictors. (Kaul et al (1981).

Machine	Restrictor	Rotational speed (rpm)	Average flow rate (ml/min)	Swath width (m)
Micron	Blue	2000	53	1.50
Herbi	Yellow	2000	82	
	Red	2000	230	
FW	Blue	1700	53	1.44
Handy	Yellow	1700	80	
	Red	1700	235	
Berthoud	Blue	2000	55	1.44
C2	Yellow	2000	82	
	Red	2000	230	
Turbair	0.9 mm	2300	22	1.42
Weeder	1.1 mm	2300	24	
	1.2 mm	2300	28	

Table 2.4 Droplet spectra of four Cda Herbicide Applicators (Kaul et al 1984)

Machine	Voltage	Restrictor	Flow rate (ml/min)	Rotational speed (rpm)	Droplet spectrum D16	Nmd (µm)	D84	D16	Vmd (µm)	D84	r
Micron	12	yellow	82	2000	176	125	135	120	160	180	1.20
Herbi	6	"	82	2000	85	134	155	140	200	240	1.50
FW	12	"	80	1800	145	160	220	175	210	250	1.30
Handy	6	"	80	2200	74	158	135	105	235	165	1.40
Berthoud	12	"	82	2000	76	190	105	115	240	205	1.30
C2	6	"	82	2000	80	168	165	140	250	245	1.70
Turbair	12	1.2mm	28	2300	80	102	130	100	125	155	1.20
weeder	6	1.2mm	28	1800	68	105	140	105	140	105	1.70
(forester)	6	0.9mm	22	2300	86	105	130	110	130	150	1.20

When the four spinning disc herbicide applicators were evaluated comparatively in the field under same operational and environmental conditions it was found that for the same type of test fluid, the turbair forester gave about half the application rate (12 L/ha) than either Herbi, Handy or Berthoud machines (Table 2.5). This reduction in application rate would be advantageous in the use of such a machine if other parameters such as droplet sizes were optimum. Although time involvement per hectare appears to be long, this is generally dependent upon the operator walking speed (in this case rather low- 0.85 m/sec) and in most situations the normal operator walking speed for spraying operation is about 1.0 m/sec, which would have resulted into appreciably reducing the time involvement per unit area.

Table 2.5 Field evaluation of four Spinning disc LV herbicide applicators (from Kaul et al (1984))

Machine	Micron Herbi.	FW Handy	Berthoud C2	Turbair Forester
Restrictor	Yellow	Yellow	Yellow	1.1 mm
Swath (m)	1.50	1.44	1.44	1.20
Application rate L/ha	24.0	22.50	25.60	12.0
Time involvement hr/ha	4.50	4.50	4.50	4.65
Walking speed	- 0.85 m/sec			
Temperature	- 28°C			
Wind speed	- 3 m/sec			
Test fluid	- water plus 'teepol'			

2.2 Modifications on some Existing Cda Spraying techniques to improve spraying efficiency.

A number of attempts have been made in some parts of the world especially Europe to modify or re-design existing controlled droplet application techniques in order to improve spraying efficiency and yet retaining the cda advantages. These attempts are however mainly limited to herbicide application and are highlighted below:-

2.2.1 Development of Pneumatically driven spinning disc herbicide applicator (Birky sprayer).

The 'Birky' sprayer, developed by the Swiss Nigerian Chemical Company (Ciba-Geigy) is a controlled droplet applicator for spraying herbicide at low volume (LV) with a pneumatically driven spinning disc. While in the conventional Cda herbicide applicator like 'Micron Herbi' and 'FW Handy' the disc driven by an electric motor powered by D size dry cell batteries, the Birky spinning disc is driven by air supplied to a turbine by a pneumatic piston pump. (Kaul and Suleiman, 1990). In a way it combines the principles of a knapsack lever operated hydraulic sprayer with that of a spinning disc Cda sprayer. The Birky sprayer has three interchangeable restrictors colour

coded Yellow, Red and Blue of different orifice sizes giving an output range of about 20-30 L/ha and droplet size range of about 190 - 300 micron vmd and a wider Swath width at about 1.6 metres compared with other conventional cda spinning disc herbicide applicators already mentioned. The Birky has a unique advantage of eliminating the use of batteries there by making it more economical to operate than other hand held spinning disc herbicide applicators.

2.2.2 Development of Peristaltic pump Sprayer (ICI).

In the ICI peristaltic pump sprayer (Matthews, 1979) liquid is forced through a piece of rubber or plastic tubing by progressive squeezing along the wall of the tube. A peristaltic pump, operated by rotating cams attached to the wheel of a small sprayer is used for inter-row application of herbicides with an impact nozzle, operated at low pressure (about 0.7 bar). The main difficulty in the field arises from mud collecting on the wheel. Minute holes developed in the tubing of the pump after field use and produced a fine spray which reaches the crop.

2.2.3 Development of the IAR Ground-metred shrouded Disc Herbicide Applicator (GMSD)

The IAR Ground metred shrouded disc herbicide applicator (GMSD) is a CDA Spinning disc manually operated herbicide sprayer based on very low volume (VLV) Spraying System (Choudhury, Kaul and Ogborn 1981). It is another attempt to improve both the spray volume distribution pattern of a conventional Cda herbicide applicator and the application rate by employing the principles of disc shrouding and the use of peristaltic pump. The pump which is ground metred is able to supply liquid to the centre of the shrouded disc at a rate that is proportional to the walking speed of the operator. By so doing the spray application rate is controlled and the spray volume distribution pattern improved.

2.2.4 Development of the IAR improved Ground metred Shrouded disc Herbicide Applicator (IGMSD)

This is another attempt made at the IAR to improve the efficiency and capacity of existing manual cda herbicide application technique. In the sprayer a boom consisting of two Micron Herbi Spinning discs shrouded at 180^{o} and spaced at 95cm apart and positioned at 60cm above the ground is employed

based on Bitrus (1985).

Two 12 volt electric motors driving the spinning discs are connected in parallel to a set of 8 U2 batteries arranged in a compact battery case mounted on the handle of the sprayer. The spray tank is placed centrally between the discs and spray delivery tubes which connect the tank out let and the restrictor through a paristaltic pump (Suleiman and Imam, 1987). Just below the shrouds of the discs are tubes leading back to the tank to enable excess spray liquid circulate back to the tank. During operation of the sprayer, the spray chemical is pumped on to the surface of the rotating disc by the paristaltic pump which rate of pumping depends only on the walking speed of the sprayer operators so that any increase in operator speed only increase flow rate and vice-versa thereby ensuring uniform application of chemical along the swath. The pump automatically stops supplying liquid to the spinning disc when the operator stops thereby preventing over does during spraying. Any excess liquid which is not atomised by the disc recirculates back into the tank thereby saving chemical.

When the sprayer was evaluated comparatively with two other cda sprayers viz The Micron Herbi Sprayer and the GMSD (After choudhary 1981) in terms of spray volume distribution pattern droplet

spectrum, field capacity, swath and application rate of spray material (Table 2.6); the sprayer droplets were found to fall within acceptable range for herbicide application. The sprayer has wider swath lower spray application rate and higher capacity. Above all, better spray volume distribution pattern.

Table 2.6 Laboratory and field performance comparison of the improved Ground-metred Shrouded Disc (IGMSD) and two other cda herbicide applicators (Suleiman & Imam, 1987)

Machine	Distribution pattern test	Droplet Size Test			Field Test		
	Coeff of variation %	(Vmd) μm	(Nmd) μm	(r)	Field Capacity (Ha/hr)	Swath (m)	Application rate (L/ha)
Micron Herbi GMSD (after choudling 1981)	77.97	240	200	1.20	0.43	1.50	6.00
	46.07	248	219	1.13	0.43	1.50	6.04
Improved GMSD	34.60	250	230	1.09	0.84	2.90	4.03

2.3 Review of CDA Sprayer Power Consumption Studies

Power consumed by a cda spinning disc sprayer during operation is the product of the current ebing drawn by the electric motor driving the rotating disc and the voltage across the electric motor. Thus:

$$P = VI \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

Where:-

P = Power consumption (Watt)

V = Voltage across the motor (Volt)

I = Current passing through the motor (A_{mp})

Power consumed by the sprayer is the main determining factor of the performance of the sprayer. The objective of any spraying operation is the emission of spectrum of droplets and placing them on a particular target. In paralled, the main objective of cda spraying is the emission of narrow spectrum of droplets of a particular size and directed to a specific target to control a specific pest. It is only normal to say therefore that for the successful production of such droplets and placing them where they are required the source of power for running the sprayer must also be specific, definate and constant. If there is a change of power at the beginning or during the course of spraying it may not be out of place to expect also a change in the emmission of the droplets. However, the type of

change in the spray droplet emmission that actually takes place and the effect of such change in pest control is not fully understood. Also there are various types of power sources that are used for running cda sprayers mainly electrical, manual or mechanical or even a combination of some of the above. A point worthy of notice here is that even within a particular class of power used for running sprayers say-electrical power - there are still various makes and models of power units such as the U2 batteries which may themselves vary in characteristics and may hence affect the sprayer performance. These are also yet to be fully studies and understood.

A number of skeletal studies concerning power supply and consumption of cda spinning disc sprayers as they affect disc speeds and as they are affected by flow rates also have been carried out in some few Research Institutes.

Investigation carried out at International the Pesticide Application Research Centre (formerly Overseas Spraying Machinery Centre), Imperial College London University on the relationship between input voltage across the spinning disc cda sprayer electric motor and period of use indicated that there was a decrease in voltage with period of use of the cda sprayer at a particular flow rate (Matthews, 1979)

This study however said very little about the nature of spray droplets being emmitted by the experimental sprayer with decrease in voltage.

Beeden, (1975) observed a decrease in battery life and reduced rotational speed of disc with increase in flow rate. He further observed a decrease in the life of battery used with spinning disc sprayer when the temperature falls from 27°C to 15°C and a decrease in life of battery when viscons liquids are sprayed.

Bals (1990) in his Battery life tests with two models of Ulva cda sprayer obtained the following results as summarised in the Table 2.

Table 2.6a Battery life test with two models of cda sprayers

Sprayer Make/model	Battery make	Battery number	Life* (hrs of running)
Micro Ulva	Ever Ready Silver seal R 205 (UK)	6	25
Micro Ulva	Varta Super 2020 (Togo)	6	12
Ulva 16	Ever Ready Silver Seal R 205	8	13

NB* Number of hours of run of sprayer upto the period when the spinning disc rotational speed drops to below 4000 rpm.

The results from the above table gave some indication of variation of lengths of life of different makes of batteries when used in same cda sprayer and also variations of life length when different types of cda equipments are used with same type of battery as power source.

2.4 Some Observations on the Literature Review

The following observations can be made from the review.

(i) Different designs of cda sprayers aimed at achieving different spraying aobjective(s) exist, either as commercially available models (Table A 2.7) or as equipments still at prototype state (Table A 2.8). However, although they are of various makes, models, operating on different principles, they can be classified into four groups; viz:-

- High speed spinning disc cda sprayers (Battery powered) for application of small droplets suitable for control of insects and disease pests in particular.
- Low speed spinning disc cda sprayers (Battery powered) for application of large droplets suitable for control of weeds.

- Electrical cda sprayers (Battery powered) for application of charged droplets at present restricted to production of small droplets for insects and disease control only.
- Manually powered spinning disc cda sprayers for insect/disease and weed control.

(ii) All the cda spraying machines so for produced and in the market today, except the Birky Sprayer, have their spinning discs powered by a set of U2 dry cell batteries. In other words they have a common power source either to rotate a disc for droplet atomation or to power a built in generator to supply voltage to produce electric field for charging droplets and breaking them into droplets.

(iii) There has been a number of attempts to modify some of the existing Cda sprayers either with the view to improving spray volume distribution pattern, Application rates or field capacity.

(iv) These attempts however, are limited only to a certain class of cda sprayers - The herbicide applicators no attempt has so far been made to improve same on the insecticide/fungicide applicators within the cda sprayers.

(v) More importantly the cda sprayers, which are powered generally by a common source of power (U2 class of batteries) lack adequate information regarding the effect of different makes of such power source(s) on droplet spectra or even the effect of same power source on different designs of cda sprayers, even though there is a pointer that such effect(s) exist (Table 2).

(vi) Moreover, all the manually carried cda sprayers so far being marketed today achieved are things only in common - Ground Crop Spraying - Non of such sprayers in their present forms could be used for tree crop pest control or for control of pests in accessible due to limited distances their droplets are projected.

(vii) Most of the cda sprayers so far designed are each for specific purpose - either insecticides/ fungicides or for herbicide application. Non of them in their present design could be used as a multi-purpose applicator - for application of more than one type of pesticide and for more than one pest location situation without the use of some other special accessary and yet maintaining the cda advantage.

These factors along with the need to develope a multi-purpose sprayer for a low scaled farmer indicate a need for the proposed study.

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CHAPTER 3

3.0 METHODOLOGY

The primary objective of this thesis was to evolve a multi-purpose sprayer which combines the advantages of both hydraulic knapsack sprayers and motorise knapsack mist-blowers as well as retains the basic merits of conventional controlled droplet applicators.

The study involves first the identification and study of the basic weaknesses (limitations) of the conventional CDA sprayers which limit their acceptability and then encorporating design modifications aimed at improving the system. The procedure for the investigation of the identified limitations and evolving design procedure for modified and improved system is given in this chapter while the design and evaluation of the improved multi-purpose sprayer prototype based on results of investigation are given on Chapters 5 and 6 respectively.

3.1 Determination of power consumption of selected CDA sprayers and effect on Droplet Spectra.

As already stated, in Chapter one, power consumption and limited versatility seem to be some of the major weaknesses of the present day battery operated CDA sprayers. It is therefore necessary to investigate and compare the relative power consumption of the various classes of existing CDA sprayers with a view to finding solution to power consumption problem.

3.1.1 Seclection of Experimental CDA Sprayers.

The following sprayers (9 nos) were chosen for power consumption studies at different input voltage levels and relative effects on their spray droplet spectra.

i) Micron Ulva spinning disc CDA insecticide/ fungicide sprayer.

ii) Techoma TI UBV and Techoma II insecticide/ fungicide sprayers.

iii) Turbair XI and Turbair XII insecticide/ fungicide sprayers (plate 3.1).

iv) Micron Herbi, FW Handy, Berthoud C_2 and Turbair forester/weeder spinning disc herbicide sprayers (Plate 3.2).

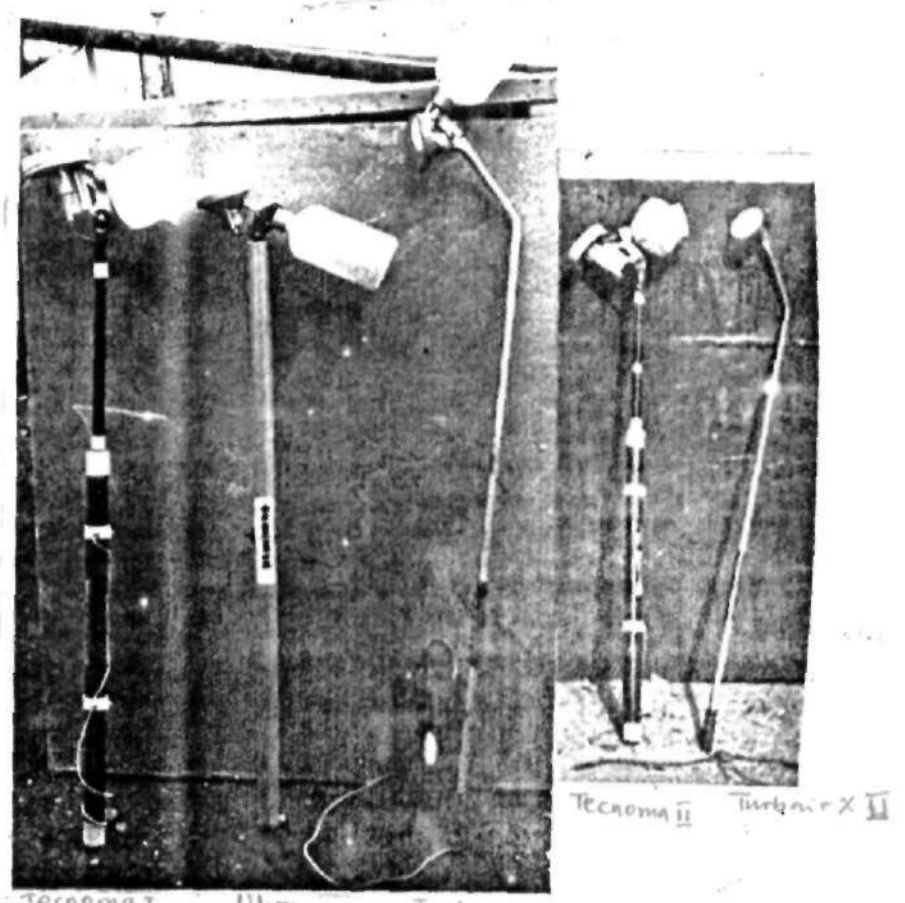


Plate Tecnoma I Ulva Turbair X I

Tecnoma II Turbair X II

3.1 The five experimental spinning disc insecticide/fungicide cda sprayers.

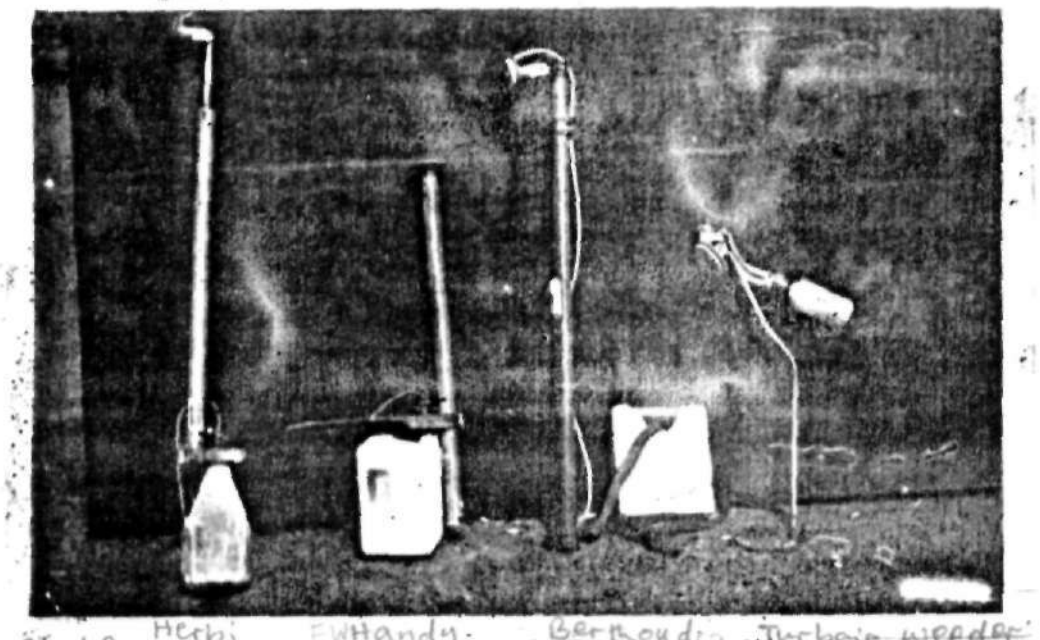


Plate Herbi FWHandy Berthoud Turbair weeder

3.2 The four experimental spinning disc herbicide cda sprayers.

Brief description of the design features and principles of operation of the chosen CDA sprayers listed above are given in Appendix I. The selection of the above mentioned sprayers for the experimental work was purely based on availability within the study locality. Based on a short market survey carried out, they found to be the most common makes and models of CDA sprayers in the locality.

3.1.2. Selection of Ultra low volume formulations

Based on Jorhstone and Johnstone (1977) Studies on the effect of meteorological factors on requirements of Ulv formulations for evaporation and ease of atomisation problem Cypermethrin 1.8 Ulv (Cymbush) was selected for use with Tecnoma and Ulva machines while Turbair Resmethrin was chosen for the Turbair X machines. These formulations were however replaced by simulated mixtures of Cora Oil and Kerosine in the ratios 3:2 and 1:6 respectively in order to avoid operator hazards and pollution to environment.

3.1.3. Selection of Droplet Size and Power consumption measuring equipments.

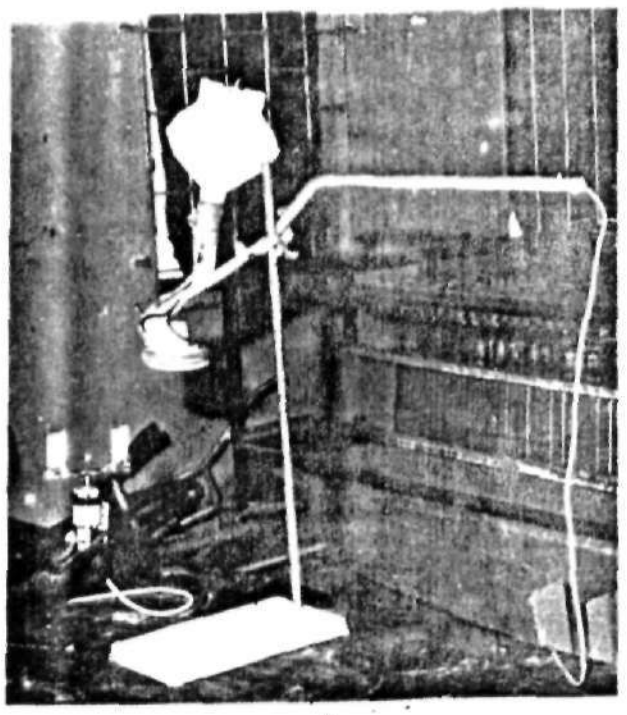
The data for droplet spectra and power consumption studies were obtained simultaneously, below is the high light of the main equipments used for obtaining the data and the bases for selection.

3.1.3.1. Droplet sampling equipment

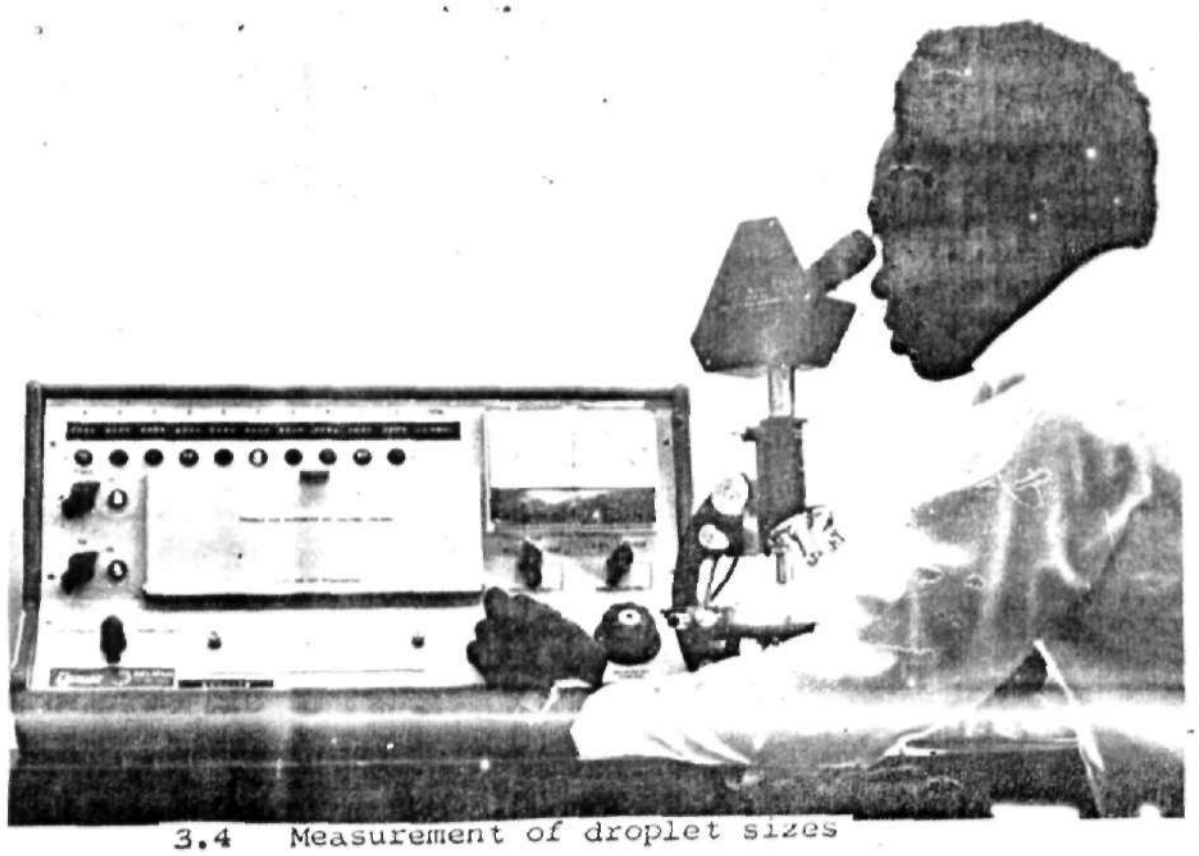
The rotorod sampler (May (1985), and May, (1986)) was selected as a droplet sampling equipment due its obvious advantage of impaction tendency of droplets on its rotating body and its suitability for use with normal glass slide coated with Magnesium oxide (Plate 3.3).

3.1.3.2. Selection of Droplet Measuring Equipment

Among the most modern methods and equipments for measuring droplets from a sprayer such as Laser holography, High speed photography, Microscope and graticule and partide size analyser, the particle size analyser was chosen for the measurement of droplet sizes due to its being the quickest and most



3.3 Droplet sampling using the rotorod sampler.



3.4 Measurement of droplet sizes using the Flemings particle size Analyser.

phisticated method available within the locality (Plate 3.4).

3.1.3.3. Selection of Power Consumption Measuring equipments

The power consumption measuring equipments used for this work include:-

i) A constant Power Source: Which the IRWIN L.T. Power supply type EJ176 with a variable voltage supply of range 0-35 Volt. DC was selected purely based on availability plate 3.5.

ii) An Ammetre:-

This was required to measure the current drawn by the sprayer motor (Plate 3.5) and the make selected was the Harris A Ammetre, selected for its simplicity and current measuring ranges of 0-1.0 Amp and 0-5 Amp in steps of 0.02 and 0.1 Amp respectively.

iii) A Voltmetre:-

This was required to measure the voltage across the sprayer electric motor (Plate 3.5). Harries V voltmetre was selected on the same basis as for the Ammetre above. It could measure

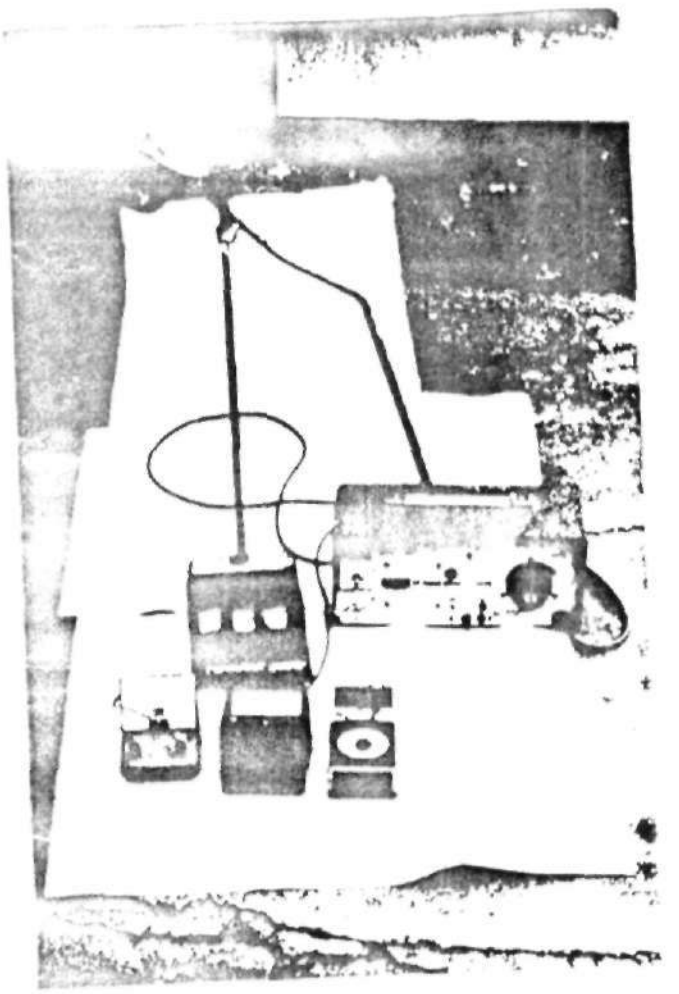


Plate 3.5 Power consumption measuring equipments.
Left to right: Voltmetre, Ampmetre, Constant power source.

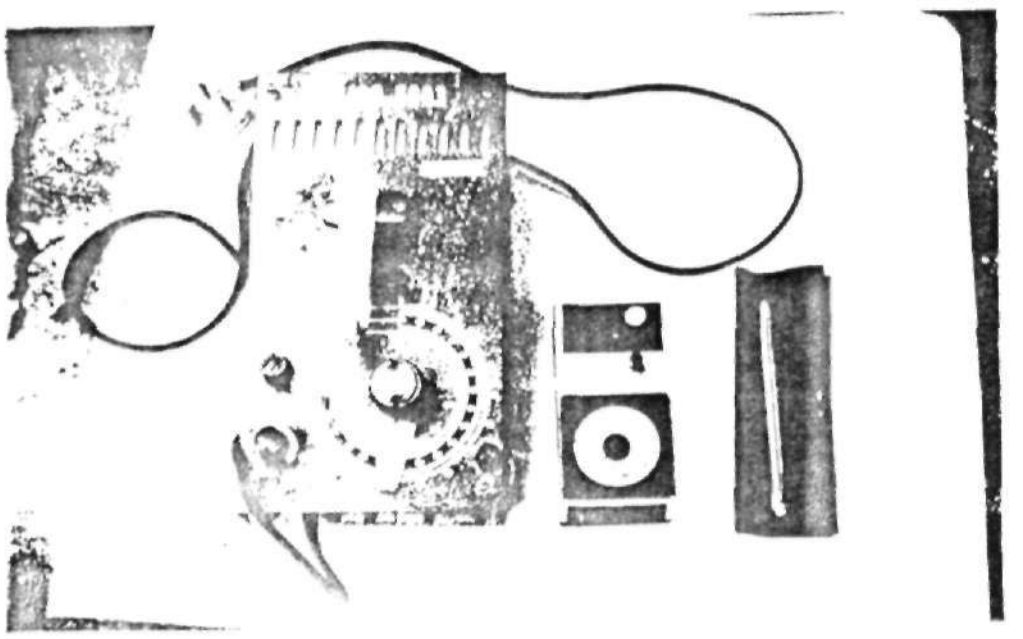


Plate 3.6 Spinning disc rotational speed measuring devices.
Left to right: Helios 5003 stroboscope, G.T. Optical Tachometre, and 'Vibratak' Tachometer

voltage in two ranges 0-5 volt and 0-15 volt in steps of 0.1 and 0.5 volt respectively.

3.1.3.4. Selection of Spinning disc rotational speed measuring device.

A suitable tachometre, G.T. Optical Tachometre was selected for this among a few makes such as vibratak and Helioth stroboscope tachometres on the basis of its higher accuracy relative to others (Plate 3.6).

3.1.3.5. Other laboratory and field apparatus/ equipments used.

In addition to the above mentioned, the following equipments were used for the experimental work.

(i) Standard Microscope with a Mechanical slide and four ocularlenses. (ii) A stop watch (iii) A measuring tape (iv) measuring cylinders (v) Glass slides (vi) Magnesium oxide ribbon (vii) A burner (viii) A Hygrometer consisting of a wet and dry bulb thermometers. (ix) A universal laboratory stand (x) A tally counter and (xi) A Glass slide marker.

3.1.3.6. Design of the first set of Experiments

The droplet spectra and power consumption of each of the nine chosen sprayers were determined at three input voltage levels viz:- 12, volt (upperlimit) and 6 volt lower limit below which the batteries used in running the sprayers would be regarded runned down (Matthews 1979) and an intermediate voltage between the two limits (9 volt) in order to detect what happens in between. This was achieved by adjusting the variable voltage supply.

3.1.3.7. Randomisation

Here, droplet samplings were allocated between treatments (i.e. particular sprayer run at particular voltage level) at random to avoid conscious or unconcious bias in collection of droplets due to possible change in environmental condition, tiredness of the sprayer operator etc. A completely randomised design was carried out.

3.1.3.8. Layout of Experiments

To satisfy the principle of randomisation, droplet samplings were numbered and arranged so that a random selection of numbers carry particular treatment,

using the table of random numbers (Lindley and Miller 1970).

3.1.3.9. Execution of the Experiments

3.1.3.9.1 Droplet Sampling Procedure

Droplets were collected on Magnesium oxide (Mg.O) coated slides on which craters of droplets were formed by the impact of the droplets on the rotating slide, formed by burning two strips of magnesium oxide ribbons each 10cm in length below a glass slide. A total of 90 slides containing droplet craters were obtained from the sprayers runned with the respective simulated mixtures.

3.1.3.9.2 Droplet Size measurements

This was carried out using the Flemings particle size analyser and a standard microscope as per described in Matthews (1975a).

3.1.3.9.3 Droplet Size Analysis

This was carried out as per described in Matthews (1975a). Samples of spray deposition, and calculation forms are as given on Appendices B and C while a sample of graph of cummulative percentages plotted against a mean diameter of droplets to obtain

the Vmds and Nmds of each sample as given on Appendix D. Due to the large number of droplet samples and the number of droplets to be counted from each slide (300 nos) manual calculations were regarded too tedious, time consuming and liable to arithmetic errors. Thus a computer programme (Portran) was developed to calculate all the necessary parameters (Appendix G) a sample of outputs of calculation of which is given on Appendix H.

3.2 Determination of the effect of type of Power source on droplet spectrum.

While in the previous set of experiments (Section 3.2) a constant supply of power from a fixed source at different levels was used to investigate the power consumption and droplet spectra from different makes/models of Cda sprayers, in this set of experiments a particular Cda sprayer was selected and run by different makes of power sources (Dry charged and Wet cells) in order to assess the individual power sources performance in terms of production of correct droplet spectrum and durability and in totality its suitability for running a Cda

Sprayer. Out of some common U2 batteries available in the locality four makes viz:- Berec, Eveready, ABC and Brister were selected, (the four being most common and also indigenous) (plate 3·7)

3.2.1 Selection of Experimental Sprayer

Among the common makes/models of Cda sprayer listed in the previous Section, Micron Ulva was found to be the most common and has the provision of being used either with 4 pairs of batteries in series or 8 pairs in paralled and hence selected for the experiment.

3.2.2 Selection of other Experimental Equipments

All other laboratory apparatus used for the experiments such as current, voltage, rotational speed measuring devices were the same as for previous experiments. Also the droplet samplings, Analyses and calculations methods were also the same.

3.2.3 Design, layout, and execution of the second set of Experiments.

The following parameters are to be measured:-

i) Rate of voltage drop of the individual batteries during the period of spraying.

ii) Effect of (i) above on the sprayer droplet spectrum.

iii) Life of individual makes of power source (i.e. the number of hours of spraying before voltage falls to below 6 volt).

iv) Consequences such effect(s) (if any) may have on crop protection.

Each of the selected make of battery was used to operate the Ulva sprayer for fifteen minutes contineously and followed by five minutes rest within which the formulation bottle was changed upto a period of two hours a day. The batteries were then allowed to rest over night and the process continued the next day until the voltage fell to below 6 volt when they were regarded runned down. During that period droplet samples were collected, current and voltage across the sprayer motor were recorded (fig. 3.2). Similarly a sample of lead acid electrolyte batteries were used and data recorded.

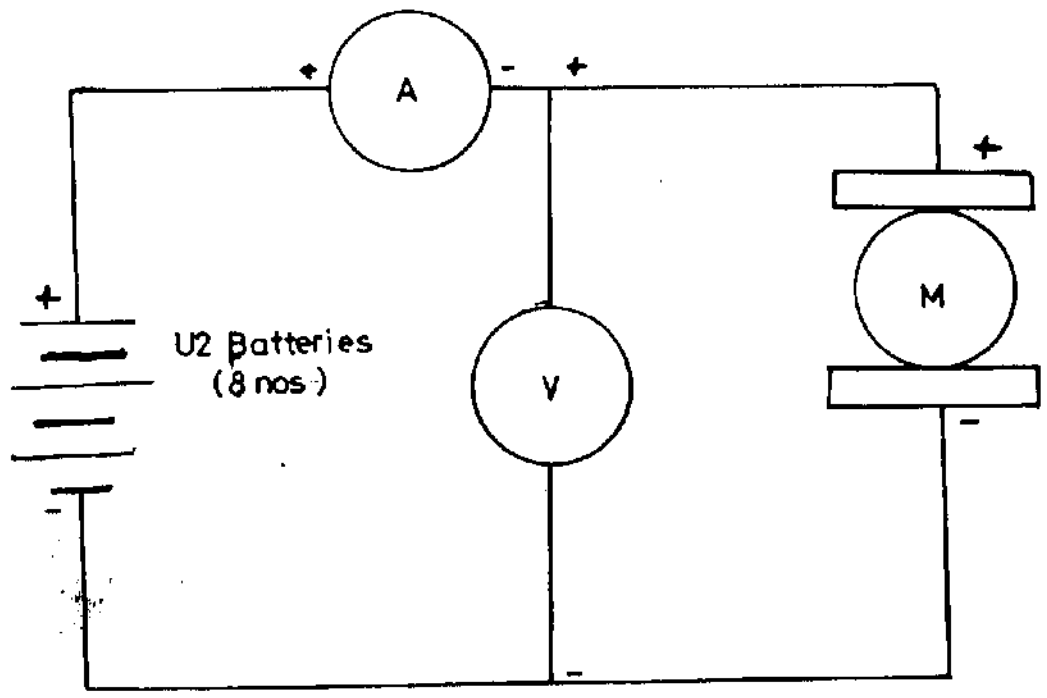


Fig 3·2. Circuit diagram used for experiment work

A = Ampmetre V = Voltmetre
M = Spinning disc electric motor

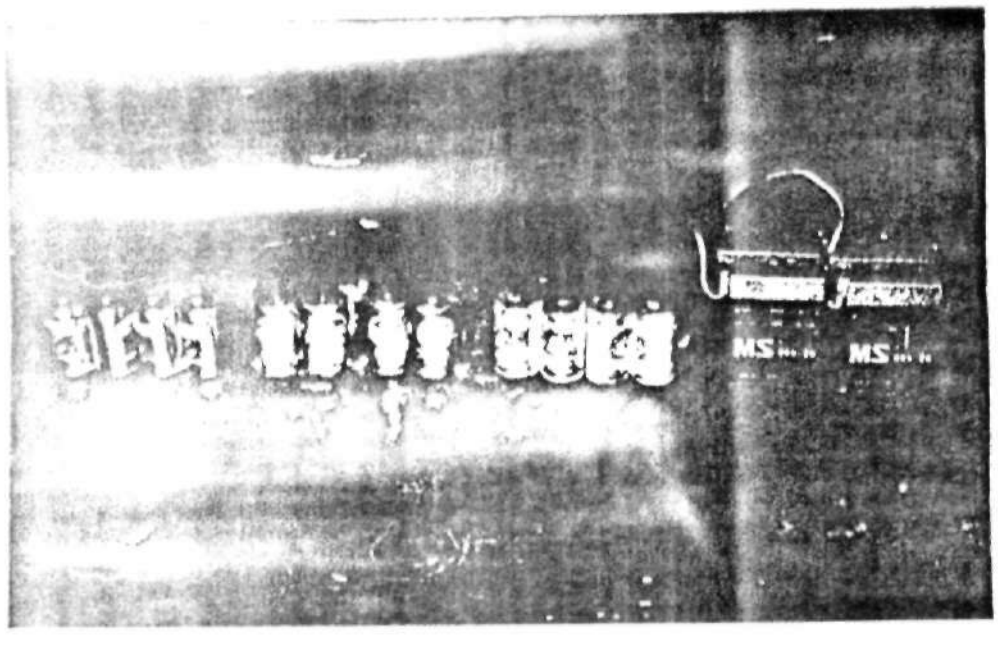


Plate 3.7 Samples of selected Experimental made in Nigeria U2 Batteries, and Lead acid Electrolyte Batteries.

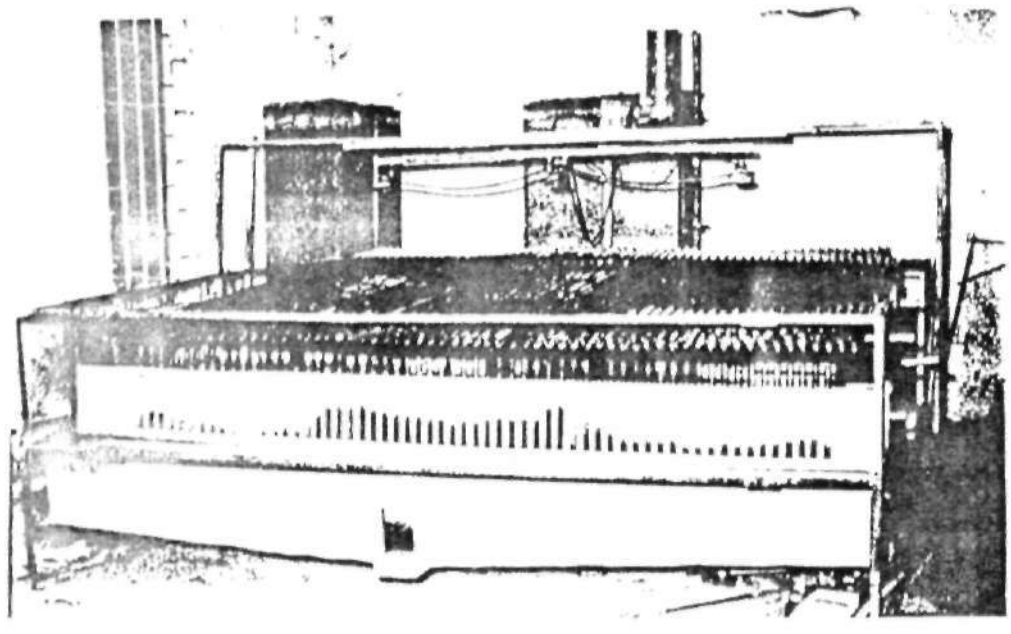


Plate 3.8 Determination of spray volume distribution using the patternator.

3.2.4 Measurement and Analysis of droplet sizes.

The sizes of droplets were measured in the usual manner as for previous experiments. Calculations of Vmds, Nmds and rs and power consumptions were carried out in the same manner.

3.3 Other Data Analyses

The statistical analysis of interest for the investigation include the following:-

i) Computation of mean, standard deviation, range and co-efficient of variation of a number of measured data especially with regards to the spray volume distribution patterns of the developed.

ii) Analysis of variance using F-ratio of the measured variables for each set of experiments for sprayer power consumption, droplet spectra and battery performance characteristics.

CHAPTER 4

4.0 RESULTS AND DISCUSSIONS

In this Chapter, results of the series of experiments conducted on the selected 9 makes/models of spinning disc low and Ultra low volume cda sprayers and 4 makes of their power sources (U2 batteries) are presented and discussed in relation to conceptualizing an improved design of a multi-purposed cda sprayer. The Chapter is divided into four main sections viz:-

i) Droplet spectra and power consumption of spinning disc cda sprayers as influenced by change in voltage.

ii) Characteristics of different makes of power sources used with spinning disc sprayer and their effects on the sprayer droplet spectrum.

iii) Influence of (i) and (ii) above on crop protection

iv) At the end of the Chapter, a summary of general inferences and evolvement of design criteria are presented which indicate the needs and formed the basis for the design of the improved multi-purposed controlled droplet applicator.

4.1 Droplet spectra and Power consumption of spinning disc cda Sprayers as influenced by change in motor voltage

In the discussions it is important to first present the summaries of some of the basic results obtained from the series of the experiments conducted during the investigations. Tables 4.2 and 4.3 show the summaries of parameters of spray droplets spectra. Rotational speeds and power consumptions of the five insecticide/fungicide spinning disc cda sprayers and the four spinning disc herbicide sprayers respectively as

they were run at different motor voltage levels. Table 4.8 on the other hand shows similar parameters measured when Ulva sprayer only was used with different makes of U2 batteries daily until the batteries were runned down. On the three Tables only the mean values of the parameters measured are represented as highlights while the actual values were used for the various analyses carried out.

4.2.1 The influence of change of motor Voltage level on droplet spectra of Spinning disc cda Sprayers.

This section gives summaries of the nature of spray droplet spectra of the selected experimental cda spinning disc sprayers as their motor voltages were changed during the course of spraying. The basic parameters of spray droplet spectra determined were volume median diameters (Vmds), Number median diameters (Nmds) and Dispersion ratios (rs) of the sprayers. The effects of change in motor voltage are presented and discussed for each parameter in turn.

4.2.1.1 Volume Median Diameters

The Summaries of Volume median diameters of the 9 spinning disc cda sprayers at different operating

voltages are presented on Fig. 4.2 to Fig. 4.3 and Table 4.3 with highlights as follows:-

(i) Irrespective of sprayer make the volume median diameters are lowest at higher motor voltages and vice versa. Thus smaller droplets (70-80 micron) that are suitable for the control of flying insects, and insects on foliage (Matthews, 1979) are those produced at 12 volt and near around for micron ulva, Turbair XII and Tecnoma II models. As the voltage decreases in all cases droplet sizes increase up to about 200-250 micron (vmd) for the above mentioned makes of machines at about 6 volt.

The situation is however different in the case of Tecnoma I model. At similar voltage levels the Tecnoma I machine produces generally smaller droplets (50-60 micron vmd) and below the sizes normally regarded as most suitable for general crop spraying (about 80 µm vmd) (Bals (1969), Matthews, (1979) and Bals (1982). The droplets produced by Tecnoma I model are thus very liable to drift and are potential operator and environmental pollutants. Such spray droplets are not only lost to non target areas and thus constitute an un-economical spraying operation but also pullute the

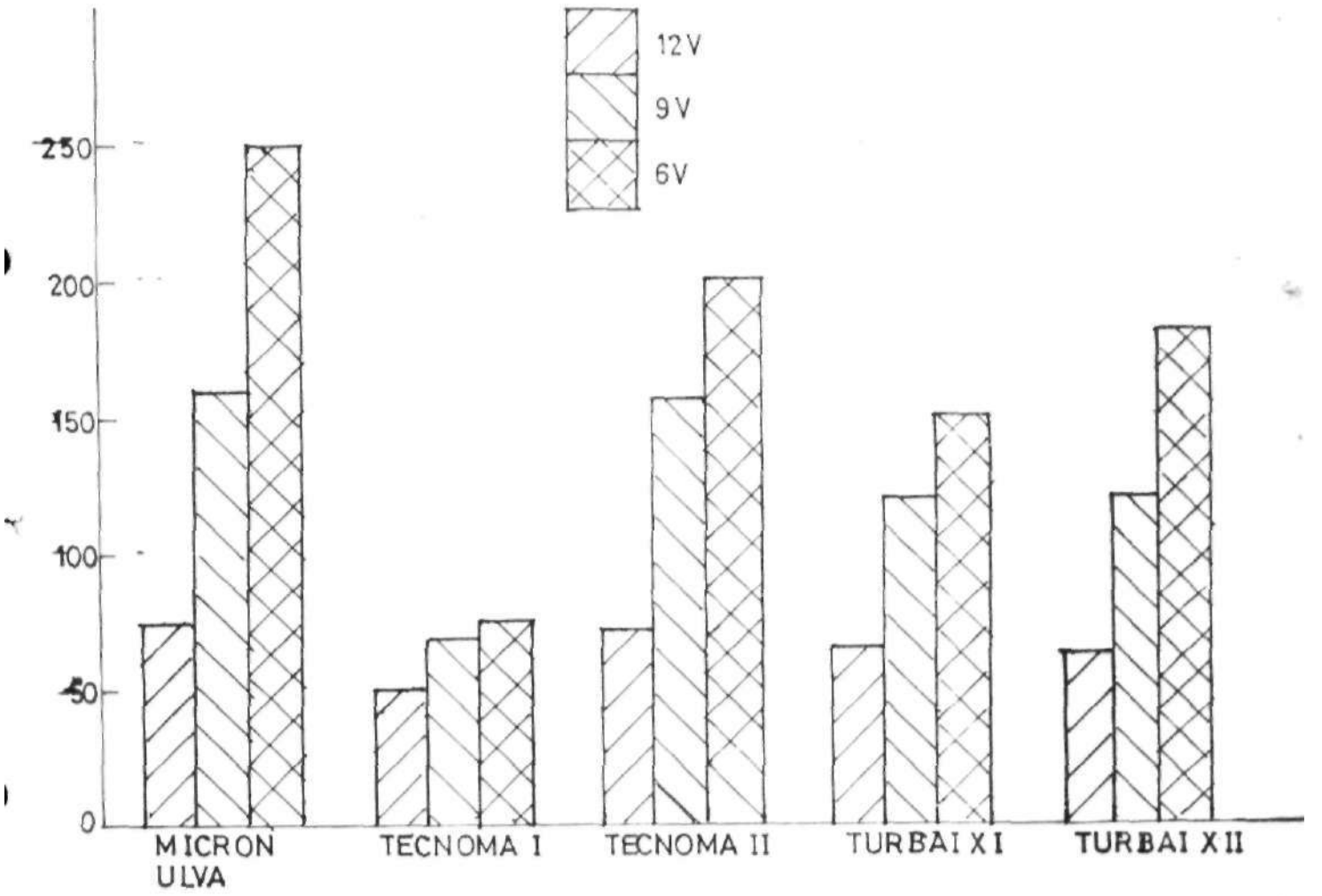


Fig. 4.2. Volume median diameter of the five insecticide/fungicide sprayers at different voltage levels

Table 4.2 Summary of Parameters of spray droplet spectra, Rotational Speeds and Power Consumptions of five Insecticide/Fungicide cda Sprayers at different voltage levels.

Machine make/model	Voltage level (volt)	Current drawn (Amp)	Rotational speed (rpm)	Droplet Vmd* (μm)+	Spectrum Nmd** (μm)	r***	Power Consumption (Watt)
Micron Ulva	12	0.54	7000	75	65	1.15	6.48
	9	0.37	4500	160	128	1.25	3.33
	6	0.33	3000	250	205	1.28	1.98
Tecnoma TlUBV	12	1.82	10500	50	42	1.18	22.80
	9	1.20	8000	68	57	1.20	10.80
	6	0.80	6600	75	60	1.50	4.80
Tecnoma TII	12	0.59	7500	72	62	1.17	7.08
	9	0.30	4200	156	129	1.21	2.70
	6	0.26	3800	200	160	1.25	1.56

Table 4.2 (Contd.)

Turbair X1	12	0.72	8000	65	58	1.13	8.64
	9	0.45	5200	120	98	1.23	4.59
	6	0.24	4600	150	116	1.29	1.44
Turbair X_{ij}	12	0.60	8500	63	53	1.20	7.20
	9	0.45	5200	120	95	1.26	2.7
	6	0.30	4000	180	141	1.28	1.8

Foot Note

* Vmd - Volume median diameter (Average)

** Nmd - Number median diameter (Average)

***r - Dispersion ratio

μm - Micron (Micro metre = 10^{-6} metre --- $(1/1000$ m.)

Table 4.3 Summary of parameters of spray droplet spectra, Rotational Speeds and Power consumptions of four spinning disc herbicide cda sprayers at different voltage levels.

Machine make/model	Voltage level (volt)	Current drawn (Amp)	Rotational speed (rpm)	Droplet Vmd* (um)+	Spectrum Nmd** (um)	r***	Power Consumption (Watt)
Micron Herbi	12	0.12	2000	210	113	1.20	1.44
	9	0.11	1800	240	185	1.30	0.99
	6	0.11	1800	260	173	1.50	0.66
FW	12	0.2	1800	260	200	1.30	2.40
	9	0.15	1750	280	206	1.36	1.35
	6	0.15	1750	280	187	1.50	0.90
Berthoud	12	0.11	2000	220	176	1.25	1.32
	9	0.10	1800	220	149	1.34	0.90
	6	0.10	1800	240	166	1.45	0.60

Table 4.3 (Contd.)

Turbair forester	12	0.12	2200	200	167	1.20	1.44
Turbair	9	0.10	1900	220	149	1.48	0.90
forester	6	0.08	1900	250	147	1.70	0.48

Foot Note

* Vmd - Volume median diameter (Average)

** Nmd - Number median diameter (Average)

***r - Dispersion ratio

μm - Micron (Micro metre - 10^{-6} metre - $^{1}/_{1000}$ m:)

Table 4.4 Summary of Analysis of Variance of Volume Median Diameters of the CDA Spinning disc Sprayers at various motor voltages

Machine/ Voltage (Variables)	Source of Error	DF	SS	MS	F
A. INSECTICIDE/FUNGICIDE APPLICATORS					
12 volt	Between sprayers	4	1134	283.6	20.2*
	Residual	10	140	14.0	
LSD (5%)-	6.8				
9 volt	Between sprayers	4	16454	4113.6	24.8*
	Residual	10	1660	166	
LSD (5%)-	23.4				
6 volt	Between sprayers	4	50460	12615	186.1*
	Residual	10	678	678	
LSD (5%)	15.0				
B. HERBICIDE APPLICATORS					
12 volt	Between sprayers	3	6225	2075	9.5*
	Residual	8	1750	218.75	
LSD (5%)-	27.9				
9 volt	Between sprayers	3	7200	2400	5.3*
	Residual	8	3600	450	
LSD (5%)-	40.0				
6 volt	Between Sprayers	3	2625	875	5.83*
	Residual	8	1200	150	
LSD (5%)-	23.0				

* Significant at P - 0.05.

environment causing hazards to both the operator, wild lives and soil fauna.

(ii) There were significant difference in volume median diameters of the five makes of insecticide/fungicide spinning disc sprayers at each and every voltage level they were operated, (Table 4.3). At 12 volt however, the differences between the vmds of Ulva and Tecnoma II models, and those between the Turbair X machines were not significant as revealled by the LSD value (6.80). This trend continues for the Turbair X models upto 9 volt level but not for other models.

At 6 volt however, the variation is more pronounced when no two sprayers produce droplets that are not significantly different (LSD (5%) = 15.0).

(iii) Irrespective of Herbicide applicator make/model, the vmds were lowest at higher voltages (12 volt) for all the four makes of sprayers investigated. However, the variation of vmds within the different makes of sprayers at all the voltage levels investigated was not significant. (200-220 at 12 volt, 220-240 at 9 volt and 240-270 at 6 volt). This may be due to the fact that the motors were governed and restricted to rotate within close rotational speed range of

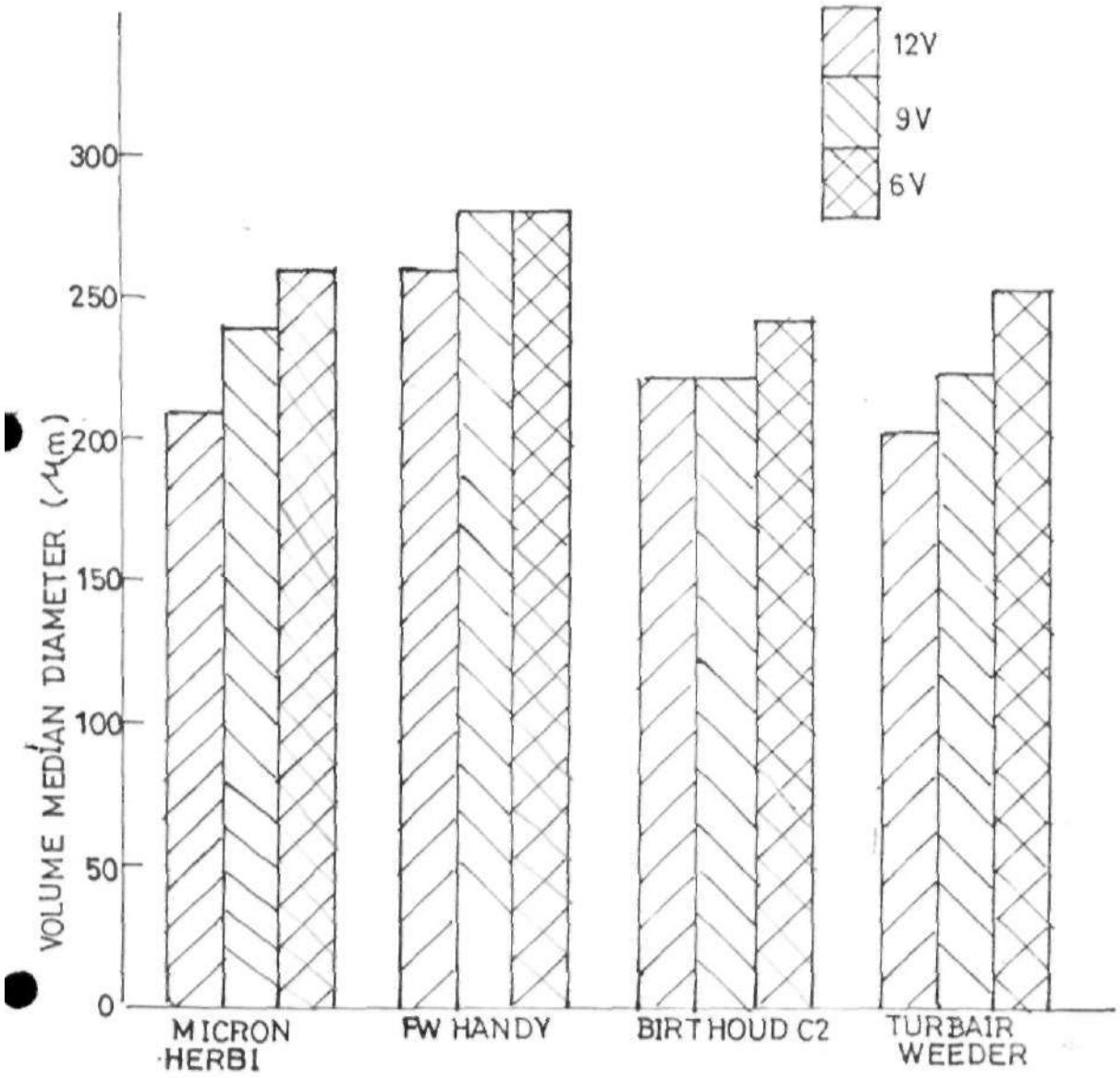


Fig. 4.3. Volume median diameters of the four herbicide spinning disc sprayers at different voltage levels

1750-2200 rpm; between the 6V and 12 volt limits.

(iv) There were significant difference in rmds of the four spinning disc herbicide applicators at all the voltage levels investigated. However only the difference in vmds between Micron Herbi and FW Handy and between the latter and Berthoud C2 are significant, all others are not at 5% level as revealed by the LSD values at all the three voltage levles investigated.

4.1.2 Number Median Diameter

The Summaries of Number median diameters of the nine spinning disc sprayers operated at different voltage levels are presented on Figs. 4.4 and 4.5 and Table 4.5 with high lights as follows:

(i) Similar to the trend of results obtained for volume median diameters, in general there was a progressive increase in the values of Number median diameters of the five insecticide/fungicide spinning disc sprayers with decrease in motor voltage. Thus lower average droplet sizes (without reference to volume) are obtained at higher voltages (say 12 volt) while higher nmds are obtained at lower voltages. This is the case for all the five makes of insecticide/

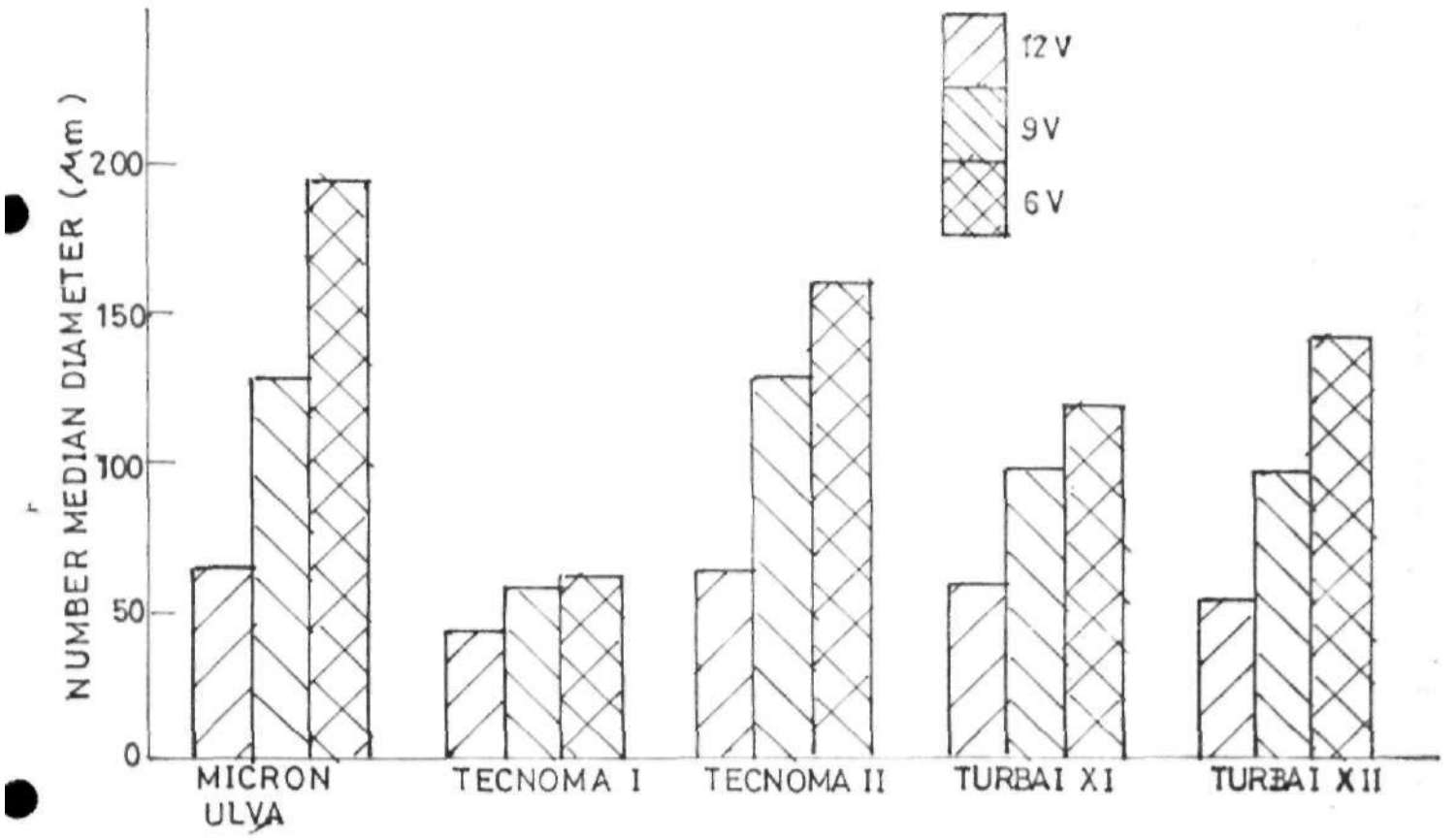


Fig. 4·4. Number median diameters of the five insecticide/ forgicide Spinning disc sprayers at different voltage

fungicide applicators.

(ii) Number median diameters vary significantly between the different makes of the spinning disc sprayers at all voltage levels investigated and this is also the case when same make of sprayer is used at different voltage levels. In the case of Micron Ulva there were about 100% and 200% increase in Nmd when the voltage dropped from 12 volt, to 9 volt and 6 volt respectively. Other makes showed similar trends of increase of Nmd with decrease in voltage but not to the same degree.

(iii) There were also significant difference in the Number median diameters of the four spinning disc herbicide applicators investigated at all the levels of voltages they were operated. However, this variation of Nmds at all the voltage levels did not follow a definate tred. In other words, there was no definate relationship between motor voltage and Nmd.

While at 12 volt the Nmd for Micron herbi was lowest it was highest at 9 volt rather than 6.0 volt as was the case with insecticide/ fungicide applicators. Similar results were obtained for the FW Handy while for Turbair weeder there was a progressive decrease in Nmd with increase in voltage across the sprayer motor.

Table 4.5 Summary of Analysis of Variance of Number Median Diameters (Nmd) of the CDA Spinning disc Sprayers at various motor voltages.

Machine/ Voltage (Variables)	Source of Error	DF	SS	MS	F
A. INSECTICIDE/FUNGICIDE APPLICATORS					
12 volt	Between Sprayers	4	978	244.5	33.0*
	Residual	10	74	7.4	
LSD (5%)-	5.0				
9 volt	Between Sprayers	4	10479.6	2619.9	4.9*
	Residual	10	5342	534.2	
LSD (5%)-	42.0				
6 volt	Between Sprayers	4	30735.6	7683.9	67.3*
	Residual	10	1142	114.2	
LSD (5%)-	19.0				
B. HERBICIDE APPLICATORS					
12 volt	Between Sprayers	3	12037	4012.3	284*
	Residual	8	113	14.13	
LSD (5%)-	7.0				

* Significant at $P \leq 0.05$.

Thus with the spinning disc herbicide applicators an increase or a decrease in motor voltage though significantly change Nmd, but does not either increase or decrease Nmds consistantly. Hence a change in motor voltage changes the average sprayer droplet size but that the degree and trend of such change defends upon individual herbicide applicator makes.

4.1.3 Dispersion Ratio

The summaries of Dispersion ratios of the 9 spinning disc sprayers operated at different voltage levels are presented on Fig. 4.6 to Fig. 4.7 and on Table 4.6 with highlights as follows:-

(i) Regardless of insecticide/fungicide applicator make or model, lower values of dispersion ratios were obtained at higher operating voltages (say 12 volt). Like wise for the same machines higher values were obtained at lower voltages (6 volt).
Thus all the sprayer makes produce droplets of narrower spectra i.e more uniform droplets at high operating voltages and wider spectra at lower operating voltages.

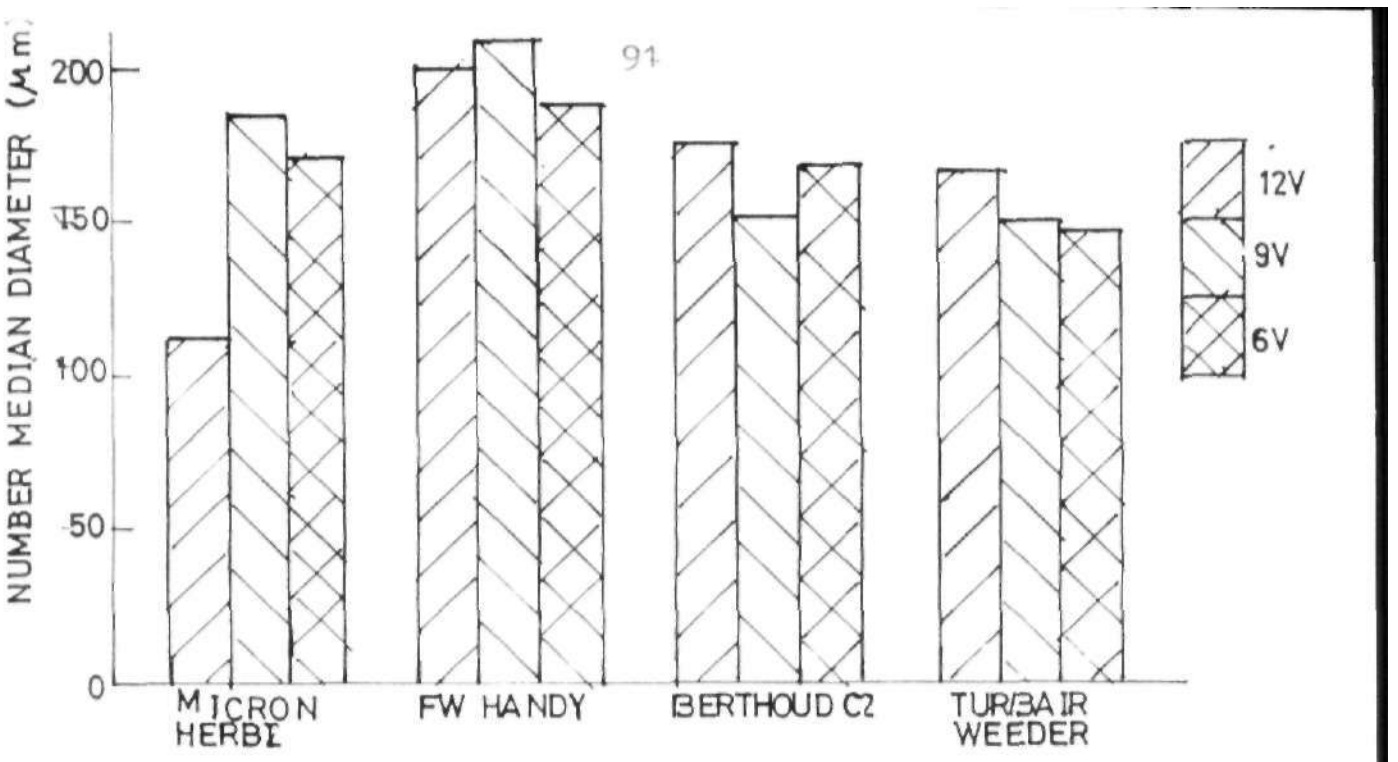


Fig. 4.5. Number median diameter of the four spinning disc herbicide sprayers at different voltage levels

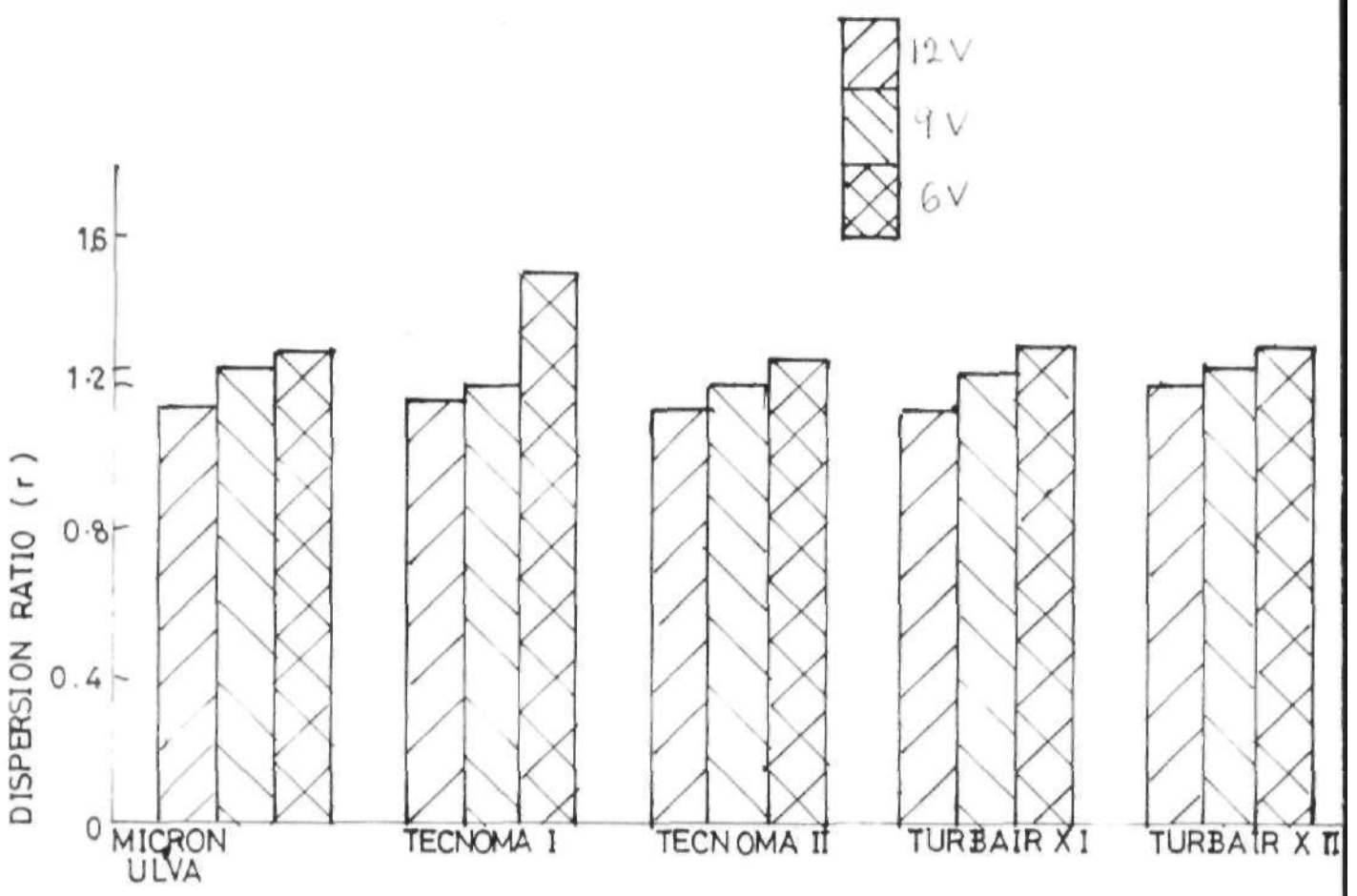


Fig. 4.6 Dispersion ratio of the five insecticide / fungicide spinning disc sprayers at different voltage levels

Table 4.6: Summary of Analysis of Variance of Dispersion Ratios of the CDA Spinning disc Sprayers at various voltage levels.

Machine/ Voltage (Variables)	Source of Error	DF	SS	MS	F
A. INSECTICIDE/FUNGICIDE APPLICATORS					
12 volt	Between Sprayers	4	0.0096	0.0024	2.60^{ns}
	Residual	10	0.0092	0.00092	
9 volt	Between Sprayers	4	0.0078	0.00195	1.8^{ns}
	Residual	10	0.0108	0.00108	
6 volt	Between Sprayers	4	0.1242	0.0311	24.6*
	Residuals	10	0.0126	0.00126	
LSD (5%)-	0.07				
B. HERBICIDE APPLICATORS					
12 volt	Between Sprayers	3	0.0206	0.006875	0.022^{ns}
	Residual	8	2.4908	0.31135	
9 volt	Between Sprayers	3	0.054	0.018	8.47*
	Residual	8	0.017	0.0021	
LSD (5%)-	0.09				
6 volt	Between Sprayers	3	0.1106	0.0368	12.93*
	Residual	8	0.0228	0.00285	
LSD (5%)-	0.1				

* Significant at P < 0.05

ns Not Significant at P > 0.05

(ii) Within higher operating voltage levels (9-12 volt) the values of the dispersion ratios obtained from the machines were not significantly different (Table 4.6). Hence at higher voltages all the machines produced droplets that were of similar or same degree of uniformity irrespective of make or model.

At lower operating voltage (6 volt) however, the values of dispersion ratios were significantly different, indicating that the degree of droplet uniformity vary from one make or model of machine to another when operated at lower motor voltage levels. So apart from theffact that the machines generally produce less uniform droplets at lower operating voltages, the degree of non uniformity also vary significantly between the makes/modles.

4.2 Power Consumptions/Rotational Speed

Summaries of power consumption of the 9 spinning disc sprayers operated at different voltage levels are given on Fig. 4.8 to Fig. 4.10 and on Table 4.7 while those of the sprayer Rotational speeds operated as described above, given on Figs. 4.11-4.12 and on Table 4.8, with highlights as follows:-

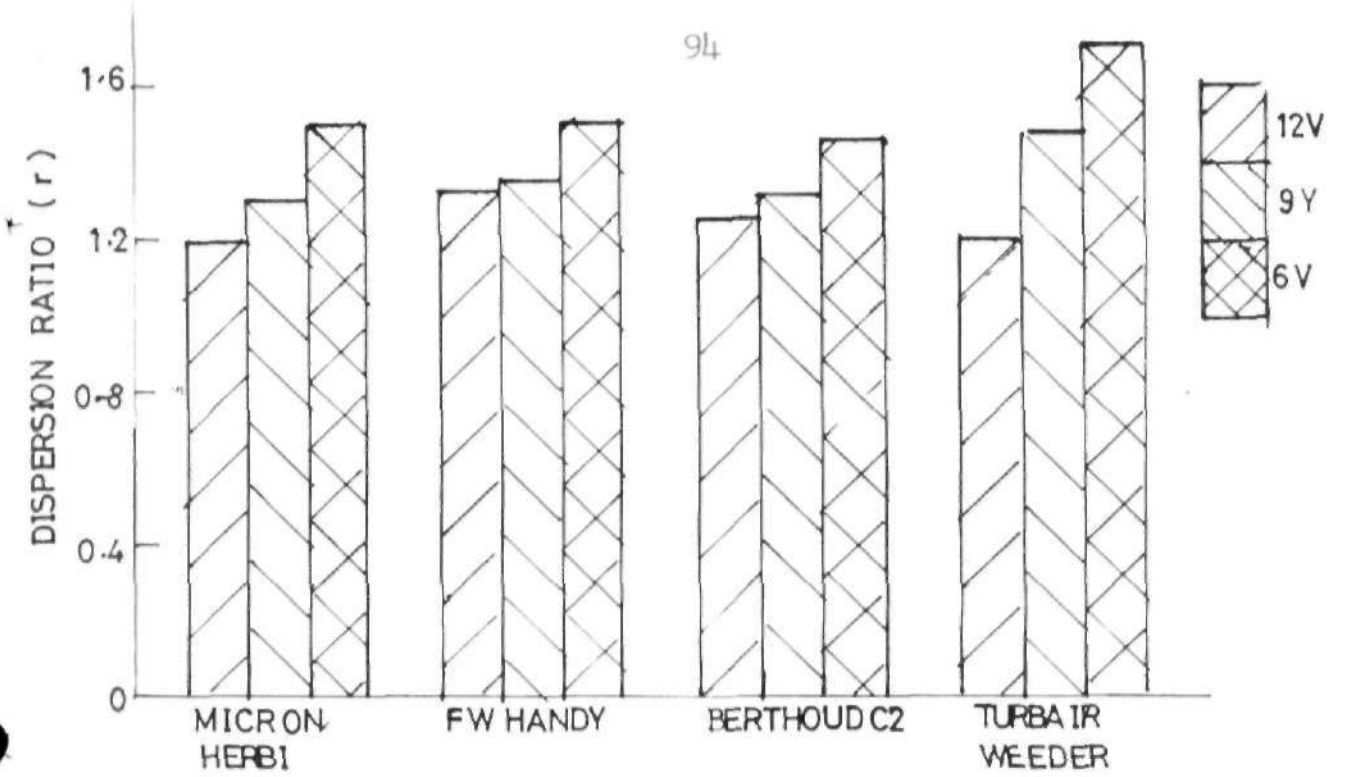


Fig. 4·7 Dispersion ratio of the four herbicide spinning disc sprayer at different voltage levels

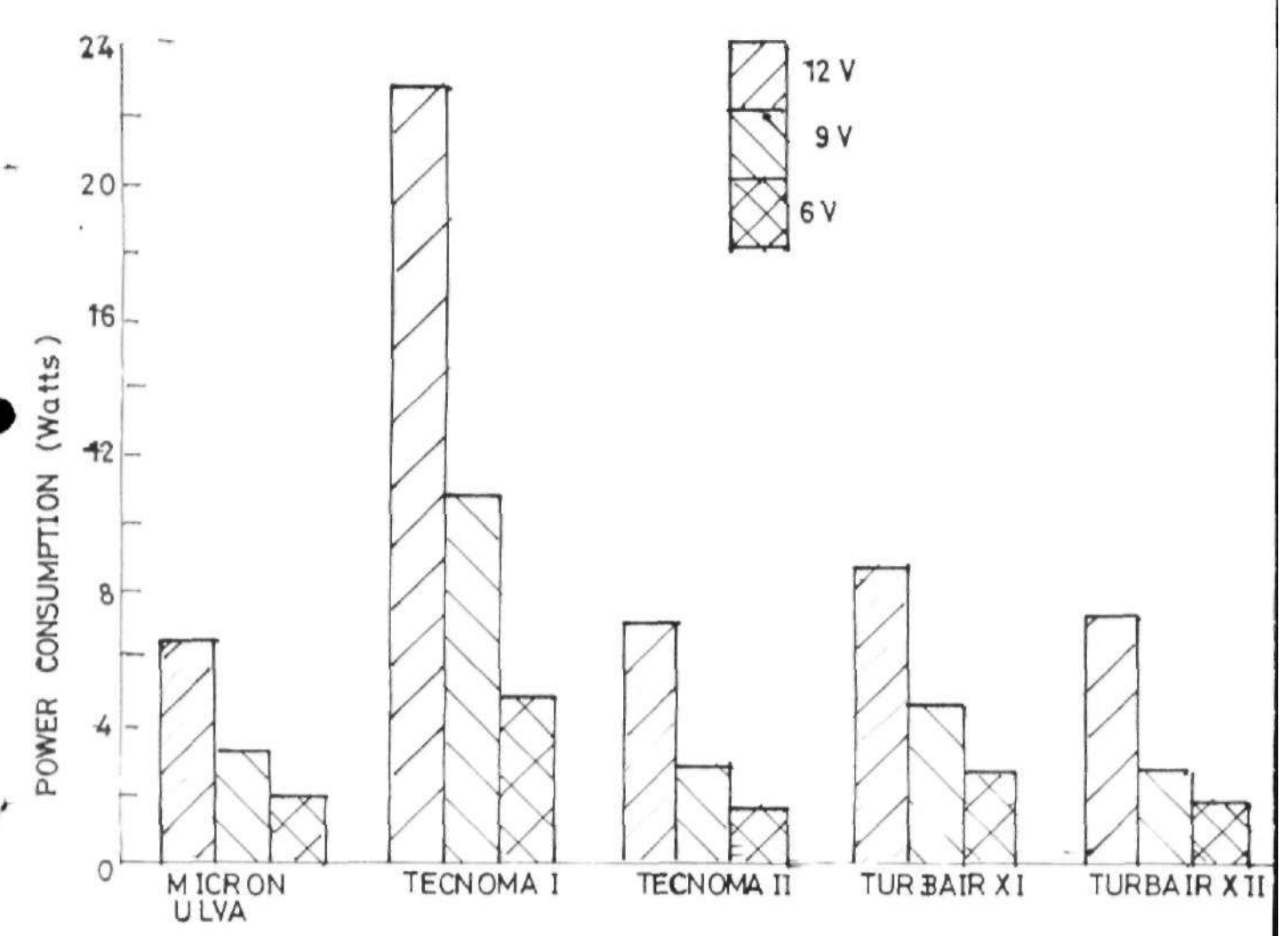


Fig. 4·8 Power consumption of the five insecticide/fungicide spinning disc sprayers at different voltage levels

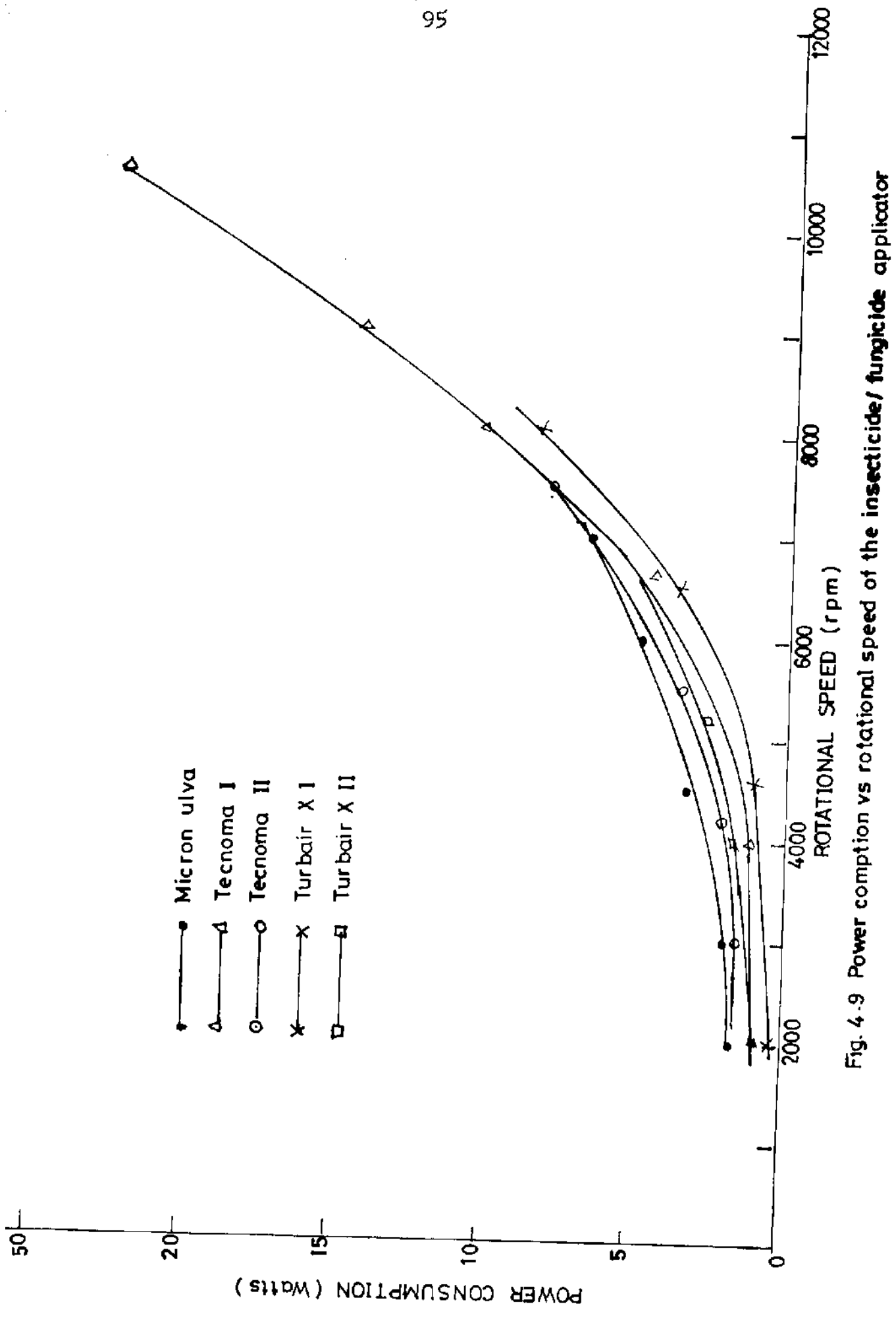


Fig. 4.9 Power comption vs rotational speed of the insecticide/ fungicide applicator

(i) For all the sprayer makes/models investigated higher power consumptions are observed at higher motor voltage levels and vice versa. This ofcourse was expected since power consumed by the sprayer is proportional to the voltage across the motor other parameters remaining constant or varying proportionally. Similarly higher sprayer disc rotational speeds were observed at higher voltages for the five insecticide/fungicide sprayers only.
For the herbicide applicators however, higher speeds were observed at 12 volt only but as the voltage decreased (from 12.v-6.0v) the rotational speeds for all the sprayers remained fairly constant due to the presence of mechanical governors which control the speed of the discs within fairly close range. So even when the voltage reduced from 12v to 6v the percentage change in the sprayer disc speed was at most about 13.6% for turbair weeder while it was only 4% for the FW Handy model, with Micron Herbi and Berthoud C2 falling in between with 10% change each.

(ii) For the insecticide/fungicide applicators, and at all operating voltage levels, power consumption between the sprayers vary significantly (Table 4.7).

Table 4.7 Summary of Analysis of Variance of Power consumptions of the CDA Spinning disc Sprayers at various voltage levels.

Machine/ Voltage (Variables)	Source of Error	DF	SS	MS	F
A. INSECTICIDE/FUNGICIDE APPLICATORS					
12 Volt	Between Sprayers	4	580.4	145.1	4357*
	Residual	10	0.33	0.033	
LSD (5%)-	0.33				
9 Volt	Between sprayers	4	141	35.3	547*
	Residual	10	0.644	0.0644	
LSD (5%)-	0.46				
6 Volt	Between sprayers	4	23.67	5.92	84.3*
	Residual	10	0.70	0.070	
LSD (5%)-	0.48				
B. HERBICIDE APPLICATORS					
12 Volt	Between Sprayers	3	2.279	0.7596	225*
	Residual	8	0.027	0.00338	
LSD (5%)-	0.11				
9 Volt	Between Sprayers	3	0.4131	0.1377	17.05*
	Residual	8	0.0646	0.008075	
LSD (5%)-	0.17				
6 Volt	Between Sprayers	3	0.2808	0.0936	0.29^{ns}
	Residual	8	0.0384	0.0048	

* Significant at $P \leq 0.05$

ns Not Significant at $P \leq 0.05$.

The two Tecnoma sprayers for instance showed striking difference viz:-
At the same voltage one rotated at high speed (Model I, 10, 500 rpm) and drew a large amount of power (about 23 watt), the other rotated more slowly (model II) and drew mich less power (about 7 watt). The large power consumption of the former resulted in its high rotational speed and hence production of very small droplets (about 50 μm) below the sizes normally regarded as acceptable for ground crop spraying using this class of cda sprayers.
The power consumed by the Tecnoma I sprayer was about 3-4 times greater than that consumed by the other makes of sprayers at all the voltage levels investigated.

(iii) For the four herbicide spinning disc sprayers, power consumption was generally higher at higher voltages and vice versa. (Fig 4.15). FW Handy model consumed greater amount of power than any other make tested at all the voltage levels but does not show any appreciable advantage in either droplet size or uniformity to that effect. Infact the other three makes of herbicide sprayers produce slightly more uniform droplets (lower dispersion ratios) than the FW Handy at 12 volt.

Table 4.8 Summary of Analysis of Variance of Rotational Speed of the CDA Spinning disc Sprayers at decreasing voltage levels.

Machine/ Voltage (Variables)	Source of Error	DF	SS	MS	F
A. INSECTICIDE/FUNGICIDE APPLICATORS					
12 Volt	Between Sprayers	4	21900	5475	23.1*
	Residual	10	2370	237	
9 Volt	Between Sprayers	4	27264	6816	83.1*
	Residual	10	820	82	
6 Volt	Between Sprayers	4	22080	5520	117.4*
	Residual	10	470	47	
B. HERBICIDE APPLICATORS					
12 Volt	Between Sprayers	3	240	80	14.22*
	Residual	8	45	5.625	
9 Volt	Between Sprayers	3	35.626	11.875	9.50*
	Residual	8	10.0	1.25	

* Significant at $P \leq 0.05$

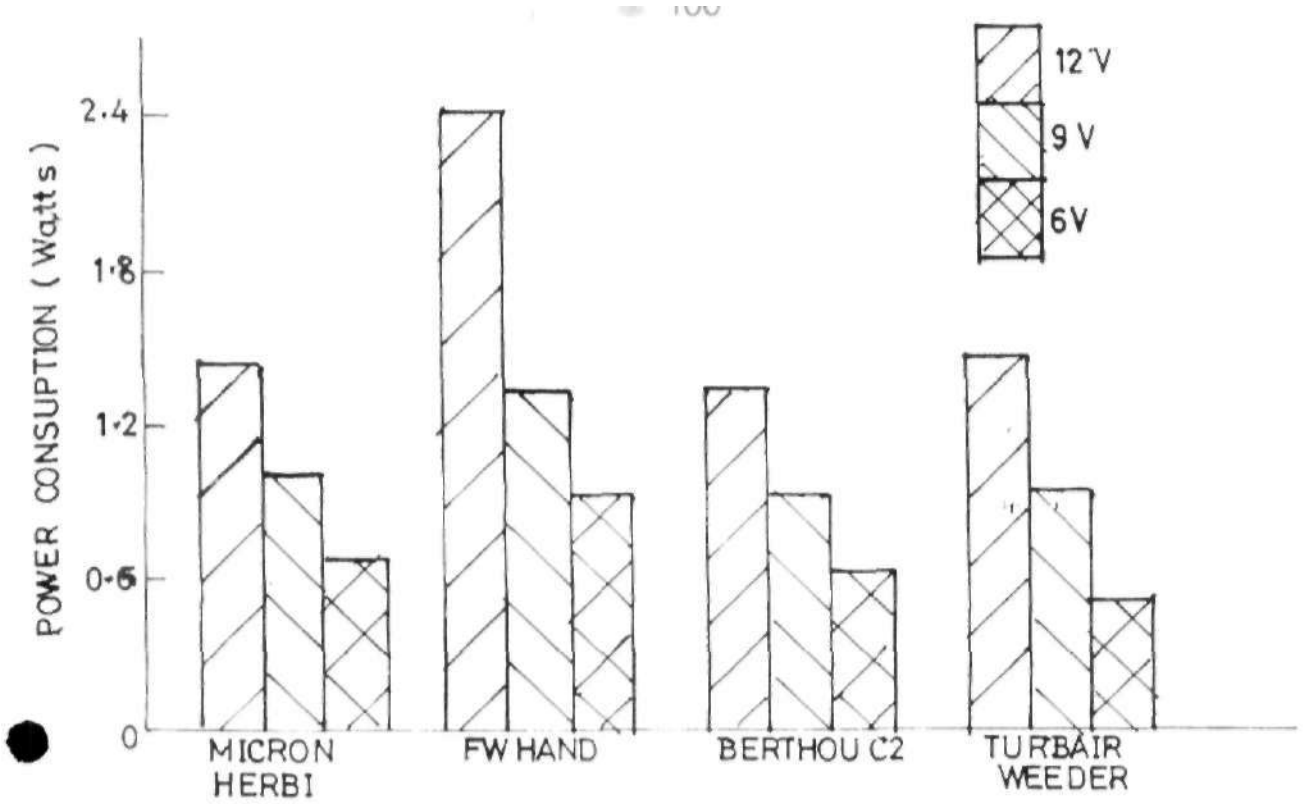


Fig 4·10 Power consumption of the four herbicide spinning disc sprayer at different voltage level

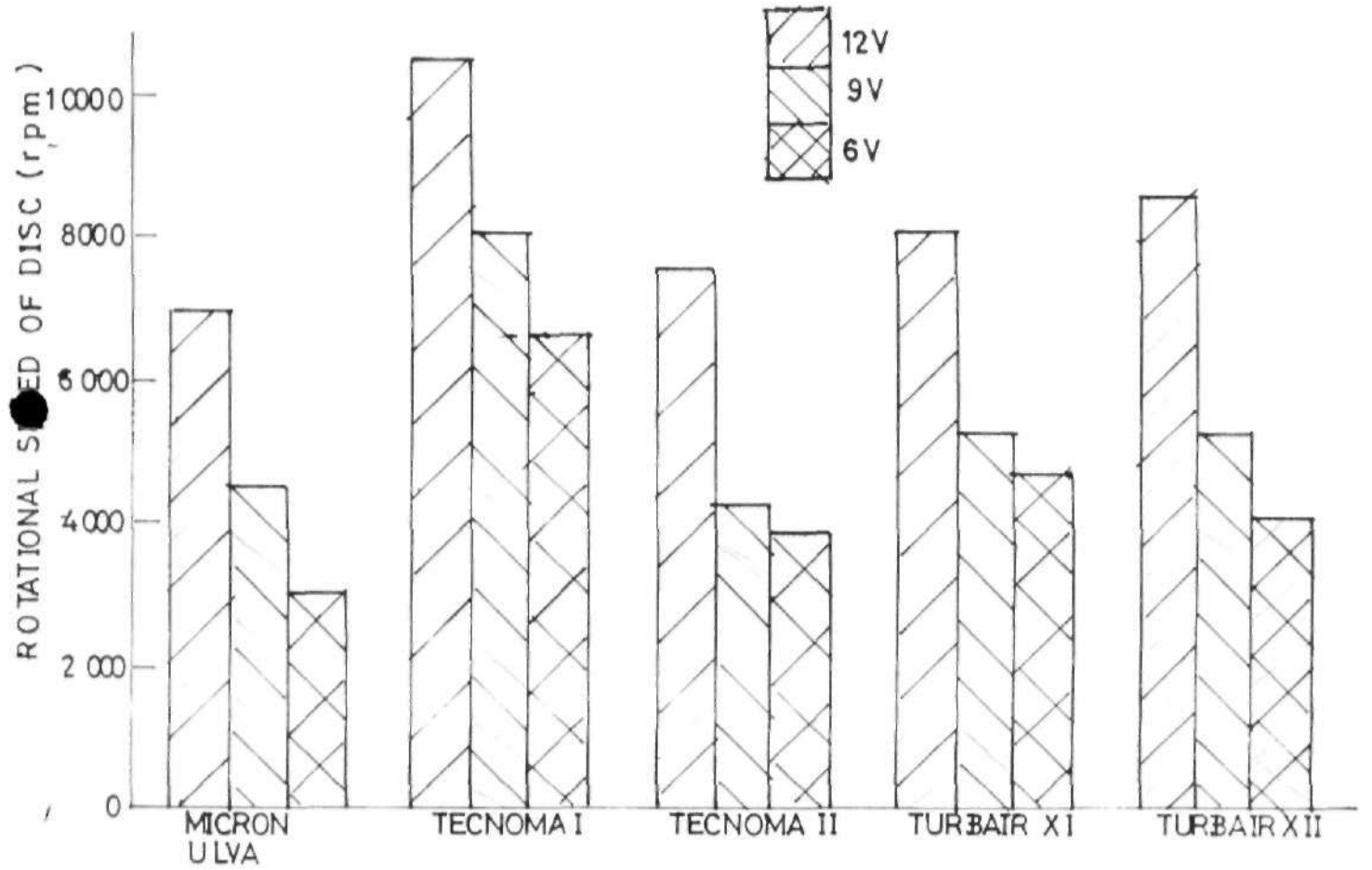


Fig. 4·11 Rotational speeds of the five insecticide/fungicide spinning disc sprayers at different voltage levels

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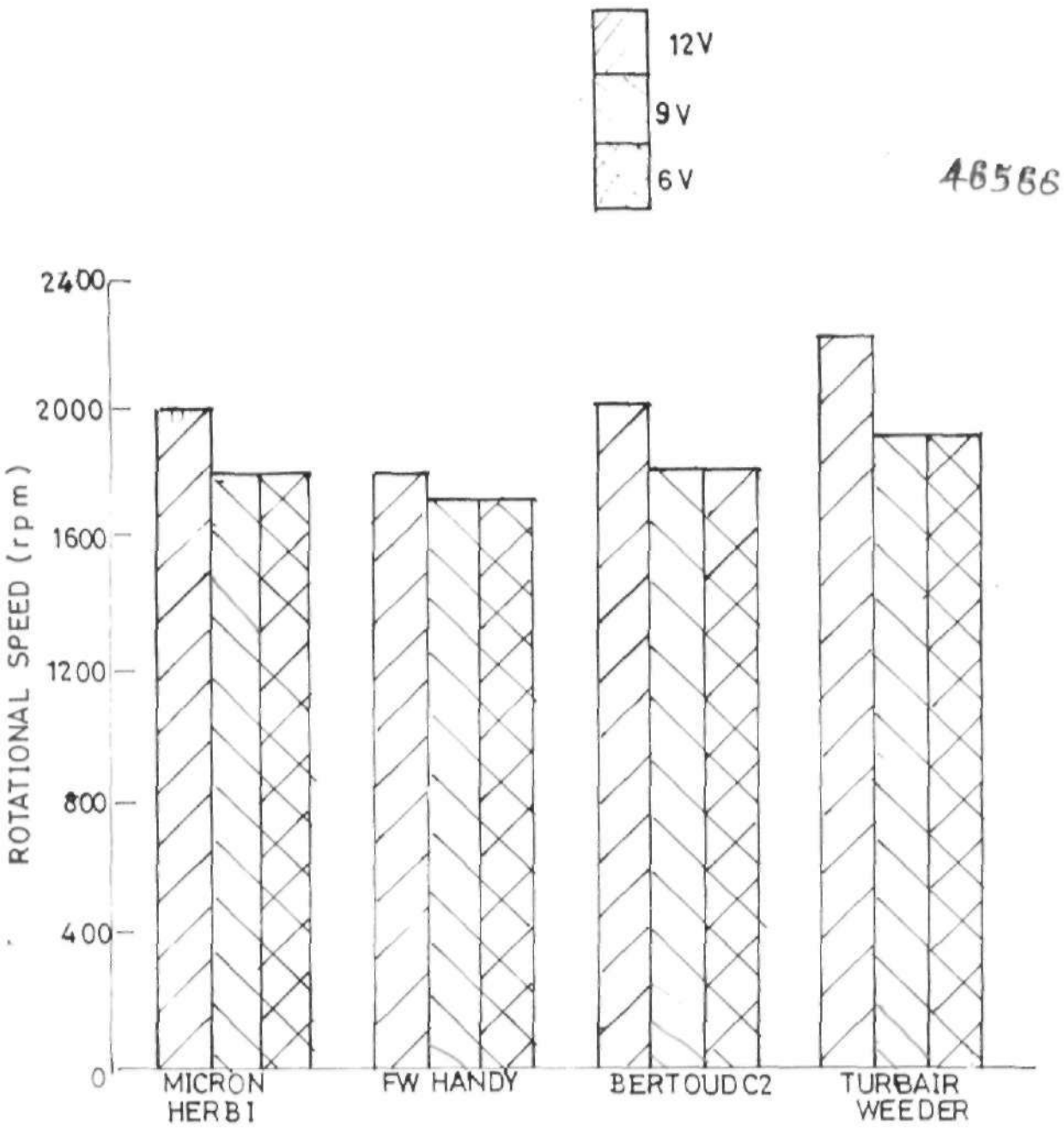


Fig. 4.12 Rotational speeds of the four herbicide spinning disc sprayers at different voltage levels

The power consumptions of the four sprayers above were however, not significantly different at 6 volt.

4.3 Characteristics of Different Makes of U2 Batteries used in CDA Sprayer and influence on Spray Droplet Spectra

Summaries of the combined changes in voltage with spraying time for all the life days of each of the four makes of U2 batteries and the nature of spray droplet spectra produced by the sprayer under each condition are presented on Figs. 4.13 to Fig. 4.16 and on Tables 4.9 to Table 4.11. The highlights are as follows:-

(i) In general, when the four makes of batteries were compared in terms of durability, their life spans when used in the same manner and with the same insecticide/fungicide spinning disc Ulv sprayer were found to vary significantly (Tables 4.9 to 4.11), with Eveready and Berec showing clear superiority over the rest when they were used for 17 and 16 hours.respectively before their voltages dropped to 6 volt showing the least average rate of voltage drop.
The ABC battery proved to have the least life span, just about half of that of th other two makes (Eveready and Berec) and with the highest

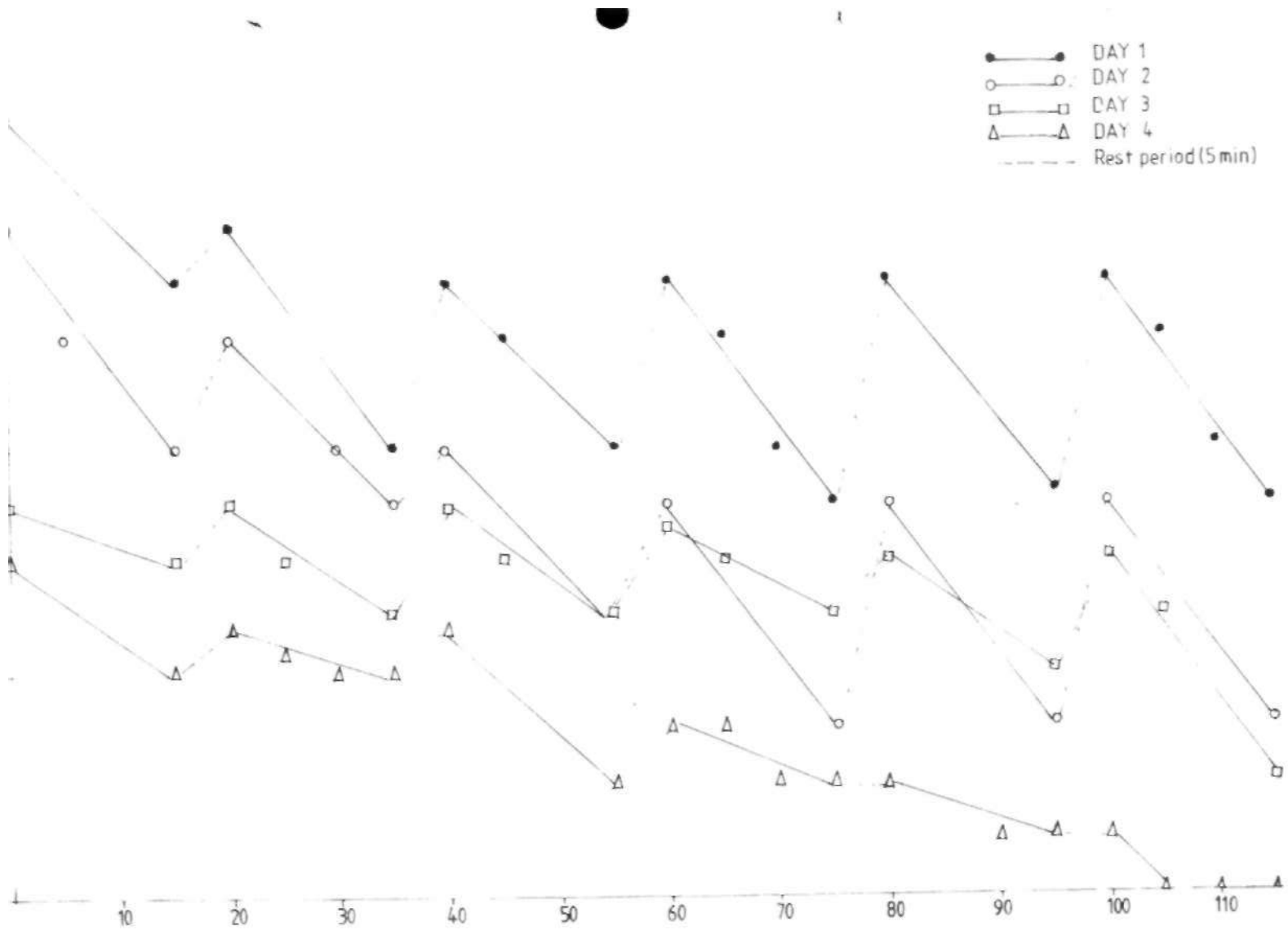


FIG 4-13

ABC battery life showing decrease in voltage for day of use when ULVA sprayer was used with eght 15 volt of the battery sprayer used for 15 min followed by 5 min rest for 2 hours each day

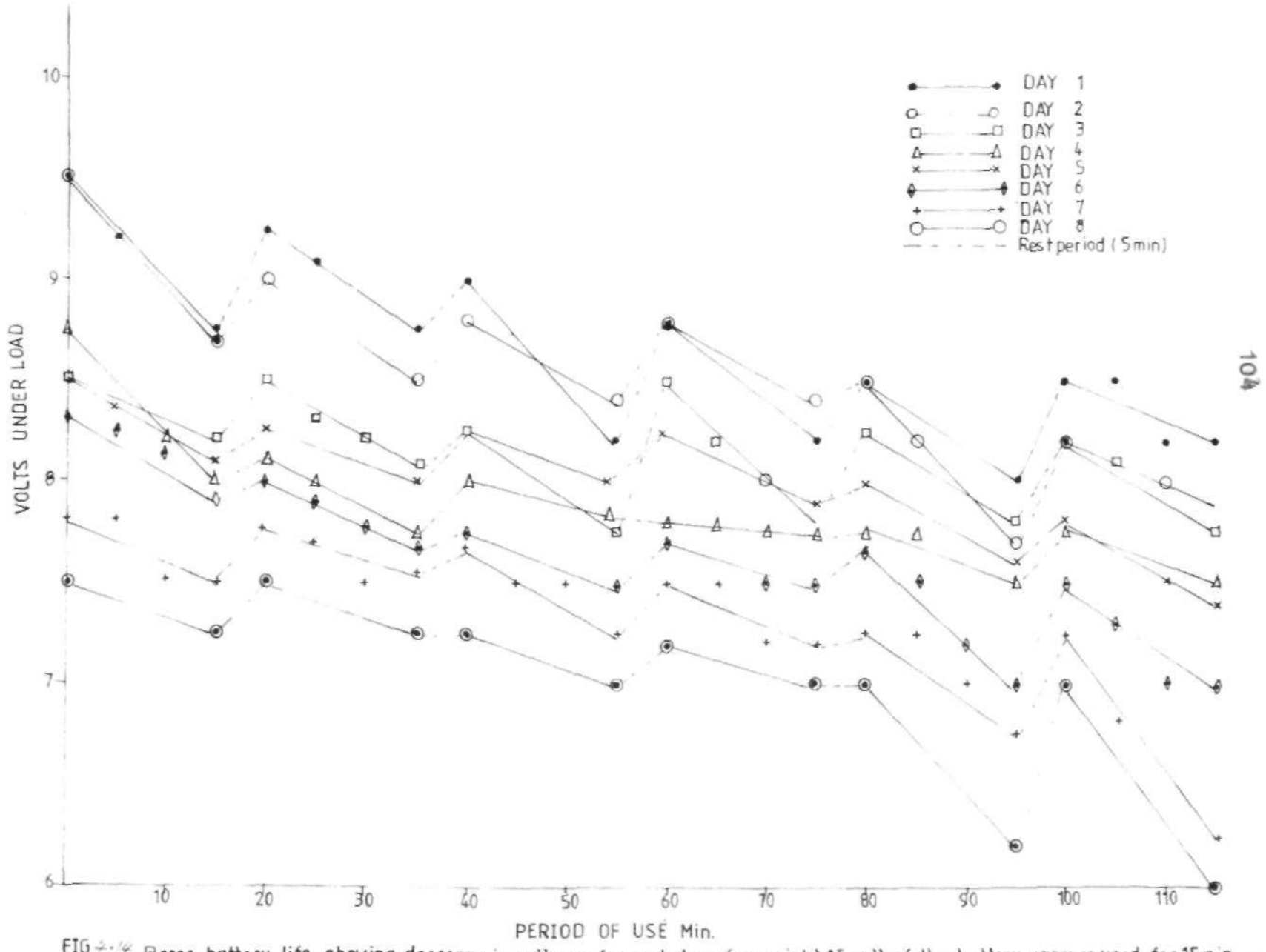


FIG 4.4 Berec battery life showing decrease in voltage for each day of use eight 15 volt of the battery sprayer used for 15 min

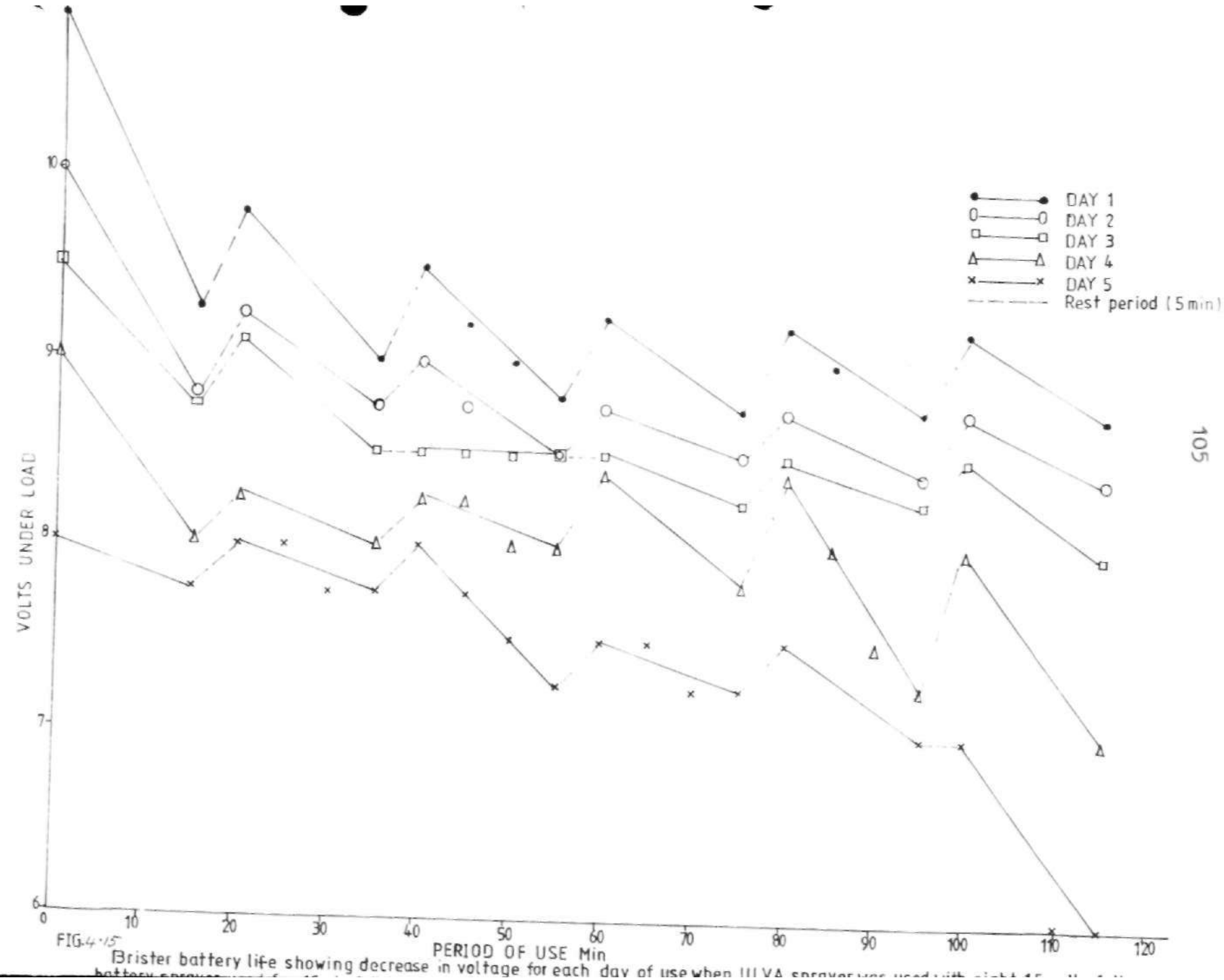


FIG. 4·15

Brister battery life showing decrease in voltage for each day of use when ULVA sprayer was used with eight 15

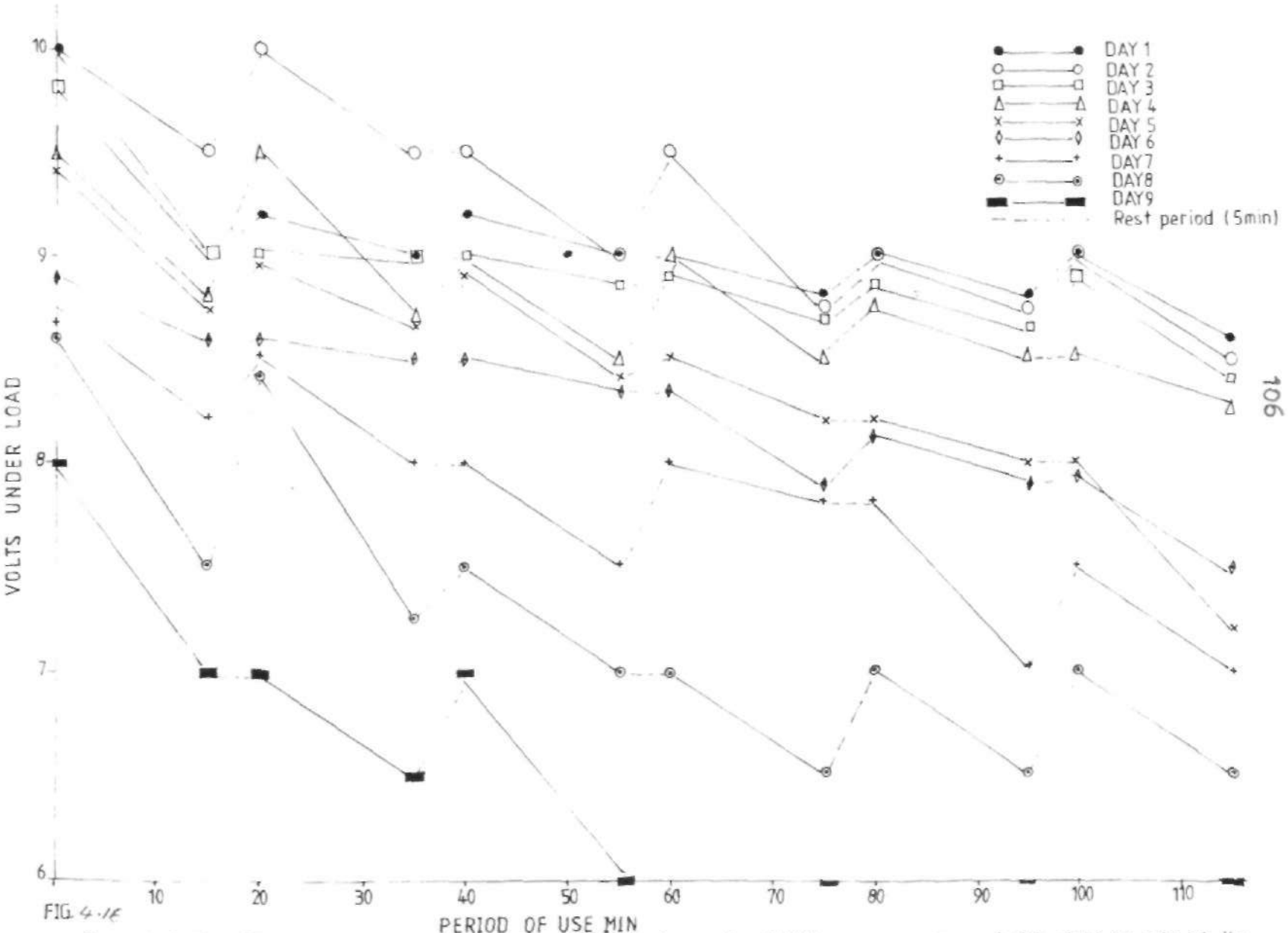


FIG. 4.1E

Eveready battery life show decrease in voltage for each day of use when V LVA sprayer was used with eight 1.5 volt of the battery sprayer used for 15min followed by 5min for 2 hours each day

Table 4.9 Effect of change in Voltage of four makes of U2 Batteries on Rotational Speed and Droplet Spectrum of ULVA Spinning Disc CDA Sprayer.

Battery Make	Day	Voltage[1] (Volt)	Current[2] (Amp)	Rotational[3] Speed (rpm)	Droplet Spectrum Vmd[4] (μm)	Nmd[5] (μm)	r[6]
ABC	1	9.50	0.36	5600	85	71	1.19
	4	6.00	0.17	3000	175	63	2.8
BEREC	1	9.50	0.45	6750	76	64	1.18
	8	6.00	0.22	2200	210	105	2.00
BRISTER	1	10.80	0.46	6000	80	67	1.19
	5	6.00	0.12	3000	120	92	2.30
EVEREADY	1	11.50	0.35	4400	98	83	1.18
	9	6.00	0.17	1800	250	113	2.21

Foot Note Symbol — Explanation

1. Voltage across the electric motor measured at the beginning of first day and at the end of last day of spraying.
2. Current passing through the motor measured as of (1) above.
3. Rotational speed of the spinning disc measured as of (1) above.
4. Mean value of volume median diameter
5. Mean value of Number median diameter
6. Mean value of Dispersion Ratio.

Table 4.10 Mean Life Spans, Rate of Voltage drop and spray droplet spectra of the four makes of U2 batteries used in ULVA Spinning Disc CDA Sprayer under Intermittant and continuous use conditions.

Battery	Mean Life Span[1] (hours) (Intermittant)	(Continuous)	Rate of Voltage drop[2] (volt/hr)	Droplet[3] Size (Vmd) μm	Droplet[4] Uniformity (r)
ABC	8.00	5.50	0.44	152.00	1.81
BEREC	16.00	10.50	0.21	128.00	1.76
BRISTER	10.00	6.50	0.40	121.00	1.71
EVEREADY	17.00	10.75	0.24	162.00	1.84

Foot Notes Symbol — Explanation

1. Average total period of spraying recorded from the initial voltage until it falls to below 6 volt when the battery is considered runned down.
2. The Ratio of the difference between the initial and final (runned down) voltage of the battery to the total period of actual spraying.
3. Average of all volume median diameters recorded at the beginning, middle and at the end of each day's spraying.
4. Average of total Dispersion Ratios measured at the beginning, middle and end of each day's spraying.

Table 4.11 Summary of Analysis of variance of Life Spans, Rate of voltage drop and droplet spectrum parameters of the four makes of U2 batteries when used with ULVA Sprayer.

(Variables)	Source of Error	DF	SS	MS	F
Life span	Between Batteries	3	176.25	58.75	2
	Residual	8	18.50	2.31	
	LSD (5%) -	2.6			
Vmd	Between Batteries	3	3392.26	1130.75	100.50*
	Residual	8	90.00	11.25	
	LSD (5%) -	6.3			
Dispersion Ratio	Between Batteries	3	0.0294	0.0098	16.33*
	Residual	8	0.0048	0.0006	
	LSD (5%) -	0.05			
Rate of Voltage drop	Between Batteries	3	0.1178	0.0393	32.7*
	Residual	8	0.0096	0.0012	
	LSD (5%) -	0.07			

* Significant at $P \leq 0.05$

average rate of voltage drop. (Fig. 4.13 and Table 4.10). The Brister battery's life span The Brister battery's life span and rate of voltage drop (Fig. 4.15 and Table 4.10) falls in between that of ABC and the other two makes. Although the life spans of Berec and Eveready makes could be compared in this situation as they proved to be not significantly different (LSD = 2.6), at 5% level, the Eveready make's performance was characterised by a lot of disc speed fluctuations with irregular change in voltage throughout the period of use. (Fig. 4.20). The spinning disc electric motor consumed varying amount of current when used with the Eveready make compared with the others resulting in generally lower rotational speeds of the disc at similar voltage levels.

(ii) All the four makes of batteries evaluated with the sprayer showed one peculiar common characteristics; viz:-
Their respective voltages drop sharply as they were used continously with the spinning disc ultra low volume sprayer and when allowed to rest for a certain period (say over night in this case) they regain back partially their power due to occurence of repolarisation, in some cases almost to the original level of

voltage at the previous day (Fig. 4-14 and Fig. 4.16). The rotational speed of the disc which also declines sharply as the voltage of the battery falls is also regained to near the previous day's levels.

When the batteries were used continuously, rather than intermittantly it was observed that their voltages fell much more rapidly resulting in shorter life duration (Figs. 4.17-4.20). Life spans of ABC, Berec, Brister and Eveready batteries were reduced by 31%, 34%, 35% and 37% respectively (Table 4.10). The battery make with the longest life span when used intermittantly seems to exhibit most acute shortening of life span when used continuously and vice-versa. These figures confirm the advantage associated with intermittant over and above continuous spraying using same set of batteries to runned down.

(iii) Droplet spectra change significantly with change in disc rotational speed (Table 4.9). Consequently the volume median diameter (vmd) increases with decrease in battery voltage and disc rotational speed. In other words, large droplets are formed as the battery get runned down. The droplet size normally regarded as most suitable for general crop spraying with this method is

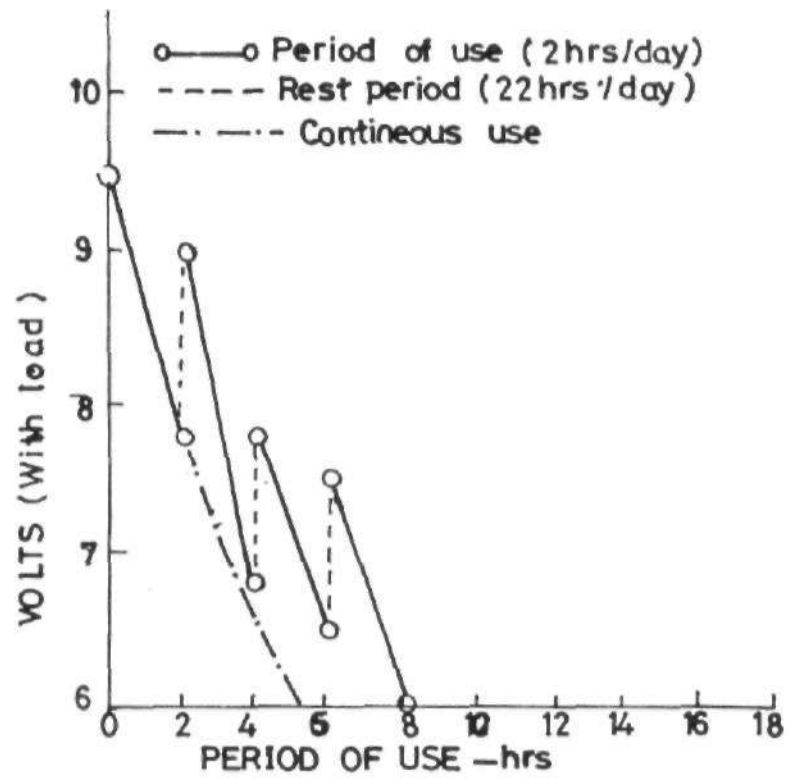


Fig 4.17 ABC battery life showing decrease in voltage for the period of use with ulva sprayer

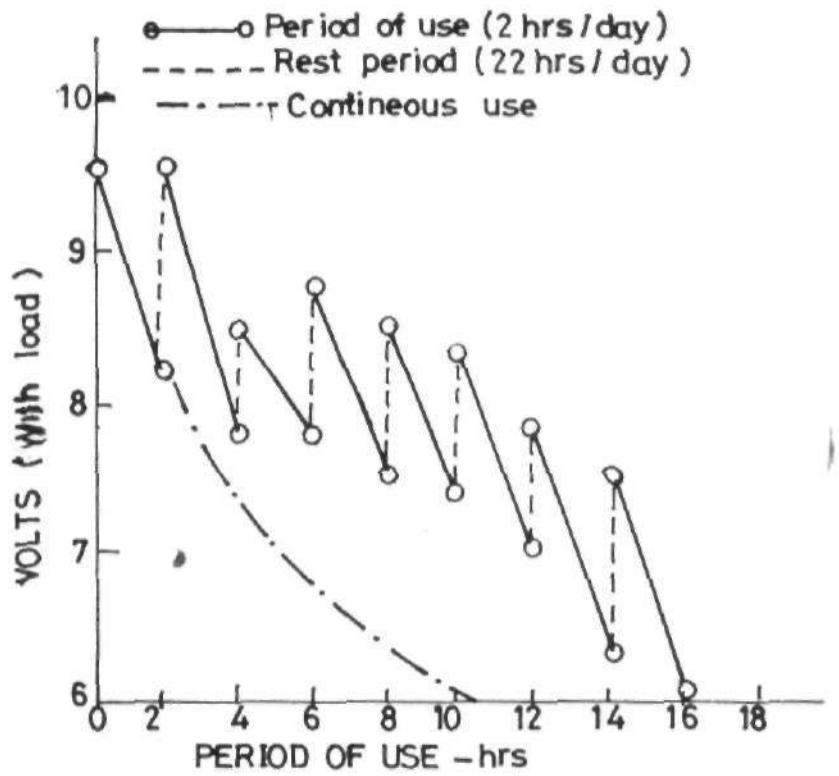


Fig. 4.18 BEREC battery life showing decrease in voltage for the period of use with ulva Sprayer

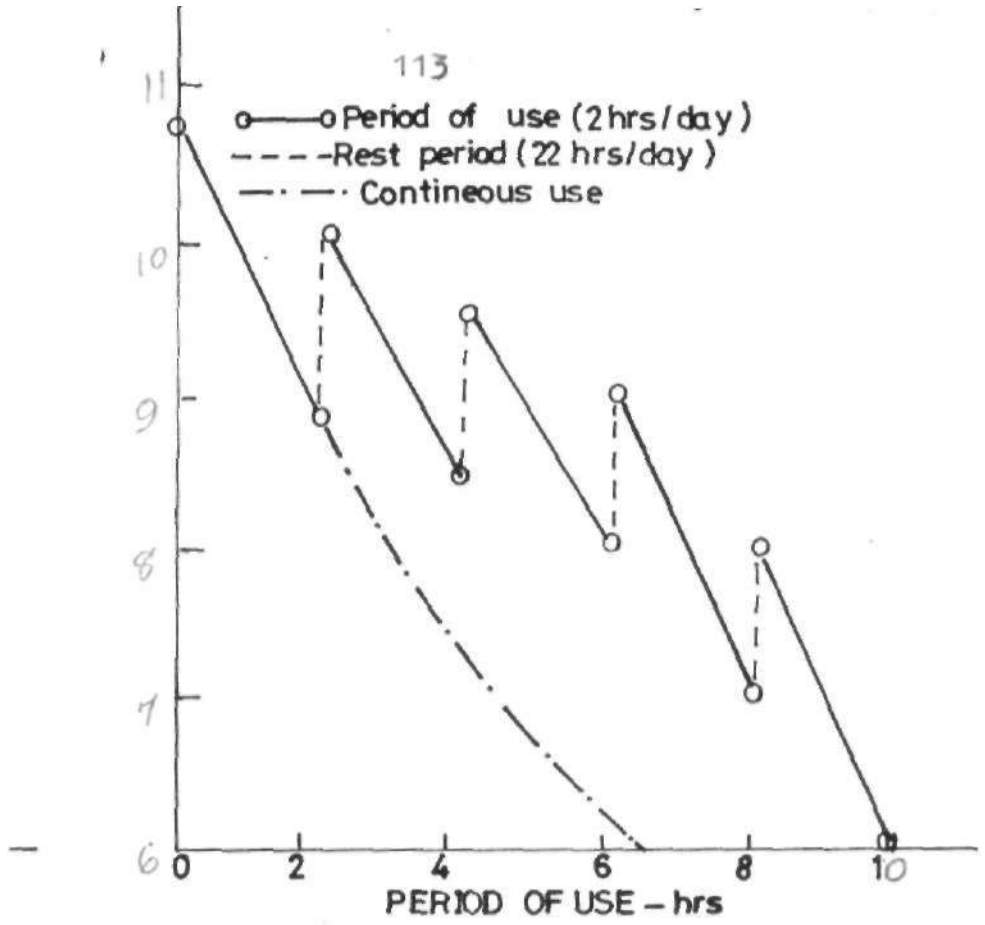


Fig.4-19 BRISTAR battery life showing decrease in voltage for the period of use with ulva Sprayer

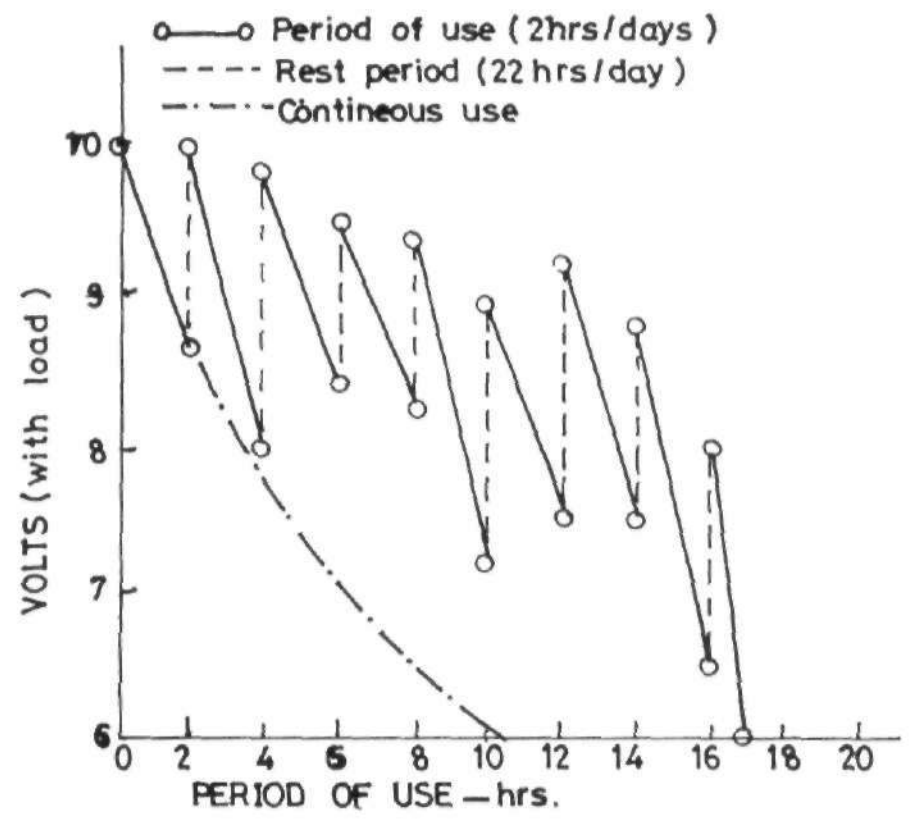


Fig.4-20 EVEREADY battery life showing decrease in voltage for the period of use with ulva sprayer

about 80 μm vmd and sizes close to this seem to be produced only at higher voltages ($\geqslant$ 8.0 volt) and by the time the voltage drops to 6 volt the types of droplets being formed (about 200 μm vmd) are almost those more suitable for herbicide application rather than insecticide/fungicide and hence very unsuitable for the purpose particularly where flying insects are to be controlled. As the voltage drops in each battery set case, the droplets uniformity also deteriorates (Higher dispersion ratio values, Table 4.9) in lower voltages (near 6 volt) the droplets sizes range approach those of hydraulic nozzles.

(iv) At individual levels the Berec battery set produced the narrowest spectrum of droplets when used with the sprayer with the least range of dispersion ratios as the voltage drops (1.18-2.00).

Eveready produced the widest spectum of droplets with the highest range of dispersion ratio (1.18-2.86) although its life span was comparatively even slightly longer than that of Berec. This was mostly due to the disc speed fluctuations characterised by the use of Eveready make of batteries and hence production of widest range of droplet sizes. The other two makes, ABC and Brister fell in-between the above two makes in

terms of production of uniform droplets within the range of voltage used (r = 1.19-2.80 and 1.19-2.30 respectively). The flow rate from the sprayer was found to remain at constant value of 0.85 cm^3 sec^{-1} irrespective of spinning disc rotational speed or voltage drop from any set of battery make. This is due to the fact that the flow of spray liquid to the Centre of the disc is controlled only by gravity and has little to do with the rotational action of the spinning disc, indicating that flow rate of any cda sprayer is independent of type of power source.

(v) On the whole the characteristics of different makes of U2 batteries when used in cda sprayer and influence of spray droplet spectrum could be summarised as follows:-

With regards to the four makes of batteries: ABC, Berec, Brister and Eveready tested, they perform significantly different in terms of durability (life span to run down) and consequently formation of spray droplet spectrum from the sprayer. Berec and Eveready makes could be used for up to 16 and 17 hours actual spraying respectively when used intermittantly. The

same makes of batteries could however, only be used for the periods of 10.5 and 10.75 hours respectively when used continuously (i.e without the 22 hrs rest a day), (figs 4.17-4.20). The Brister and the ABC makes could respectively be used for five and four days of spraying when used intermittantly (i.e 10 and 8 hours actual spraying time) and 6.5 and 5.5 hours respectively when the batteries were used continuously until they run down.

The voltage of each individual battery set drop sharply when used continuously but recovers partially its lost power when allowed to rest overnight due to the occurance of repolarisation making it possible to be used for the periods mentioned above.

With Berec make of batteries the narrowest droplet spectrum was produced by the spinning disc sprayer while with Eveready which has similar life span with Berec, the widest and hence less desirable droplet spectrum was produced among all the makes evaluated due to its voltage fluctuations and hence the sprayer spinning disc rotational speed. In terms of spray droplet uniformity, Brister and ABC makes fell in between Berec and Eveready. Droplet sizes produced by sprayer when used with each of the battery makes

were within the range acceptable for general crop spraying only at higher voltages ($\geq$8.0 volt).

4.4 Consequences of the Sprayers and Power source effects on Crop Protection

When the results of this study is viewed at a glance in its totality a number of silent features of cda sprayers are discovered as follows:-

(i) Variations of Vmds, Nmds, rs and Power consumptions of same classes of cda sprayers operated at similar spraying conditions.

(ii) Variations of Vmds, Nmds, rs and Power consumptions of same cda sprayer at different levels of operating power.

(iii) Deterioration of a particular power source voltage with time when used in cda sprayers and droplet spectra changes with usage.

(v) Variation in performance of similar power sources used in cda sprayers and effects on sprayer droplet spectrum.

The ultimate goal of this study is to, through the results obtained in the study, improve the efficiency of the method of spray droplet atomisation for the application of different classes of pesticides for plant protection against pest and at least or reduced costs. It is therefore important to consider first the

consequences of the silent features of the cda machines and their various makes of power sources on crop protection with the aim of finding solutions to negative effects or devicing method(s) of further improvement.

4.4.1 Consequences of changes in Volume median diameter

Volume median diameter of a spray droplet sample is a measure of droplet size in relation to the volume of chemical applied. It is important because different pest situations require different droplet sizes and within a particular pest situation, the narrowest droplet spectrum is required for the most efficient pesticide application. Any significant variation in excess of the optimum droplet size would definately result in some negetive effect on droplet deposition efficiency.

4.4.1.1 Losses of Pesticides

Increase in Vmd in excess of the optimum value (e.g 80 μm vmd for crawling insects) means that the droplets are too big and as they land on the targets (e.g plant canopy) they may become unstable and run off the target depending of course of the plant leaf configuration, topography and inclination. This may result in serious losses of pesticides which may

consequently reflect in the volume of pesticide being applied per unit area. By and large this would result in increase in cost of chemical application since the excess volume of pesticide that 'run off' and does not stay at the intended target still has to be paid for by the user. This is particularly important when fungicides are being applied in which= case the spores have to be almost totally covered by suitable droplets especially if pesticides are not systamic.

Parallel adverse effects are encountered when droplets are too small (e.g for below the optimum) for instance those produced by Tecnoma I Ulv sprayer. When droplets are too small they may not after all land at the intended target (e.g aerosols droplets about 50$^{\mu}$m) unless when they are charged, rather they may be carried away by the wind (drift) to another non target area where they are not required and are as such lost to the environment.

4.4.1.2 Environmental Pollution

Not only losses of pesticides results due to either droplets being too big or too small in excess of optimum sizes, but also greater environmental pollution. The greater the 'run off' the greater the environmental pollution. Lives of certain advantageous soil fauna responsible for improving soil structure such as earth worms might be affected

by greater chemical residues due to environmental pollution. This may be more notice either when operating a particular cda sprayer at too low an operating voltage (say 6 volt) or by using an unsuitable make of power source even at higher voltage level as seen from the results. Similarly when droplets are too small and are carried away from the intended target area to neighbouring crops or fields, they do not only got lost but also pollute the environment.

4.4.1.3 Operator Hazard

Chemicals are hazardous especially insecticides/ fungicides. Even though sprayer operators are strongly adviced to use protective clothings, they are at the high risk of in-haling chemical pesticides especially droplets that are very small. (e.g 30 μm) and worse still is that such droplets are often the high toxicity ones from insecticides or fungicides rather than even the lesser toxic herbicides. Higher chances of skin contact prevails when droplets are small since they are likely to remain in suspension for a time long enough to come in contact with the body of an operator and this worsens when droplets are excessively small.

4.4.1.4 In-effective Pest Control

When controlling flying insects for instance, we need droplets that are small enough to remain in suspension in the target environment for sufficient length of time to enable the flying insects to come in contact with them. If however, the droplets increase in size due to either deterioration in voltage of a particular type of power source or sprayer motor design, then this suspension ability is cost and effectiveness of control of flying insects is reduced.

4.4.1.5 Phytotoxicity

Phytotoxic burns on plants leaves result when droplets are too big. Phytoxic effects may be caused by chemical burning, physically by droplets on the plant surface acting as lenses and focus the sun's rays on the plant tissue, or by subsequent effects on plant growth (Matthews, 1979). Thus increase in volume median diameter as a result of rapid decrease in voltage of a power source could result in phytoxic burns which consequently affects plant growth and hence yield.

4.4.2 Consequences of variation in Dispersion ratios

As already defined and explained, the dispersion

ratio (r) of a spray droplet spectrum is the measure of spray droplet uniformity, and is controlled by the values of both the volume and Number median diameters. The closer the value of the dispersion ratio to unity the narrower the spectrum of spray droplets. The main aim of developing a controlled droplet applicator of any class is to be able to produce a narrow spectrum of droplet for particular pest situations since different pest situations require different droplet sizes. Thus for any reason, either operational or otherwise when that narrow spectrum of droplets from a cda machine is altered (widened) then the basic aim for which it is designed and developed would be defeated. Ideally the dispersion ratios for all cda applicators should be less than 1.4 ($r < 1.4$) (Matthews, 1979). Any value higher than this indicates an unacceptable spectrum that is below the required standard.

From the results of these investigations it could be observed that once the motor voltage falls to below 9 volt, the r values increase appreciably to even above the 1.4 acceptable limit. Also for all the makes of power sources evaluated it could be observed that once the sprayer is used for upto 2 hours a day the r values exceed the 1.4 limit at the end of each day.

These variations in r values for the different operating conditions would result in production of non uniform droplets, in many cases approaching values obtained using hydraulic nozzles (Table 4.9) the major weakness of which is the production of wide range of droplet sizes. The efficiency of spraying is therefore reduced when the r values change with operating conditions of the sprayer which consequently affects plant protection.

4.5 Consequences of Variations in power consumptions

Power consumption of spinning disc cda sprayers is one of the major concerns of the user during chemical application. Infact it is the first question the farmer asks himself: "How many batteries would the machine take' And How much money is involved "

The user is therefore not only interested in the make and model of cda sprayer with the least power consumption but also on the type and or make of power source for the sprayer that lasts longest all parameters of spray droplets formation remaining the same.

Increase in power consumption means increase in running cost of the spinning disc cda sprayer by way of frequent battery replacement. Increase in running cost means un economical pesticide application

in the long run.

At similar voltage levels (12 volt) one machine tecnoma I drew large amount of power and produce small droplets that would after all easily get drifted by wind, while another Ulva, consumes much less (less than ⅓ of Tecnoma I power consumption) and produce better droplet spectrum. Even if the former's droplet spectrum were better the user would run away from it since he is likely to replace his dry cell batteries at least 3 times before the user of the latter machine replaces his battery set. Since the sprayer user is not likely to have prior knowledge on the power consumption of the machine before use or purchase as it is not normally stated in the instructional manual/leaflets accompany the sprayer, he is likely to get discouraged in using ethe modern cda technology if he happens to by chance own a large power consumption machine make such as the Tecnoma I. This situation may be compounded further if he happens to use the Tecnoma I machine with say an ABC get of dry cell batteries that lasts only four days using the sprayer with the least power consumption. (the Ulva in the case).

4.6 Evolving Design Critaria for Modifying CDA Sprayers

From the results of the foregoing investigations and the logical conclusions from the data obtained the following could be evolved as critaria for modifying controlled droplet applicators.

1. Looking at the variation in spray droplet sizes, distributions and uniformity with change in operating conditions for all machines especially insecticide/fungicide cda sprayers and considering the basic objectives of cda application technique, the present method of operation of cda equipment must be changed if such objectives are to be achieved. Presently in the normal method of cda spraying in the field today, the operator is never concious of what type of droplets his machine is producing at any one moment and where they are directed to. Once the cda sprayer is loaded with U2 batteries it is used continuously until either the total amount of chemical intened for application is finished or when the machine's disc almost stops spinning due to lack of power (low voltage) from the power source before they are re-loaded with fresh batteries. Despite Matthews (1979), recommendation of two hours continuous spraying per day and 22 hours battery rest the droplets change significantly after the first hour of

contin ous spraying. Therefore spraying should stop with a particular set of U2 batteries after one hour of contin ous spraying as against the contin ous spraying to battery run down or even the two hour former recommendation. One would observe that from Figs. 4.13-4.16 (inclusive) the fall in voltage one hour after conti ous spraying in most cases for all power sources makes is not more than 1.0 volt on average. The droplets sizes, distribution and uniformity would not have changed so considerably during this period.

So in a nut shell for efficient cda spraying a set of eight U2 batteries should be used for spraying for 1 hour only a day to be followed by 23 hour rest to allow for repolirasation.

Where a large hactarage is involved requiring spraying for more hours, more than one set of U2 batteries should be obtained and a set replaced after each hour, although this may have economic repercussion on the part of the operator. However, once this method is adopted, the operator is sure of obtaining correct range of spray droplet spectrum for his pest situation.

2. There has to be a change in approach in the design and development of controlled droplet applicators. At present, various manufacturers develope and produce various cda sprayers with different motor characteristics thus producing varying spray droplet spectra for same pest situation (e.g insecticides/fungicide application). This cannot lead to total achievement of cda advantages since in many cases incorrect spray droplet sizes are produced by some makes of machines (e.g Tecnoma I - about 50 μm vmd for insecticide application). The approach should therefore be to standardize the type(s) of electric motors to be produced for a particular spraying operation. These motors must also be governed electric motors to regulate and restrict the disc speeds to certain close range even when there is some slight fall in voltage (say within the one hour continuous spraying recommended above).

Since it is not only the disc speed that govern droplet sizes (thouhg it is the main factor) other machine and spray chemical parameters such as disc size, spray chemical density and surface tension also contribute. Those parameters must also be standardized if cda advantages are to be fully achieved. So that all cda sprayers of each

class should have a standard size electric motor, same diameter and configuration of spinning disc, and spray liquid of same density and surface tension unlike the present situation.

3. As already concluded, the present makes and models of power sources (batteris) used for running cda sprayers are not suitable for the purpose for which they are intended. None of them maintain a constant voltage for sufficiently long period to enable meaningful cda spraying without change in spray droplet spectrum. (Figs 4.13-4.16).

Here we are left with three options to improve the situation. One is to operate the disc manually so that there is always an assured continuous spinning action of disc as in the case of Birky 286 sprayer (Suleiman et-al 1984) and the other is to use a different type of power (battery) source altogether. However, the former method may be still of very little significance at the moment as Yusuf (1992) pointed out that operator stroke length and stroke rate all affect the spray droplet spectrum produced by the sprayer.

The latter option may include either the use of re-chargeable U2 dry cell batteries the voltage

of which generally remains fairly constant for longer periods of time before running down or to use still rechargeable wet cells that are portable enough relatively cheap and easily available to users which voltage also remain fairly constant for longer periods of time. (Table A3) The third option which is to use solar energy to power cda sprayers though possible but in practicable due to the astronomical cost of solar cells needed to generate the desired motor voltage (About ₦1,000 for 12 volt as of 1992-source: Kaduna International trade fair 1992).

4. The main weakness of cda spraying with manually carried machines today is limited application. The normal hand-held battery operated cda sprayer is not versatile. It is either an insecticide/fungicide or a herbicide spinning disc sprayer and could only be used for that very purpose and no more as already confirmed from the survey.

   If the basic advantages of cda technique is to be fully utilized at reduced costs the machine in its present state must be made more versatile. A hand-held cda machine must therefore be able to accomplish at least if not more different

spraying operations that are of vital importance viz:-

(a) Insecticide/fungicide Spraying - requiring production of droplets of about 70-80 μm vmd.

(b) Herbicide spraying - requiring the production of droplets of about 200-250 μm vmd.

(c) Tree crop spraying - requiring production of droplets of similar sizes as of (a) above and projecting them to for distance.

(d) Any other specialized pest control job such as avicide spraying for control of brid pests.

It is therefore strongly desirable that future designs of CDA machines be multipurposed (and yet retain the CDA advantage of production of uniform droplets and application of least spray volume rate) a feature which is presently one partly possessed by knapsack hydraulic sprayers and partly by motorized knapsack Mistblowers.

CHAPTER 5

5.0 DESIGN OF CONCEPTUAL CONTROLLED DROPLET APPLICATOR, PROTOTYPE

The literature review, the analysis and discussions of the experimental results obtained from the study indicate that controlled droplet applicators have distinct advantages in modern pesticide application technology as summarised below:-

(i) Their very low (LV) to Ultra low (ULV) volume application rates (/ 30 L/ha to 5 L/ha) of spray liquid make them highly advantageous especially in areas where water is a constaint.

(ii) Production of generally smaller droplet (about) 80 um vmd for Ulva machines) and of very high concentration and above all of very narrow range (r ≤ 1.4) of sizes much more uniform them those produced by conventional hydraulic sprayers.

(iii) Their oil based formulations facilitates least evaporation tendency of droplets and requires no mixing beofre or during spraying.

(iv) Possession of relatively wider swath widths due to the use of wind for drift spraying.

(v) Better retention of chemical as a result of production of small droplets that do not 'run off' the intended targets.

(vi) Better bush penetration as a result of wind effect (drift) on smaller droplets which they produce.

(vii) Faster spray application due to wider swaths widths and

(viii) Ease of operation as less human energy is used for operation unlike for conventional lever operated or compression hydraulic knapsack sprayers.

The cda technique should therefore stay in view of its obvious merits.

In the same way, the limitations inherent in their present design which limits the exploitation of their obvious advantages most of the time have also been discussed in Chapter 4 (4.4 and 4.5). Recommendations as ways and means of improving their present situations have also been made as highlighted on Chapter 4.6. In view of their appropriateness and the need to solve some of their performance problems it is imperative to eliminate some of their limitations. This Chapter contains

details of some attempts aimed at eliminating some of those limitations so as to enhance their efficient usage.

5.1 THE MULTI-PURPOSE CDA SPRAYER

One of such attempts is that of the design and development of a conceptual multi-purpose cda sprayer system.

The basic objective of this attempt is to eliminate most (if not all) of those investigated limitations of the existing cda sprayer system as revealed from the survey and experimental results.

The conceptual universal cda sprayer should therefore be capable of meeting the following basic requirements:-

(a) Must be used as a ground crop cda sprayer for insecticide/fungicide application using conventional ULV formulation.

(b) Must be used as a ground crop cda sprayer for herbicide application using the appropriate formulation.

(c) Must produce droplet sizes of 70-80 μm vmd range for (a) above.

(d) Must in addition produce droplet sizes of 200-250 μm vmd range for (b) above.

unsuitable for such purpose at least as they stand presently (although rechargeable types may be a lot better when costs of purchase and maintainance are not considered). This is due to their very short life under constant load, reduction in output voltage with load, poor shelf life; prone to leakage and loss of power at low temperatures.

Secondary cells, in the form of lead acid liquid electrolyte types are chosen as more suitable power source than the conventional primary cells discribed above. This is because lead acid types have the advantage of being relatively cheap and widely available for motor cycles etc, in the 6 volt form although they are not available in D size form. However, they could easily be arranged into suitable packs and easily and quickly re-charged. Above all, the lead acid liquid electrolyte batteries are relatively much more common and hence easily obtainable in any part of the locality.

(iii) Versatility

One of the major weaknesses of the existing cda sprayer designs as found and highlighted from this investigation is their limited applications in day to day spraying situations.

As such it has been strongly recommended that their limited applications be improved, so that they are made more versatile; in order to cater for more spraying situations. The proposed design of the conceptual universal cda sprayer would therefore aim at satisfying both insecticde/fungicide and Herbicide spraying as well as tree crop spraying in addition to the possibility of being used for inaccessible bushes and or acquatic spraying situations.

(iv) Local Production and Maintenance

The conceptual universal cda sprayer should be simple to produce and repair by local artisans using locally available equipments and material. As such as far as possible, easily available materials have been used.

(v) Production and Operating Costs

In view of the economic level of an ordinary peasant farmer particularly in Nigeria the sprayer should relatively be of low capital and operating costs.

5.3 Design of the Sprayer Prototype Components

(i) Spinning Disc Atomizer size.

(a) Requirements:-

Droplet sizes:- Must be able to produce droplets of 70-80 μm vmd for insecticide/fungicide application and 200-300 μm vmd for Herbicide application through change in rotational speed.

Dispersion ratio (r):- ≤ 1.4

Flow rate :- 2 ml/sec = $(2 \times 10^{-6} m^3/sec)$

Spray form tion density:-

$1 g/cm^3 = (10^3 kg/m^3)$ (measured) *

Spray formulation viscosity:-

10^{-2} NS/m^2 (measured) *

Spray formulation surface tension:-

33×10^{-3} N/m "

(b) Determination of disc size:-

Assume a rotational speed (N) of 6000 rpm

Angular velocity $W = \frac{2 \pi N}{60}$ $\pi = \frac{22}{7}$

$$W = \frac{2 \pi \times 6000}{60}$$

$$W = \underline{628.32 \text{ rad. } sec^{-1}}$$

Using Frost, (1981),

$$V = \frac{q}{f} \qquad \text{(1)}$$

* Symbush 1·8 ULV

where V = Volume of droplet

q = Volume flow rate along one ligament

f = Frequency of drop production for one ligament.

$$q = Q/n \quad \text{_____ (2)}$$

where Q = Total volume flow rate

n = Number of ligaments.

From (1) and (2)

$$V = Q/nf \quad \text{_____ (3)}$$

$$n = 0.29 \left(\frac{W \rho D^2}{\mu}\right)^{0.93} \left(\frac{\sigma D}{\mu 2}\right)^{-0.44} \quad \text{_____ (4)}$$

where W = Angular velocity of disc.

ρ = Liquid spray density

D = Diameter of disc

μ = Liquid spray viscosity

σ = Liquid spray surface tension.

$$\frac{fD^3}{Q} = \left(\frac{W D^3}{Q}\right)^{1.33} \quad \text{_____ (5) (Frost, 1981)}$$

Combining expressions (3), (4) and (5) an expression for the drop diameter was obtained

$$d = 1.87 \frac{Q^{0.44} \sigma^{0.15} \mu^{0.017}}{D^{0.80} W^{0.75} \rho^{0.16}} \quad \text{____ (6)}$$

From (6) above an expression for the disc size was obtained as follows:-

$$D^{0.80} = 1.87 \frac{Q^{0.44} \rho^{0.15} \mu^{0.017}}{d \quad w^{0.75} \rho^{0.16}} \quad \text{——— (7)}$$

where d = diameter of droplet (μm)

The size of a spinning disc capable of producing a 75μm droplet (assumed from (a) for insecticide/fungicide spraying) could therefore be found as follows:-

$$D^{0.80} = 1.87 \frac{(2\times10^{-6})^{0.44} \times (33\times10^{-3})^{0.15} \times}{(628.32)^{0.75} \times (10^{3})^{0.16} \times}$$

$$\frac{(10^{-2})^{0.017}}{75 \times 10^{-6}}$$

$$D^{0.80} = 1.87 \frac{3.1078\times10^{-3} \times 0.599483 \times 0.924698}{125.498 \times 3.01995 \times 7.5\times10^{-5}}$$

$$D^{0.80} = 0.1133375$$

$$D = 0.06576\text{m} \quad \text{(diameter)}$$

Thus the diameter of the spinning disc required for the prototype sprayer is 66 mm

However, the size of the spinning disc closest to this value and which is available from the range of insecticide/fungicide cda sprayers evaluated is that of 80 mm diameter.

Disc size chosen is therefore - 80 mm.

(ii) Required rotational speed for Herbicide spraying

Since the same spinning disc is intended to be used for herbicide spraying. The minimum rotational speed required to produce a suitable herbicide droplet of 200 μm vmd is calculated as follow:-

From the following relation,

$$W^{0.75} = 1.87 \frac{Q^{0.44} \sigma^{0.15} \mu^{0.07}}{d \quad D^{0.80} \quad \rho^{0.16}} \quad \text{——} \quad (8)$$

The angular relocity required to produce a given spray droplet size is given by:-

$$W = 1.87 \left(\frac{Q^{0.44} \sigma^{0.15} \mu^{0.017}}{d \quad D^{0.80} \quad \rho^{0.16}} \right)^{1.33} \quad \text{——} \quad (9)$$

(from 8)

Hence

To produce the 200 μm droplet

$$W = \left(1.87 \frac{(2\times10^{-6})^{0.44} \times (33\times10^{-3})^{0.15}}{200\times10^{-6}\ (0.06576)^{0.80}} \times \frac{(10^{-2})^{0.017}}{(10^{3})^{0.16}} \right)^{1.3}$$

$W = 126.188$ rad/sec

RPM required - $N = \frac{60W}{2\ \Pi}$

$$N = \frac{60 \times 126.188}{2\ \Pi} = 1205.0066$$

$N = 1205$ r.p.m.

The disc must have a rotational speed of 1205 rpm

This speed is obtainable even at voltages lower than 6 volt.

(iii) Required Number of Discs and Disc Spacing

Required application rate (upper level) = 20-30 L/ha (Mean = 25 l/ha)

Mean Swath width = $\frac{3.0^{*} + 1.5^{**}}{2}$ = 2.25 m

Area to be covered in 1 second at 1 m/sec = 2.25 m^2

---

* Normal swath for insecticide/fungicide application.

** Normal swath for improved cda herbicide applicators.

Flow rate per disc = 2 ml/sec.

Output per disc per hactare = $\frac{2}{2.25} \times \frac{10000}{1000}$

= 8.8 Litres

Number of discs required to apply mean spray rate = $\frac{25}{8.8}$ = 2.84

Select 3 Spinning Discs

Bitrus (1985) in his investigation of spray volume distribution patterns of multi disc arrangements obtained the best disc spacing in terms of spray uniformity as 75 cm apart and at about 45 cm above the target crop or soil as this arrangement has the least value of co-efficient of variation.

For this design a disc spacing of 75 cm apart is therefore selected based on the fore mentioned investigation.

(iv) From the foregoing, two different rotational speeds of disc are required to be produced by the sprayer to enable it generate the two required droplet sizes (for insecticide/fungicide and for herbicide spraying). This could be generated by voltage variation across the spinning disc

electric motor, by a suitable power source design. The dry U2 battery cells normally used with these types of sprayers have already been shown to be unsuitable for the purpose and alternative power source were suggested as per the recommendations given in 4.6.

The power source suitable for this sprayer is therefore the lead acid type cell normally used in motor cycles. This is on the basis of its relatively low cost and high power capacity per unit volume. It usually has a liquid electrolyte- strong sulphuric acid - in most vehicle applications but are now available with either a jelly like electrolyte (gel - cell) or a solid electrolyte eliminating the risks of spillage and maintenance problems (Arnold, 1985).

To use the above cell in the prototype sprayer it requires 2 ready made units of the cells of 6 v block each, to be fitted in a case and carried by a shoulder strap. When 2 units of the cells of 6v each are connected in series a 12 volt unit would be obtained to enable the disc rotate at about 6000-7000 rpm (Table 5.1) to produce droplets of about 75-80 μm vmd and 1.15 dispersion ratio for insecticide/fungicide applications.

On the other hand when 1 unit of the cell of 6v block is connected across the disc motor it would rotate at about 1205 rpm to produce a droplet of about 200 μm vmd, for herbicide spraying. The battery was first evaluated using an Ulva Sprayer and the change in voltage and achieved droplet spectrum obtained is given on Table AJ (Appendix)

(v) Required Spray droplet Projection

The requirement for versatility has to be met, in other words the sprayer must be capable of being used for both ground crop and tree spraying where droplets must be projected over long distances which at present is only met by motorised knapsack mistblower.

Suleiman and Kaul (1980), evaluated comparatively, the performance of five motorised knapsack mistblowers commonly available in Nigeria and their vertical throws were measured and found to be as follows:- Turbine K90 supper (Italian), 8 metres, As pee Bolo Junior (Indian) - 5.5 metres, Yanmar MK 150 (Japan) - 4.0 metres, Fontan RII (German) - 4.0 metres and Kinkelder L35 (Dutch)- 8 metres.

Hence for effeicient projection of spray droplets up trees for control of tree crop pests in orchards the height of the prototype sprayer should be in the neighbour hood of 8 metres. However, here human factors concerning operational comfort, and convinience would be considered apart from the total weight of the sprayer.

The 8 m height was therefore only used as a guide for design but the actual height would defend upon individual subject (operator) convenience. The rotary atomizer used in this sprayer ware supported horizontally on a mast at a height which is adjustable up to 8 metres above the ground.

5.4 SUMMARY OF DESIGN PARAMETERS

The Table below gives the summary of values of design parameters obtained in 5.3 and used for the fabrication of the conceptual universal cda sprayer.

Table 5.3 Design parameters used for the Prototype cda sprayer.

	Parameter	Value obtained/Type selected
1.	Size of Spinning disc (diameter)	80 mm
2.	Spacing between spinning discs	750 mm

Table 5.3 (Contd)

3.	Power source	2 units of lead acid electrolyte cells of 6v block each in a pack
4.	Height of sprayer	8 metres (maximum)
5.	Structure of handle	8 inter locking sections each 1.0 metre in length.
6.	Tank capacity	1 litre (normal Ulv sprayer size tank)
7.	Spray flow restrictor	0.5 mm diameter

8. Rotational speed of disc (rpm)	Expected droplet size (μm vmd)	Purpose
<u>At 12 volt</u>		
6,000	80	Insecticide/ fungicide spraying.
<u>At 6 volt</u>		
1205 (minimum)	200	Herbicide spraying

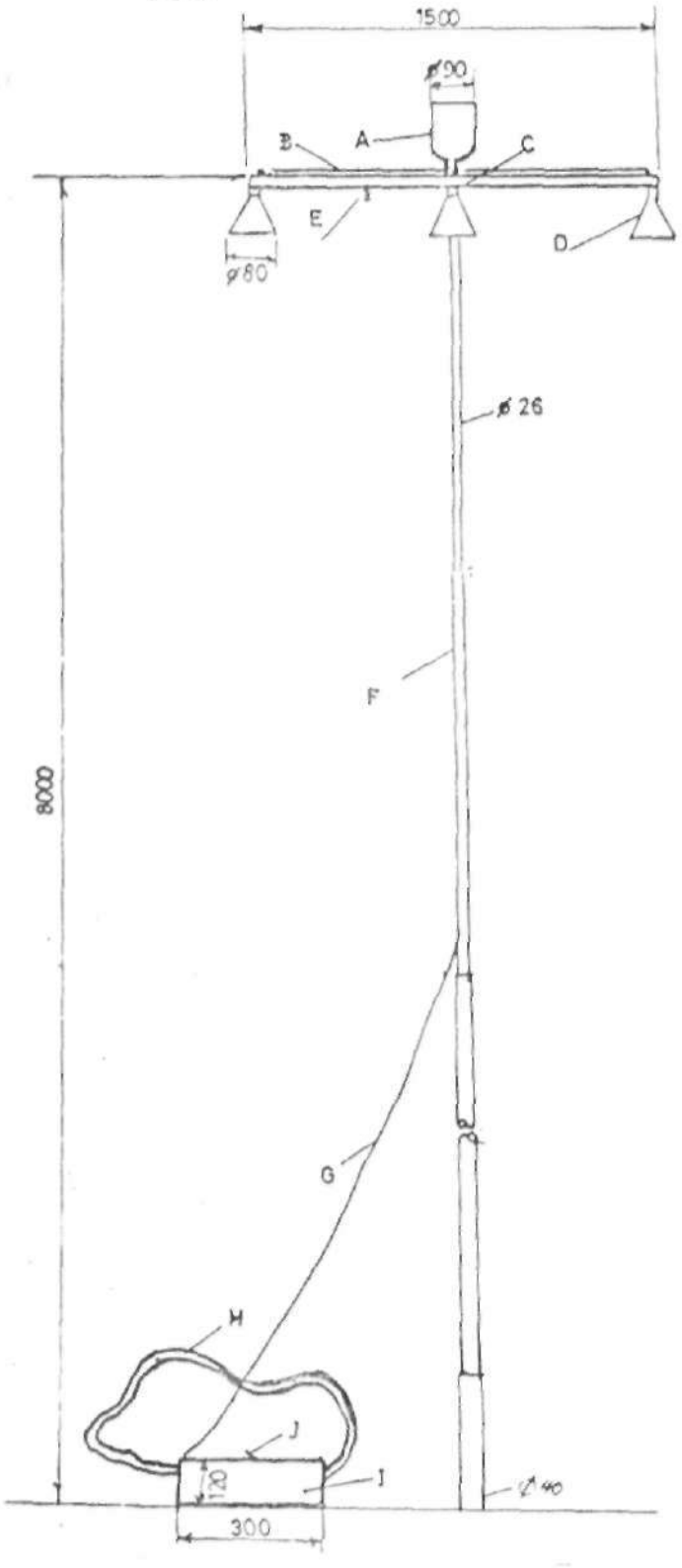
5.5 DESCRIPTION OF THE SPRAYER PROTOTYPE

The multipurpose cda sprayer is designed to meet the specific requirements outlined in 5.1 (a - i). It consists of three electrically driven rotary atomizers mounted on a 1.5 metre wide boom supported horizontally on a mast at a height which is adjustable up to about or near 8 metres (i.e the maximum vertical throw from a mistblower. Suleiman and Kaul (1980), above the ground (Fig. 5.1).

The mast consists of eight inter-locking sections each 1.0 m in length and both the boom and mast constructed of aluminum tubing.

Pesticide liquid is delivered from a 1.0 litre bottle placed centrally above the boom by gravity via three transparent spray deliver tubes to inter-changeable restrictors near the centre of the rotating discs. The discs are driven by DC electric motors powered by two 6 volt DC, re-chargeable lead-acid electolyte batteries, in a power box. A switch on the power box provides either 6v or 12 v DC electricity to the atomizers allowing droplets sizes to be altered to suit different spraying situations.

viz:- 70 - 80 μm at 12 volt for insecticides and or fungicides spraying and 200 - 250 μm vmd at 6 volt for herbicide spraying.



All DIMENSIONS IN MILLIMETRES

	COMPONENT	DIMENSION	MATERIAL	QTY
A	Spray Tank	ø90mmx200mm	Plastic	1
B	Spray delivery tube	ø10mmx750mm	Plastic tube	3
C	Boom	ø26mmx1500mm	Aluminium	1
D	Spray head with disc	ø80mmx90mm	Motor & plastic disc	3
E	Spray indication lamp	ø20mmx25mm	Electric lamp	1
F	Interlocking Section (handle)	8000mm	Aluminium	8
G	Electric cable	9600mm	Wire and plastic	1
H	Strap (Adjustable)	900mmx40mm	Reinforced plastic	1
I	Power pack	300mmx120mmx100mm	Plastic	1
J	Switch	15mm	Plastic	1

Fig. 5.1 THE CONTROLLED DROPLET APPLICATOR PROTOTYPE

At the middle of the 1.5 metre wide boom is a spray indication lamp which especially in the night gives an indication of the work of the sprayers. The intensity or brightness of the lamp may also be an indicator of the voltage level of the battery used with the sprayer.

5.6 PRINCIPLES OF OPERATION

The universal cda sprayer is designed for use as a ground crop insecticide/fungicide applicator, Herbicide applicator, as well as a tree crop/avicide spraying device. Setting the sprayer for one form of spraying operation or the other is achieved by adjustment of droplet sizes as well as height of the sprayer. Thus encorporating the features of both cda sprayers, Highe volume sprayers and Motorised Mistblowers.

5.6.1 Ground Crop Spraying

For ground crop spraying of insecticide/ fungicide where smaller droplets of about 80 micron vmd are required, the height of the sprayer is first adjusted by moving in the inter-locking sections until a suitable length of handle is obtained that is comfortable enough to the sprayer operator. The power pack is slung at the operators shoulder and the sprayer held in position as of any other conventional

Ultra low volume applicator. (Plate 6.1). The sprayer motors are then operated at 12 volt by turning the 'on' and 'off' switch, on the power pack, after fixing the chemical bottle and the restrictors. The sprayer is then used like any other hand held Ulv sprayer at same operator speed (1.0 m/sec) but maintaining the appropriate swath width selected during the sprayer calibration. Like during the use of any other spraying machine, the wearing of protective clothing is necessary especially the long overall coat, face shield, boats and hand gloves to reduce the operators contact with chemical. It is not adviseable to spray when the wind speed is zero since small droplets formed by the sprayer at that voltage levle have little energy of their own for impaction and therefore will drift for long distances under steady air. It is, however, also not adviseable to use the sprayer when the wind speed is greater than 5 metre/sec; unless where the field is very large that there is no dangers of drift. Wind speed should be about 4 m/sec which must be measured by a pocket wind metre or a cup anaemometre. The height of the sprayer boom above the target should also be adjusted to suit wind velocity. A height of about 0.5 metre is suitable for high wind speed while that of 1.0 metre above the target for lower wind speeds.

For ground crop herbicide spraying either pre-emergence or post emergence, the sprayer is operated in exactly the same way as described above but with the power pack switched to 6 volt, there by reducing the spinning disc rotational speed and thus producing bigger droplets (200 - 250 ^{u}m vmd) for herbicide application. Especially for post emergence non-selective herbicide application extreme care must be taken to prevent drift of chemical especially to neighbouring field by ensuring usage at lower height above target and correct voltage (6 volt).

5.6.2 Tree Crop Spraying

All aspects of spraying operation preparation regarding operator protection and equipment settings used for ground crop spraying are carried out in the same manner for tree crop pspraying. The height of the sprayer is then adjusted by drawing out the inter locking sections until a suitable height required is reached. Apart from insecticide and fungicide tree spraying the sprayer could be used for application of avicide for control of birds such as qualea fairly accurately and effectively since the lack of noise (unlike mistblower) would enable the brids be sprayed before they get frightened by engine noise. The



Plate 6.1 Ground Spraying using the Prototype Sprayer



Plate 6.2 Tree Crop Spraying using the Prototype Sprayer.

spraying indication lamp is specifically useful here for the operator to have an idea of the actual working condition of the sprayer.

5.7 Cost Estimate of the Prototype Sprayer

At the current market price the cost estimate of the prototype universal cda sprayer is as follows:-

Table 5.4 Estimated cost of one unit of the universal cda sprayer prototype.

	Component	Estimated Unit Price* (₦)	Quantity required	Cost* (₦)
1.	Spray Tank	100.00	1	100.00
2.	Spray delivery tube	15.00	3	45.00
3.	Boom	50.00	1	50.00
4.	Spray indication lamp	50.00	1	50.00
5.	Spray head with disc	500.00	3	1500.00
6.	Interlocking sections	100.00	8	800.00
7.	Electric cable	15.00	10(metres)	150.00

* Based on market price as of 20/5/94

Table 5.4 (Cont'd)

8.	Strap	50.00	1	50.00
9.	Power pack 2 (6.0v) batteries	160.00	2	320.00
10.	Switch	75.00	1	75.00
	Total Cost of one Unit	:		2895.00

CHAPTER 6

6.0 EVALUATION OF PROTOTYPE

In this Chapter, the procedure and results of some major laboratory and field evaluation tests carried on the controlled droplet applicator prototype are presented and discussed.

While the laboratory tests were carried out under the following:-

(i) Flow rate test

(ii) Spray volume distribution pattern test

(iii) Droplet spectrum analysis and

(iv) Power consumption tests, the field tests were conducted under the headings mentioned below:

(i) Post-emergence herbicide spraying

(ii) Ground crop insecticide/fungicide spraying

(iii) Tree crop pesticide application.

6.1 Laboratory Evaluation

This consists of a number of tests conducted on the prototype in the crop protection machinery laboratory of the Institute for Agricultural Research under controlled environment. Some of the results

obtained from the laboratory tests were later compared with those obtained in the field.

6.1.1 Flow Rate Test

The objectives of this test are:

(i) To investigate the efficiency of the prototype sprayer air bleed system.

(ii) To find out wheather the flow rate remains constant as the sprayer tank empties and

(iii) To obtain data that would serve as a basis for the sprayer calibration.

The prototype sprayer was allowed to operated without turning on the spinning discs electric motors. The sprayer tank was filled with cypermethrin 1.8 Ulv (cymbush ULV) insecticide and the spray liquid collected from three glass measuring cylinders one for each disc at one minute intervals until the tank empties. This was raplicated three times and the average values of flow rates obtained given on table 6.1.

Table 6.1 Flow rates from the insecticide/ fungicide nozzles of the prototype sprayer using cypermethrin 1.8 Ulv as test fluid.

	MEAN FLOW RATE		
Time (min.) No.	Nozzle 1 output (nu)	Nozzle 2 output (nu)	Nozzle 3 Output (nu)
1.	50.0	55.0	50.0
2.	40.0	45.0	40.0
3.	35.0	40.0	35.0
4.	35.0	40.0	35.0
5.	35.0	40.0	35.0
6.	30.0	35.0	30.0
7.	30.0	35.0	30.0
8.	30.0	35.0	30.0
9.	30.0	35.0	30.0
10.	30.0	35.0	30.0

During the check made to ensure that flow rate remained constant for any liquid level in the reservoir tank, in each case and for each nozzle there was an initial surge of liquid until a partial vacuum formed in the tank. Then the flow rate slows down until the air bleed system began to operate and the flow rate began to stablise. In general, for each nozzle there was s decrease in flow rate as the sprayer tank empties. At initial stage of spraying this decrease was more pronounced with nozzle 2 (fig. 6.1) (middle nozzle) due to a more direct influence of gravity on its as a result of its position in relation to the liquid reservoir (fig. 5.1). The whole tank emptied in 10 minutes using the smallest orificed restrictor, but from the middle of the tank the flow rate decreased by about 40% of the iniital value (from 50 ml/min to 30 ml/min). This would obviously affect application rate by resulting in the application of lower dosage in towards the last half of the sprayer tank. This would necessitate either the refilling of tank at shorter interval than 10 minutes or decrease in operator walking speed to maintain the same concentration of active ingredient over the target.

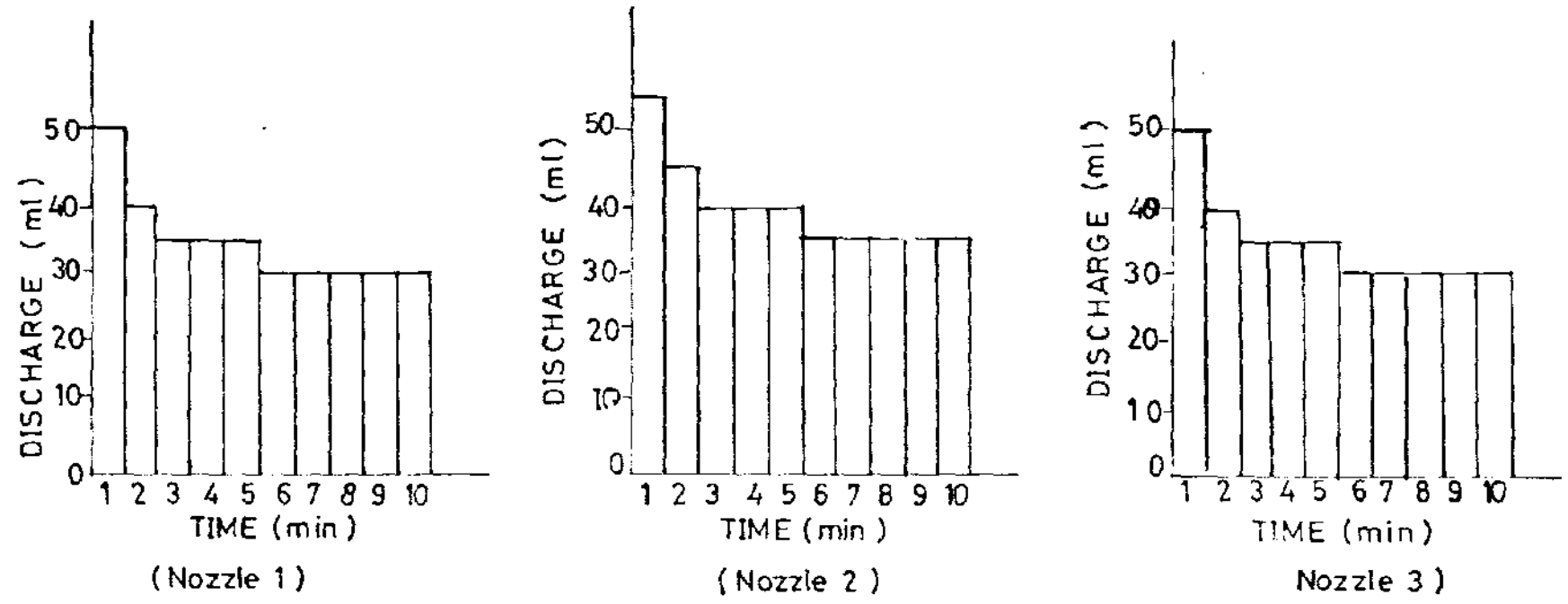


Fig. 6-1. Change in flow rate for the three nozzle as the [illegible] sprayer prototype tank empties

6.1.2 Calibration of Prototype for Insecticide/Fungicide Spraying

The prototype sprayer was calibrated using the procedures laid down by Kaul and Suleiman (1990) as follows:-

Assuming an operator walking speed of 1.0 metre per second and a swath width of 3.0 metres.

The volume (V) of spray liquid emmitted by the sprayer in the first 5 minutes was 610 ml (Table 6.1).

From the relation given below, the application rate (A) was calculated as follows:-

$$A = \frac{V}{30WS} \quad L/ha$$

where V = Amount of spray collected from the sprayer nozzle(s) in 5 minutes (ml)

W = Swath width (metres)

S = Operator walking speed (metres/sec)

A = Volume application rate (L/ha)

Hence

$$A = \frac{610}{30 \times 3 \times 1.0} \quad \text{——} \quad 6.8 \text{ L/ha}$$

Thus the expected application rate of spray chemical from the prototype is approximately 7.0 litres per hactare at an operator forward speed of 1.0 metre per second and maintaining a spray swath width of 3 metres.

An increase of operator walking speed to 1.5 metres per second would decrease the application rate to about 4.5 litres per hactare, thus falling well within the Ultra low volume spraying application range.

6.1.3 Calibration of Prototype for Herbicide Spraying.

The prototype sprayer was operated as previously done under 6.1.2 but with Herbicide nozzles of wider orifice sizes and using Galex 500 FW pre-emergence herbicide as test fluid. The sprayer was allowed to operated normally but with the motor off until it emptied completely. The results obtained are given in Table 6.2.

Table 6.2 Flow rates from Herbicide nozzles of the prototype sprayer using Galex 500 FW as test fluid.

Time (Min.no)	MEAN FLOW RATE Nozzle[1] output (ml)	Nozzle[2] output (ml)	Nozzle[3] output (ml)	Total output (ml)
1	70 .0	75.0	70.0	215.0
2	70.0	70.0	70.0	210.0
3	65.0	70.0	65.0	200.0
4	65.0	70.0	65.0	200.0
5	65.0	70.0	65.0	200.0
TOTAL (in 5 min.)	335.0	355.0	335.0	1025.0

Assume an operator walking speed of 1.0 metre per second and 9 swath of 1.5 metre (being a placement spray (no drift).

The spray volume application rate was calculated using same relation as for insecticide spraying.

Thus $A = \frac{V}{30WS}$ L/ha

V = 1025 ml W = 1.5m and S = 1.0 m/sec.

$A = \frac{1025}{30x1.5x1}$

A = 22.78 L/ha

Thus the expected application rate for herbicide was approximately 23.0 litres per hactare at an operator walking speed of 1.0 metre per second and a swath width of 1.5 metre.

6.1.4 Spray Volume Distribution Pattern Test.

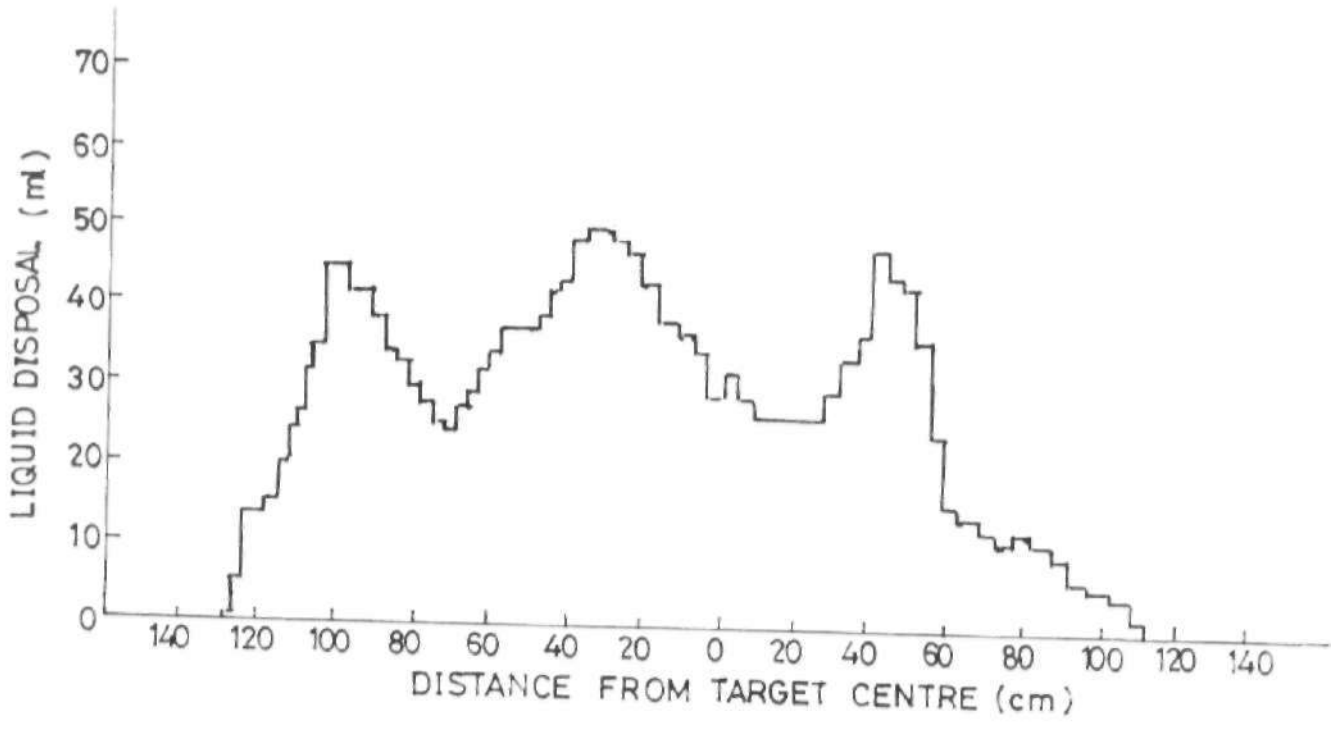
Since the ultimate goal for any spraying operation is applying chemical on an intended target in as even a manner as possible it was necessary to know the degree of uniformity of chemical emitted by any prototype sprayer. This is specifically important especially in pre-emergence herbicide application in which un even distribution could result in either over dose or under dose. The former resulting in reduced selectivity of herbicide while the latter in an erratic weed control (Suleiman et-al 1984).

The prime objective of this test was therefore to determine the degree of uniformity of spray chemical emitting from the prototype sprayer nozzles to the swath and to determine the best nozzle height above target for obtaining the most uniform spray application.

During the test, the spray boom of the prototype sprayer was positioned at 15cm, 30cm 45cm and 60cm above the patternator fig. and spray liquid collected at 12 volt, 9 volt and 6 volt using the lead acid electrolyte battery as a power source.

6.1.4.1 Analysis and Intepretation of Spray Volume Distribution Pattern Data.

Values of average liquid disposal from each patternator channel collected by the tubes beneath (Fig. 3.8) were plotted against the distance from the target centre. Some of such graphs drawn are presented on Figs. 6.2 - 6.4. Co-efficient of variations (CV) of the spray volume distribution was calculated according to clearke and Cooke (1982) for each spraying voltage and nozzle height combinations.



Eig. 6.2. Spray volume distribution pattern of the sprayer at 15 cm above patternator and 12 V power supply

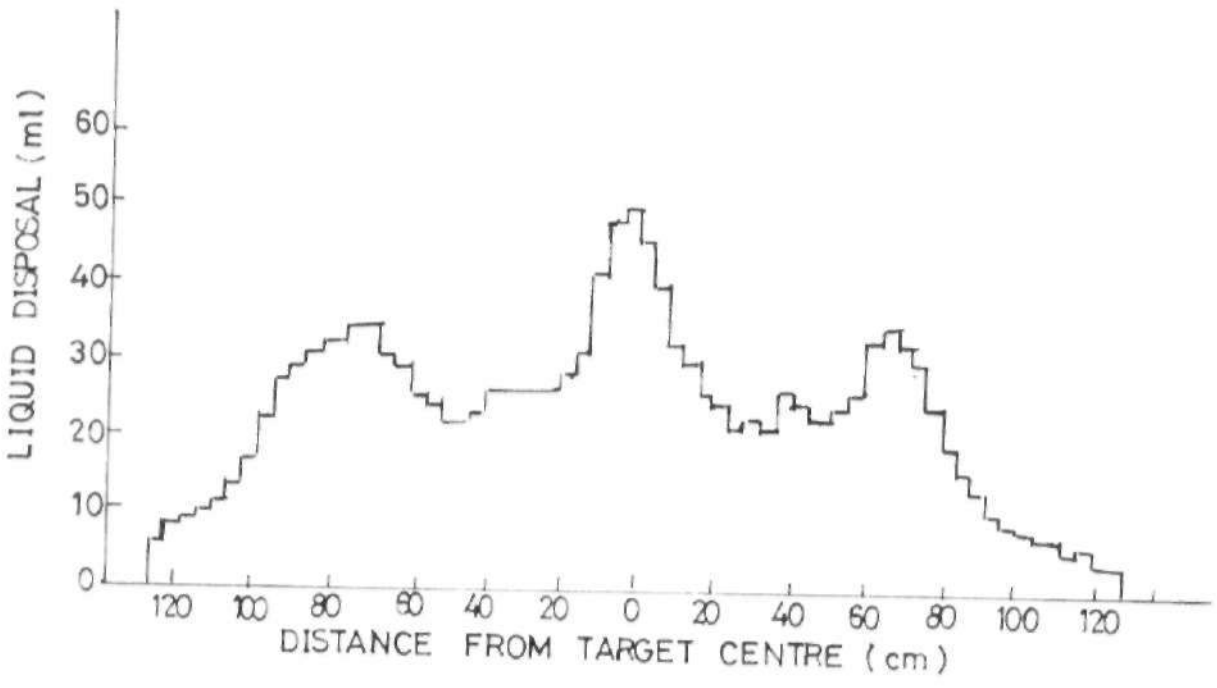


Fig. 6.3. Spray volume distribution pattern of the prototype sprayer at 60 cm above patternator and 12V power supply.

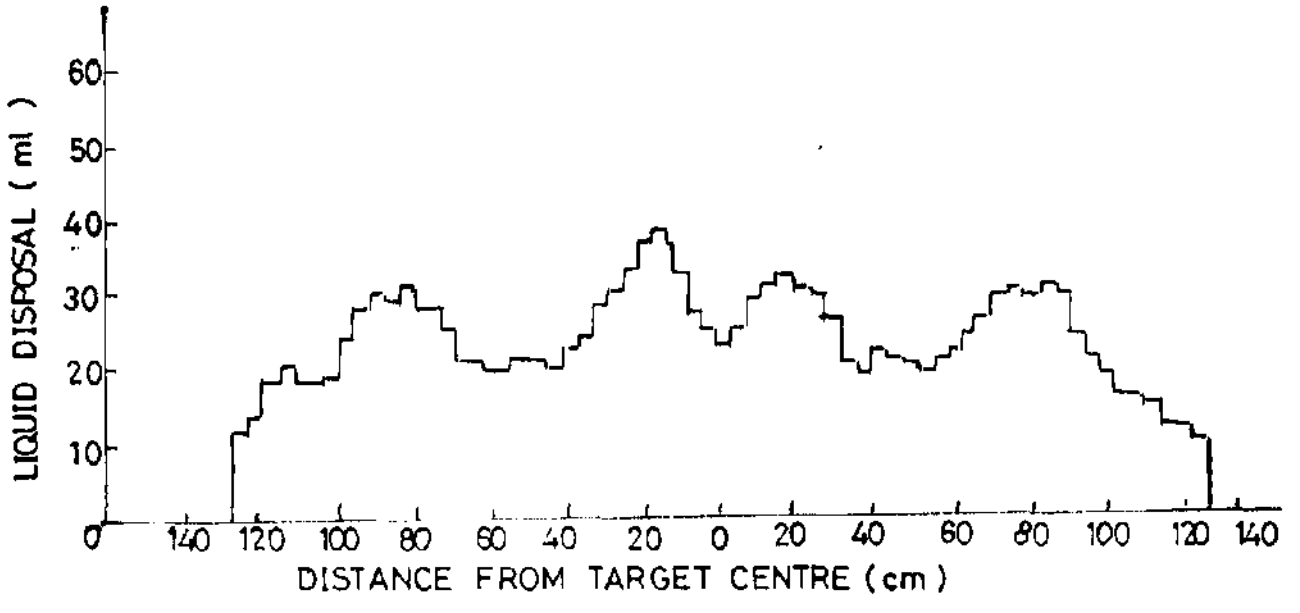


Fig. 6-4 Spray volume distribution pattern of the sprayer at 15 cm above patternator and 6V power supply

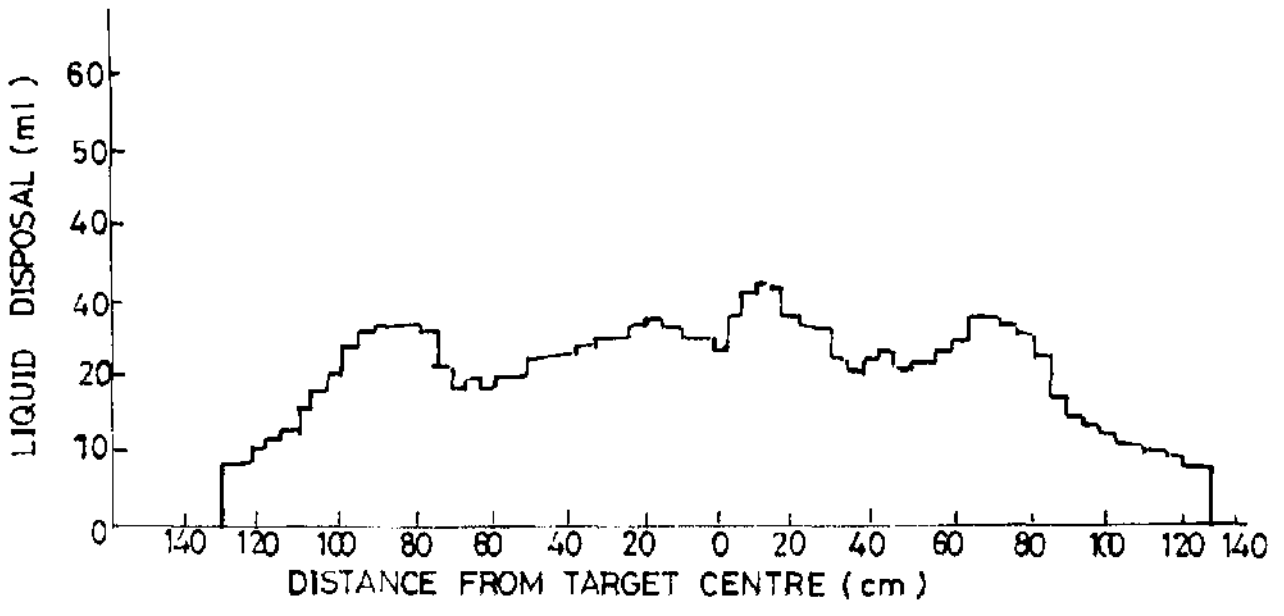


Fig. 6.5 Spray volume distribution pattern of the sprayer at 60cm above patternator and 6V power supply.

For example, at 15cm nozzle height above patternator and for 12 volt power supply.

$$n = 58 \quad \frac{Ex^2 = 50701}{\sqrt{\frac{Ex^2 - n\,(Ex)^2/n}{n}}} \qquad Ex = \frac{1565\ \bar{x} = 26.98}{\sqrt{\frac{50701 - (1565^2/58}{58}}}$$

$$= 12.087$$

$$\% \text{ Co-efficient of variation } CV = \frac{SD}{X} \quad \frac{12.0866 \times 100}{26.983}$$

$$\underline{CV = 44.8\%}$$

The average values of co-efficient of variation as calculated from the spray volume distribution pattern data, the samples of which are given on Appendix F, are shown on Table 6.3.

Table 6.3 Co-efficient of Variation of the Prototype spray volume distribution patterns obtained from different nozzles positions at three voltage levels.

Boom (nozzle) height (cm)	Co-efficient of Variation (%) at three voltage levels.		
	(6V)	(9V)	(12V)
15	25.2	35.6	44.8
30	26.0	40.5	45.0
45.	28.5	42.0	45.6
60	30.6	42.0	46.6

From figure 6.6 which showed the relationship between the co-effivient of variation of the spray patterns and the relative positions of the prototype nozzles above the target, the following could be deduced:-

(i) Values of co-efficients of variation are higher at higher sprayer motor voltages used regardless of the height at which the sprayer nozzles were positioned above the target. Uniformity of distribution of spray droplets produced along the swath by the prototype sprayer decreased with increase in voltage across the sprayer electric motor. This implied that herbicide droplets which were those produced at lower voltages (say 6 volt) were more uniformly distributed in general irrespective of the height at which the sprayer was held above the target, than the insecticide/ fungicide droplets which were those produced at higher voltages (say 12 volt).

This difference in distribution pattern uniformity between sprays formed at different voltage levels could be explained by the differential behaviour of spray droplets of different sizes as they are

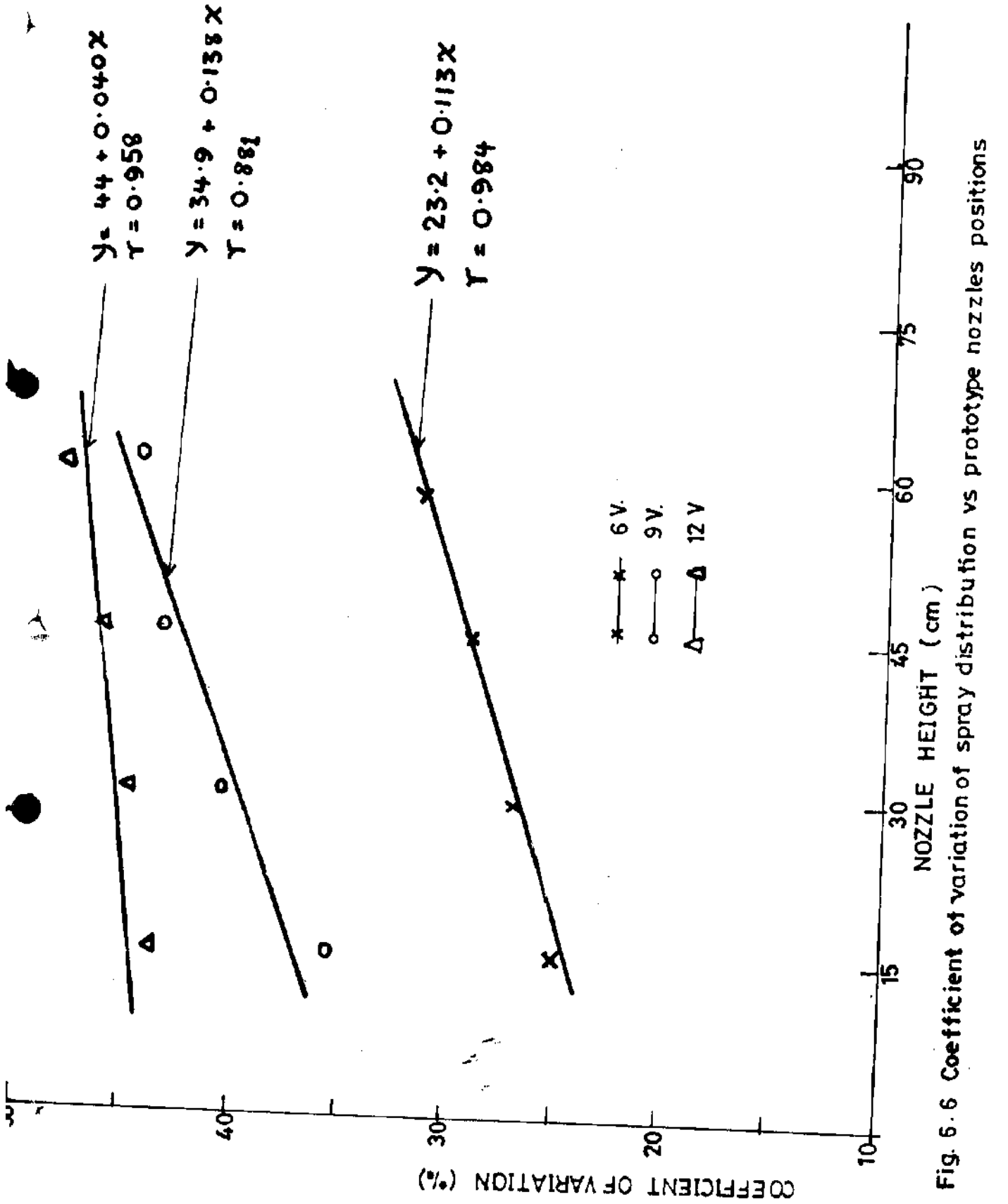


Fig. 6.6 Coefficient of variation of spray distribution vs prototype nozzles positions

released from a particular position to the same given target. At 6 volt when larger droplets were formed (as will be seen in Section 6.1.5) and released from the nozzles they approached the target and land directly on it with minimal effect of air resistance between the nozzle and the target due to their sizes and therefore least deviation off the target or collision with other neighbouring droplets. The result is hence spread of droplets in a relatively more even manner.

At 12 volt on the other hand, smaller droplets were formed and were hence influenced more by the effect of air resistance between the nozzle and the target due to their smaller sizes. There was therefore higher tendency of some droplets getting suspended for longer periods in the air losing weight due to evaporation (although the environment is relatively controlled) and collising with some other neighbouring droplets. The result was that some droplets may be thrown off the course haphazardly resulting in relatively less uniform distribution along

the swath. However, this effect of non-uniformity of spray volume distribution pattern along the swath of 12 volt may not be that detrimental to the sprayer performance since at that voltage level it is insecticide/fungicide droplets that are being formed in which case the important factor is spray droplet size uniformity rather than distribution pattern.

(ii) At a particular motor voltage level, the sprayer prototype produced more uniform spray distribution along the swath at lower heights of the nozzles above the target. This was indicated by the least values of co-efficient of variations at 15 cm heights above target in all voltage levels used. This could be explained by the fact that the longer the distance travelled by a particular droplet from the point of release to the target the higher the chances of external influences causing it to deviate from its course or collide with other droplets, thereby resulting in non-uniform distribution and vice versa. This indicates that the closer the sparyer is held above the target (soil or crop) the

more uniformly distributed the spray from it is likely to be; a point worthy of notice by the sprayer operator.

6.1.5 Droplet Spectrum Test

While in the previous section 6.1.4, the emphasis was on the uniformity of distribution of chemical spray along the swath which is a reflection of distribution of the active ingredient, it is also important to know the actual sizes and uniformity of the droplets themselves that are being emmitted from the sprayer at a particular spraying situation. This is particularly important so as to see whether the prototype sprayer produces those required droplet sizes and uniformity that were assumed originally as bases for the prototype design as per section 5.3 (i.a).

The prime objective of this test was therefore to determine the values of the vmds, Nmds and rs of the prototype sprayer at the insecticide/fungicide and herbicide operating voltage levels and compare them with the expected values.

During the laboratory evaluation of the prototype for droplet spectra, droplet sampling were conducted at the two voltage levels 6v and 12 v corresponding to the herbicide and insecticide/fungicides spraying

situations respectively. Magnesium oxide slides were used to collect droplets using the method described in section 3.1.3.1 and using the rotorod Sampler (plate 3.3) as a smapling equipment. The collection of droplets were done as usual at random as described in section 3, and they were measured as per described in section 3.1 using the flemings particle size Analyser (plate 3.5).

6.1.5.1 Analysis and Interpretation of the Prototype spray droplet spectra.

Based on the droplet data obatained for the prototype from the particle size analyser a similar sample of which is given on Table a (Appendix A), the graphs of the cumulative percentages were plotted against the mean diameters for the spray data obtained at the three voltage levels. Values of the volume median diameters and Number median diameters were read from the above graphs (fig.) and the summary of the obtained droplet spectra parameters are given on Table 6.4.

Table 6.4 Summary of Spray droplet parameters obtained from the prototype sprayer at three voltage levels.

Motor Voltage (Volt)	Rotational speed of disc (rpm)	Spray Droplet Spectrum (Vmd)* (μm)	(Nmd)** (μm)	(r)***
12.0	6000	82	67	1.22
9.0	4800	150	115	1.30
6.0	2700	285	220	1.30

NB *, ** and *** - See foot notes on pages xviii and xx for details.

Table 6.4 shows the summary of spray de droplet parameters obtained from the prototype sprayer when operated at 3 motor voltage levels. The upper (12 v) and the lower (6v) voltage levels droplet parameters are regarded as most significant

as these represent the respective motor voltages within which suitable droplets for insecticides/ fungicides and herbicides applications are produced. At 12V, when two units of lead acid batteries are used the droplets of about 80 micron vmd were produced fitting well into acceptable droplet size range suitable for insecticide/ fungicide ultra low volume spraying and falling closed to the assumed range of values (5.3 i.a). The droplet sizes are above those liable to serious wind drift and below those prone to run-off.

The droplet density produced by the prototype which is a measure of spray concentration over the target is important since high concentration of droplets are required for disease control, medium for insect and low (or scattered) for weed control and avoidance of drift.

At the application rate of 6.8 L/ha (section 6.1.2) and with droplet size of 82 μm vmd being produced the expected number of droplets (n) from the sprayer prototype could be calculated according to Matthews, (1979).

$$n = \frac{60}{\pi t} \left(\frac{100}{d}\right)^3 Q$$

Where d = diameter of droplets and Q = Application rate

for the above d = 82 $^{\mu}$m vmd Q = 6.8 L/ha

$$n = \frac{60}{11} \left(\frac{100}{82}\right)^3 \times 6.8 = 236$$

giving a droplet density of 236 droplets per square centimeter. This droplet density is very satisfactory since a typical density of 1 drop/mm^2 i.e (100 droplet/cm^2) is acceptable.

At 6v, when the use of one unit only of lead acid battery was switched over to, the droplet sizes produced also fell within an acceptable range for herbicide application (200-300 ^{u}m vmd) with the dispersion ratio increasing to 1.30 indicating slight decrease in spray droplet uniformity. The droplet density at this voltage level was found to be about 19 droplets per square centimeter. This droplet density is also acceptable since with 300 ^{u}m droplets at an average density of 14 droplets/ cm^2 has given good weed control (Matthews' 1979).

6.1.6 Power Consumption Test

The primary objective of this test was to determine the amount of power consumed by the prototype sprayer in producing the two different classes of droplets it was designed to. The test

was also carried out with the view to determining the life span of the power source (lead acid electrolyte battery) recommended for use with this prototype sprayer. Determination of power consumption of the prototype sprayer was conducted by operating the sprayer in accordance with the set up shown in the circuit diagram on fig. 3.6. Samples of results of power consumption test are given on the Appendix G and a Summary of results given on Table 6.5.

Table 6.5 Power Consumption and Rotational Speed from 3 Spinning Discs of the Prototype Sprayer at two Voltage levles.

Voltage levle (volt)	Current drawn (Amp)	Rotational speed (rpm)	Power consumption (watt)
11.50	1.4	6500	16.1
5.75	0.8	3000	4.6

The power consumed by the prototype sprayer for the production of insecticide/fungicide droplets is found to be much higher than for herbicide spraying. This is expected since much higher spinning disc rotational speed is needed for the former situation in order to produce smaller droplets required for the purpose. Even though a relatively high power consumption is recorded from the prototype at insectivide/fungicide spraying situation which is mainly due to the fact that more than one disc is driven by the power source, this power consumption is still below the levle consumed by some of the commercial cda sprayers evaluated (e.g over 22 vwatt for Tecnoma Tl UBV, (Table 4.1).

The life span of the lead acid electrolyte batteries used with the prototype for insecticide/ fungicide spraying was also determined by operating the sprayer as described in the previous page until the voltage level fell to below 6 volt, and the number of hours of spraying recorded. The summary of results are given on Table 6.6.

The average rate of voltage drop of the lead acid electrolyte batteries used with the prototype sprayer (from 11.5v to 6.0 in 20 hrs) amounted to below 0.3 volt/hr which is lower than even that of

the longest life U2 battery tested (0.32 volt/hr for Eveready U2 battery - Table 4.8) at a much lower power consumption situation. Thus the lead acid electrolyte battery shows a clear superiority in terms of druability under any spraying situation than the conventional dry cell U2 battery. The voltage and hence spinning disc rotational speed remain fairly constant for the first 13 hours of spraying with a drop of only about 0.5 volt and only 250 revolutions of the spinning disc. This maintains the droplet spectrum of the sprayer fairly constant. Both droplet sizes and uniformity remain within the acceptable range for cda spraying for most part of the battery life.

Table 6.6 Change in Voltage of Lead acid electrolyte batteries, rotational speed and dro;et spectrum of the Prototype Sprayer.

Day[1] (no.)	Voltage[2] (Volt)	Current[3] (Amp)	Rotational[4] speed (rpm)	Power consumption (Watt)	Droplet Spectrum (Vmd) (μ_m)	(Nmd) (μ_m)	(r)
1.	11.50	1.40	6500	16.10	82	67	1.22
	11.25	1.40	6400	15.75	82	67	1.22
2.	11.50	1.40	6500	16.1	82	67	1.22
	11.25	1.40	6400	15.75	82	67	1.22
3.	11.30	1.40	6400	15.82	82	67	1.22
	11.20	1.40	6300	15.68	85	67	1.27
4.	11.25	1.40	6400	15.75	82	67	1.22
	11.00	1.40	6250	15.40	90	75	1.20
5.	11.20	1.20	6250	13.44	85	70	1.21
	11.00	1.20	6250	13.20	90	70	1.29

Table 6.6 (Cont'd).

6.	11.00	1.20	6250	13.20	90	70	1.29
	10.00	1.00	6200	10.00	100	85	1.20
7.	11.00	1.20	6250	13.20	95	80	1.20
	9.50	1.00	6100	9.50	100	75	1.30
8.	9.50	1.00	6100	9.50	100	85	1.20
	8.00	0.80	6000	7.65	120	80	1.50
9.	9.00	0.85	6000	7.65	100	70	1.43
	7.00	0.75	5000	5.25	160	100	1.60
10.	8.50	0.85	5500	7.30	120	95	1.26
	6.00	0.75	3500	4.50	200	125	1.60

Table 6.6 (Cont'd)

Foot note

1. - Day's spraying. Spraying for a period of two hours in the method described in the previous page.

2 - Voltage across the sprayer motors measured at the beginning and at the end of each days spraying period (2 hours).

3 - Current drawn by the motors measured at the beginning and at the end of each day's spraying period.

4 - Rotational speed of disc measured as described in (3) and (2) above.

6.2 Field Evaluation

The objectives of the field tests were to compare some of those performance parameters of the sprayer measured in the laboratory such as the flow and application rates, with their field values and also to assess the general performance of the prototype in the field especially with regards to operator comfort during tree crop spraying, and general operational problems where found.

6.2.1 Ground Crop Spraying

In this test the prototype sprayer was used with the prepared mixture (described in Section 3.1.2)

as test fluid in order to avoid environmental pollution and operator hazard on ridged plot (plate 6.1) after the sprayer was calibrated in accordance with the procedure as described in Section 6.1.2. The plot area was 0.75 ha with ridges spaced at intervals of 75 cm apart. The sprayer was operated at 1.0 m/sec walking speed while maintaining a swath of 3 metres (4 ridges). The results are shown on Table 6.7.

Table 6.7 Results of Ground Spraying field test

Type of mixture (formulation) used	Amount of mixture used in plot (avr) (L)	Area of field (M^2)	Swath width (M)	Walking speed (M/Sec)	Application rate (L/ha)
C : K*					
2 : 3	5.4	7500	3.0	1.0	7.2
Galex : Water					
1 : 7	18.0	7500	1.5	1.0	24.0

* See Section 3.1.2, Table 3.2

The field test on the machine using the insecticide/fungicide nozzles and mixture of corn oil and kerosine 2:3 representing the cypermethrin 1.8 Ulv gave a volume application rate of 7.2 L/ha table 6.7, about 6.0% higher application rate than that earlier predicted during calibration. This may be mainly due to variation in operator walking speed which may not necessarily be maintained at 1.0 m/sec due to tiredness during spraying etc.

Test carried out using Galex 500FW water mixture and using the herbicide nozzles gave a v volume application rate of 24 L/ha, about 4% higher than that expected from machine calibration. This again may be due to same reason as given above for insecticide/fungicide spraying situation.

6.2.2 Tree Crop Spraying

This test was carried out with the sprayer prototype operating using the insecticide/fungicide nozzles in an orchard consisting mainly of citrus and using the same formulation mixture as in 6.2.1 (plate 6.2). The trees, which are mostly mangos were approximately 5m high and 6.6m diameter, planted at about 12 metre interval.

Liquid spray involvement per hactare was determined as per 6.2.1 and was found to be about 10 L/ha. This increase in volume application rate was mainly due to low operator walking pspeed during tree spraying since individual trees have to be sprayed with extra care that spinning discs teeth did not come in direct contact with tree branches, etc to avoid disc teeth damage, which may cause change in droplet spectrum (Suleiman, 1986).

6.2.2.1 Operational Difficulties

The prototype sprayer is rather a bit difficult to operate for tree crop spraying due to the length of its handle at the first spraying experience of the operator. The operator needs to learnt to have proper balance of the prototype before it is operated with ease. Also the use of the prototype sprayer for tree crop spraying absolutely necessitates the use of protective clothings especially the face shield since the user would normally direct his eyes up above the tree canopy to monitor the movement of spray droplets and spinning discs, through the spray indication lamp.

6.3 Advantages of the Prototype

The prototype sprayer has the following basic advantages over and above conventional hand-held controlled droplet applicators:-

(i) Higher Field Capacity

With the use of three spinning discs for droplet atomisation, the out put from the sprayer would be relatively higher especially when appropriate nozzle restrictors are used. The operator could therefore walk faster and maintain same swath or slower but maintaining wider swath widths depending upon the wind velocity at the time of spraying.

(ii) Versatility

This is one of the most unique achievements of the prototype sprayer. Through instant change of motor voltage from the power pack, suitable voltage level is selected for particular droplet formation to suit particular spraying situation. (e.g. 6v for herbicide droplet etc).

Through the withdrawal or extension of the inter-locking sections of the tubular

handle the prototype sprayer could be adjusted and set for either ground crop or tree crop spraying. Thus the sprayer is able to achieve spraying performance of a conventional knapsack mistblower yet maintaining the CDA advantages.

(iii) Better Droplet Spectrum

The voltage of the sprayer is maintained at a relatively constant level for longer period of time than for conventional CDA sprayer, as such droplet produced are relatively more uniform.

(iv) Power Consumption

The operating cost which is almost wholely governed by rate of power consumption (i.e frequency of battery replacement) is compared on Table 6.8 for a CDA sprayer using the conventional U2 batteries and lead acid electrolyte batteries recommended and tested for the prototype.

Table 6.8 Comparison on Battery cost per year of U2 and Lead acid electrolyte Batteries used in CDA Spraying.

Costs	Battery Type	
	U2	Lead acid
1. Purchase cost per set (₦)	80.00 *	320.00*
2. Expected life (years)	0.02**	5.00+
3. Purchase cost per year (₦/a)	4000.00	64.00
4. Recharging cost per year (₦/a)	Nil	730.00***
Total Battery Cost/year (₦/a)	4000.00	794.00

Thus for same periods of spraying the lead acid electrolyte batteries cost only about 20% of U2 batteries even though the initial cost of the former is much higher.

N.B

* 4 pairs of U2 batteries at ₦25.00 per pair and one pair of lead acid batteries at ₦320.00 as at the time of comparison 20/9/94

** Assuming maximum performance of 16 hours spraying i.e 8 days per set.

*** ₦20.00 per 10 day spraying, as at the time of comparison.

\+ After Arnold (1985).

The prototype therefore when used with the recommended type of battery would prove much more economical to use than the conventional cda sprayer using the U2 dry cell batteries.

CHAPTER 7

7.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary and Conclusions

From the investigations carried out in this study it has been found that it is possible to encorporate the unique features of hydraulic sprayers, and motorise knapsack Mist-blowers in a controlled droplet applicator and yet retain the CDA advantage.

The study resulted in the production of a CDA sprayer prototype that is multi-purpose in nature and capable of being used to apply insecticides/fungicide and Herbicide by interchanging appropriate nozzles and adjusting appropriate power source voltage. It could also be used for tree crop spraying by adjusting its configuration thus achieving the mistblower advantage.

Laboratory and field tests using the prototype revealed reasonable performance in both insecticide/ fungicide, Herbicide and tree spraying within set specifications in terms of spray droplet spectra, spray volume distribution and throws.

7.2 Suggestions and Recommendations for Further Study

A number of modifications could be incorporated to further improve the machine as follows:-

(a) Provision of improved foldable spray boom to facilitate easy handling especially during transportation.

(b) Provision of pumping device (e.g. a positive displacement pump to facilitate direct pumping of spray chemical from the operators back (say) to the spinning discs in order to facilitate better chemical flow control and to reduce the burden of operation especially during tree crop spraying. This will also reduce the effect of gravity on flow rate from the tank.

(c) The power source, should be provided with a small charging device to facilitate quick recharge of the power source without having to look for such services always.

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APPENDIX A

Table 4.2 : Various commercially available CDA Sprayer designs, purpose and expected spray droplet spectra.

	Machine make/model	Design purpose	Disc speed (rpm)*	Droplet size (um)**	Remark
1.	Micron Ulva	Insect and disease control	5500-8000	70-100	Ground crop spraying.
2.	Turbair X	"	"	"	Ground crop spraying with more special Turbair formultion
3.	Tecnoma TlUBV	"	6000-8000	50-60	Ground crop spraying
4.	Tecnoma TII	"	"	70-100	"
5.	Micron Herbi	Weed control	2000	250-300	"
6.	FW Handy	"	1800	"	"
7.	Berthoud C2	"	2000	200-250	"

* Depending on power source condition

** Depending on power source condition and flow rate.

APPENDIX B

SPRAY DEPOSIT MEASUREMENT RECORD

Designated class	Number of Droplets	Total (N)
4	1	1
5	𝍸 𝍸 //	12
6	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 //	32
7	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 ////	64
8	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 /	101
9	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 ////	93
10	𝍸 𝍸 𝍸 𝍸 𝍸 //	27
11	///	3
12		
13		

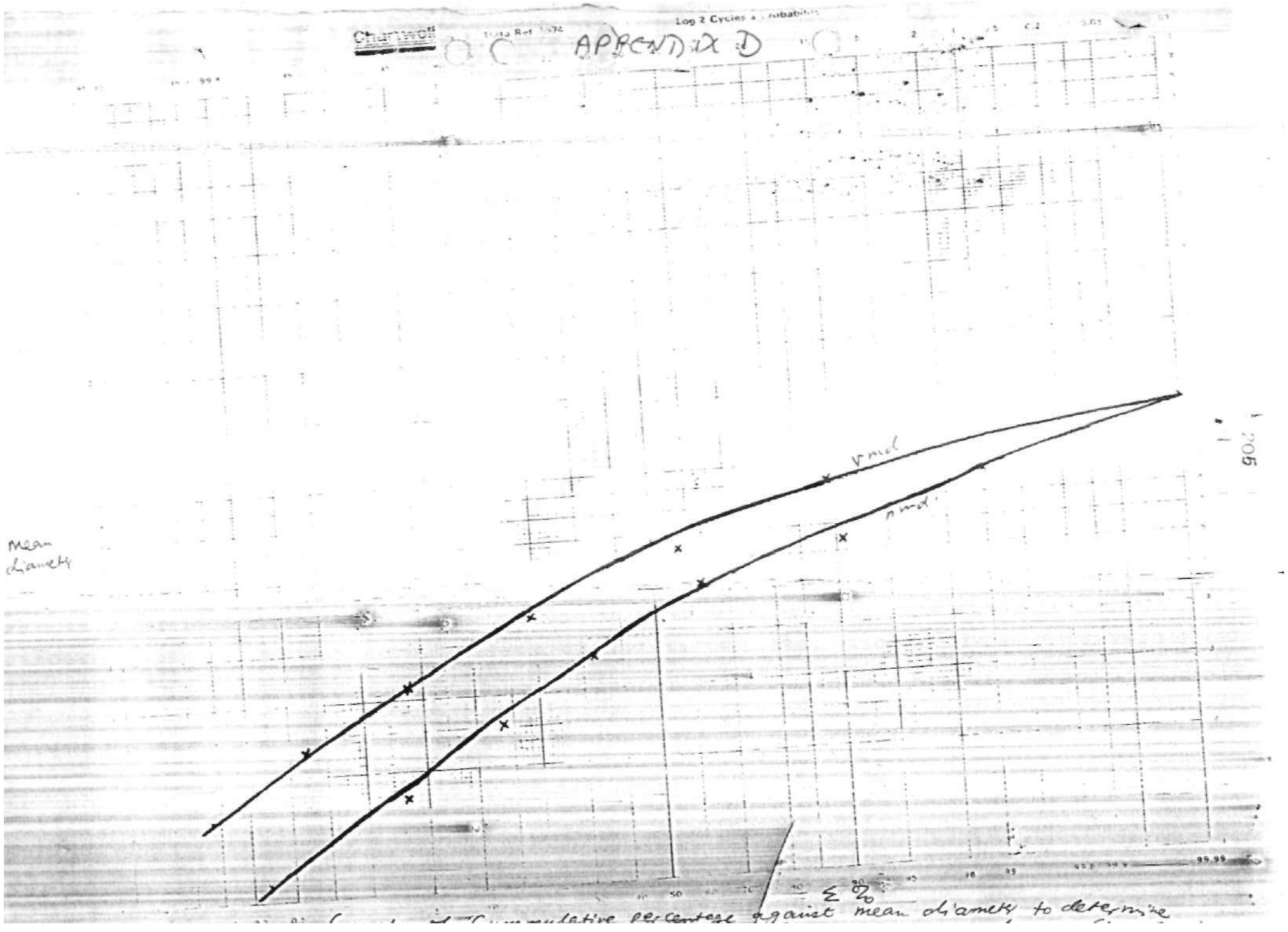
Table AC

APPENDIX C

SPRAY DEPOSIT CALCULATION FORM

Designated class	Upper class size	True size upper limit	Mean size (dm)	Number in class N	%N	E%N	dm^3	Ndm^3	$\%Ndm^3$	$E\%Ndm^3$
4	16	13	11	1	0.3	0.3	1331	1331	0.002	0.002
5	22	19	16	12	3.6	3.9	4096	49152	0.08	0.82
6	31	27	23	32	9.6	13.5	12167	389344	0.61	0.692
7	44	38	32	64	19.2	32.7	32768	2097152	3.3	4.0
8	62	53	46	101	30.3	63.0	97336	9830936	15.5	19.5
9	88	75	64	93	27.9	90.9	262144	24379392	38.4	57.9
10	124	107	91	27	8.1	99.0	753570	20346390	32.0	89.9
11	175	151	129	3	0.9	99.9	2146690	6440070	10.0	99.9
12	248	213	182	-	-	-	-	-	-	-
		Total		333				63,533,767		

APPENDIX D



cumulative percentage against mean diameter to determine

Table AE APPENDIX E

Effect of change in voltage of four makes of U2 batteries on rotational speed and droplet spectrum of the ULVA Spinning disc CDA Sprayer.

Battery make	Day	Voltage[1] (volt)	Current[2] (Amp)	Rotational[3] speed (rpm)	Droplet Spectrum Vmd[4] (^{u}m)	Nmd[5] (^{u}m)	r[6]
ABC	1	9.50	0.36	5600	85	71	1.19
		7.75	0.22	3100	175	91	1.92
	2	9.00	0.30	4400	98	82	1.19
		6.75	0.16	2200	208	96	2.16
	3	7.75	0.24	3400	160	125	1.28
		6.50	0.14	2000	220	82	2.67
	4	7.50	0.26	4500	98	75	1.30
		6.00	0.17	3000	175	63	2.8

Table AF1 APPENDIX F

SPRAY VOLUME DISTRIBUTION PATTERN MEASUREMENT DATA SHEET

Boom height ..15cm.. Disc spacing ..75.. Voltage ..12V.. Formulation .....

Dry Bulb Temp..... Wet Bulb Temp..... Relative Humidity..... Date.....

	Volume of Spray collected in Millitres (ml)								
Tube No.	R1	R2	R3	Average	Tube No.	R1	R2	R3	Average
1	-	-	-	-	31	44	48	45	46
2	2	1	1	1	32	46	49	47	47
3	7	7	8	7	33	46	46	48	47
4	17	16	14	16	34	46	45	47	46
5	18	16	14	16	35	44	40	43	42
6	20	16	16	17	36	37	35	34	35
7	24	20	19	21	37	31	30	30	30
8	30	24	25	26	38	29	27	28	28
9	35	26	30	34	39	25	25	26	25
10	39	34	36	36	40	27	25	26	26
11	45	44	44	44	41	24	25	23	23

APPENDIX G

Computer Programme Developed to Calculate Vmds and Nmds

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C.THIS PROGRAM CALCULATES AMONG OTHER DROPLET PARAMETERS,
C.THE CUMULATIVE PERCENTAGE BY NUMBER(E%N) AND BY VOLUME(E%NDM**3)
C.OF DROPLETS FROM EACH SIZE CLASS(D) WHICH WHEN PLOTTED AGAIST
C.THE MEANSIZE(DM) (ALSO CALCULATED), PRODUCES CURVES FROM WHICH
C.THE NUMBER MEDIUM DIAMETER(NMD),THE VOLUME MEDIUM DIAMETER(VMD)
C.AND THE DISPERSION RATIO(R),COULD BE OBTAIND,GIVEN THE APPROPRIATE
C.DATA FROM A SPRAY DROPLET SAMPLE.
C.THE DROPLET SAMPLE COLLECTING SURFACE IS MAGNESIUM OXIDE COATED SLIDE.
 8 DIMENSION D(10),N(10),DT(10),DM(10),PERN(10),CUPERN(10)
 9 DIMENSION DMCUB(10),NDMCUB(10),PERNDC(10),SPRNDC(10)
10 WRITE (6,500)
11 500 FORMAT(1H1 ,115(1H-))
12 WRITE (6,100)
13 100FORMAT(1H ,5X,'UPPER',5X,'TRUE SIZE',3X,'MEAN',5X,'NUMBER',
   +3X,'%N',6X,'E%N',
   +8X,'DM**3',9X,'NDM**3',10X,'%NDM**3',5X,'E%NDM**3',/4X,
   +'CLASS',6X,'UPPER',6X,'SIZE',4X,'IN CLASS'/7X,
   +'SIZE',7X,'LIMIT',5X,'(DM)',6X,'(N)'/7X,'(D)',
   +8X,'(DT)'/)
19 WRITE (6,700)
20 700 FORMAT(1H ,115(1H-))
21 DO 20 I=1,10
22 20 INPUT D(I),N(I)
23 SUMN=0
24 DO 30 I=1,10
25 30 SUM N=SUMN+N(I)
26 I=1
27 CUPERN(1)=0
28 SPRNDC(1)=0
29 DT(I)=D(I)+0.86
30 WRITE (6,200) D(1),DT(1)
31 200 FORMAT (F10.2,F12.2)
32 SUMNDC=0
33 40 DT(I+1)=D(I+1)+0.86
34 DM(I+1)=(DT(I)+DT(I+1))/2
35 PERN(I+1)=(N(I+1)/SUMN)*100
36 CUPERN(I+1)=PERN(I+1)+CUPERN(I)
37 DMCUB(I+1)=DM(I+1)**3
38 NDMCUB(I+1)=DMCUB(I+1)*N(I+1)
39 SUMNDC=SUMNDC+NDMCUB(I+1)
40 IF(I.EQ.9)GOTO 50
41 I=I+1
42 GO TO 40
43 50 SPRNDC(1)=0
44 DO 60 I=2,10
45    PERNDC(I)=(NDMCUB(I)/SUMNDC)*100
46 SPRNDC(I)=PERNDC(I)+SPRNDC(I-1)
47 60 WRITE (6,300) D(I),DT(I),DM(I),N(I),PERN(I),CUPERN(I),
   +DMCUB(I),NDMCUB(I),PERNDC(I),SPRNDC(I)
49 300 FORMAT(F10.2,F12.2,F10.2,I8,F9.2,F8.2,F16.2,F17.2,F10.2,F12.2)
50 WRITE(6,800)
51 800 FORMAT(1H ,115(1H-))
52 WRITE(6,400) SUMN,SUMNDC
53 400 FORMAT (31X,'TOTAL:',I4,27X,'TOTAL',F18.2)
54 WRITE (6,600)
55 600 FORMAT(31X,10('-'),27X,22('-'))
56 STOP
57 END
```

APPENDIX II

Computer Output for Calculation of Vmds and Nmds

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	%N	E%N	DM**3	NDM**3	%NDM**3	E%NDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	7	2.33	2.33	9938.37	69568.00	0.16	0.16
40.00	34.40	30.10	30	10.00	12.33	27270.90	818127.00	1.83	1.98
50.00	43.00	38.70	73	24.33	36.67	57960.60	4231124.00	9.45	11.43
60.00	51.60	47.30	67	22.33	59.00	105823.82	7090195.00	15.83	27.26
70.00	60.20	55.90	59	19.67	78.67	174676.88	10305935.00	23.01	50.27
80.00	68.80	64.50	40	13.33	92.00	268336.12	10733444.00	23.96	74.23
90.00	77.40	73.10	10	3.33	95.33	390617.89	3906178.00	8.72	82.95
100.00	86.00	81.70	14	4.67	100.00	545338.51	7634739.00	17.05	100.00

TOTAL: 300 — TOTAL 44.822310.00

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	%N	E%N	DM**3	NDM**3	%NDM**3	E%NDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	
30.00	25.80	21.50	8	2.67	2.67	9938.37	79506.00	0.1	
40.00	34.40	30.10	31	10.33	13.00	27270.90	845397.00	1.7	
50.00	43.00	38.70	81	27.67	40.67	57960.60	4694730.00	9.6	
60.00	51.60	47.30	74	24.67	65.33	105823.82	7830962.00	15.7	
70.00	60.20	55.90	32	10.67	76.00	174676.88	5589660.00	11.	
80.00	68.80	64.50	24	8.00	84.00	268336.12	6440066.00	13.	
90.00	77.40	73.10	18	6.00	90.00	390617.89	7031122.00	14	
100.00	86.00	81.70	30	10.00	100.00	545338.51	16360155.00	33.	

TOTAL: 300 — TOTAL 48987598.00

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	%N	E%N	DM**3	NDM**3	%NDM**3
10.00	8.60							
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0
30.00	25.80	21.50	4	1.33	1.33	9938.37	39753.00	0
40.00	34.40	30.10	12	4.00	5.33	27270.90	327250.00	0
50.00	43.00	38.70	73	24.33	29.67	57960.60	4231124.00	8
60.00	51.60	47.30	62	20.67	50.33	105823.82	6561076.00	12
70.00	60.20	55.90	79	26.33	76.67	174676.88	13799473.00	27.
80.00	68.80	64.50	35	11.67	88.33	268336.12	9391764.00	18.
90.00	77.40	73.10	21	7.00	95.33	390617.89	8203975.00	16.34
100.00	86.00	81.70	14	4.67	100.00	545338.51	7634739.00	15.21

TOTAL: 300 — TOTAL 50188154.00

APPENDIX I

Description of the Experimental Sprayers

The Micron Herbi Sprayer

It has a 2½ litre bottle which contains the spray mixture, and this is fed to an atomizer (spinning disc) by gravity. The atomizer is driven by a constant speed motor powered by eight U2 batteries. Restrictors of three sizes colour coded blue, yellow and red in ascending order of orifice sizes are supplied so that the standard flow rate of about 1 ml/sec can be achieved for mixtures of different iviscosities. The spray head comprises the atomizer and the motor in a housing two lugs on the motor housing fit on either side of the extension tube, a bolt passes through the lugs and is tightened by a wing nut. The angle of the head is altered by loosening the wing nut. The Herbi has two positions - open and closed. The open position is such that the extension tube is drawn out and the batteries are inserted. This is the working position. The closed position is for ease of transport or starage. In this position, the batteries are carried separately and the extension

Table 7. Change in Voltage of Two 6.0 volt lead acid electrolyte batteries, versus Rotational speed and droplet spectrum of an ULVA Sprayer.

Day (no)	Voltage (volt)	Current (Amp)	Rotational speed (rpm)	Power Consumption (Watt)	Droplet Spectrum (Vmd) (μ_m)	(Nmd) (μ_m)	(r)
1.	11.50	0.65	7000	7.48	78	67	1.16
	11.25	0.63	6500	7.09	80	67	1.19
2.	11.50	0.65	6800	7.48	78	68	1.15
	11.25	0.62	6500	6.98	80	66	1.21
3.	11.40	0.65	6800	7.41	78	68	1.15
	11.25	0.62	6500	6.98	82	68	1.21
4.	11.40	0.65	6700	7.41	80	68	1.18
	11.20	0.60	6300	6.72	85	65	1.31
5.	11.40	0.65	6700	7.41	82	68	1.21
	11.20	0.60	6300	6.72	85	60	1.42
6.	11.35	0.60	6500	6.81	85	65	1.31
	11.15	0.60	6200	6.69	90	68	1.32

Table (Contd)

7.	11.25	0.60	6300	6.75	85	68	1.25
	11.00	0.55	6000	6.05	95	65	1.46
8.	11.00	0.55	6000	6.05	95	68	1.40
	10.50	0.50	5500	5.25	105	70	1.50
9.	10.50	0.50	5500	5.25	105	75	1.40
	9.50	0.48	5000	4.56	115	87	1.32
10.	9.70	0.48	5000	4.70	110	87	1.26
	8.00	0.40	4700	3.20	120	85	1.41
11.	9.00	0.50	5000	4.50	110	90	1.22
	7.50	0.40	4500	3.00	120	90	1.33
12.	7.50	0.40	4500	3.00	120	92	1.30
	6.00	0.35	3000	2.10	190	150	1.26

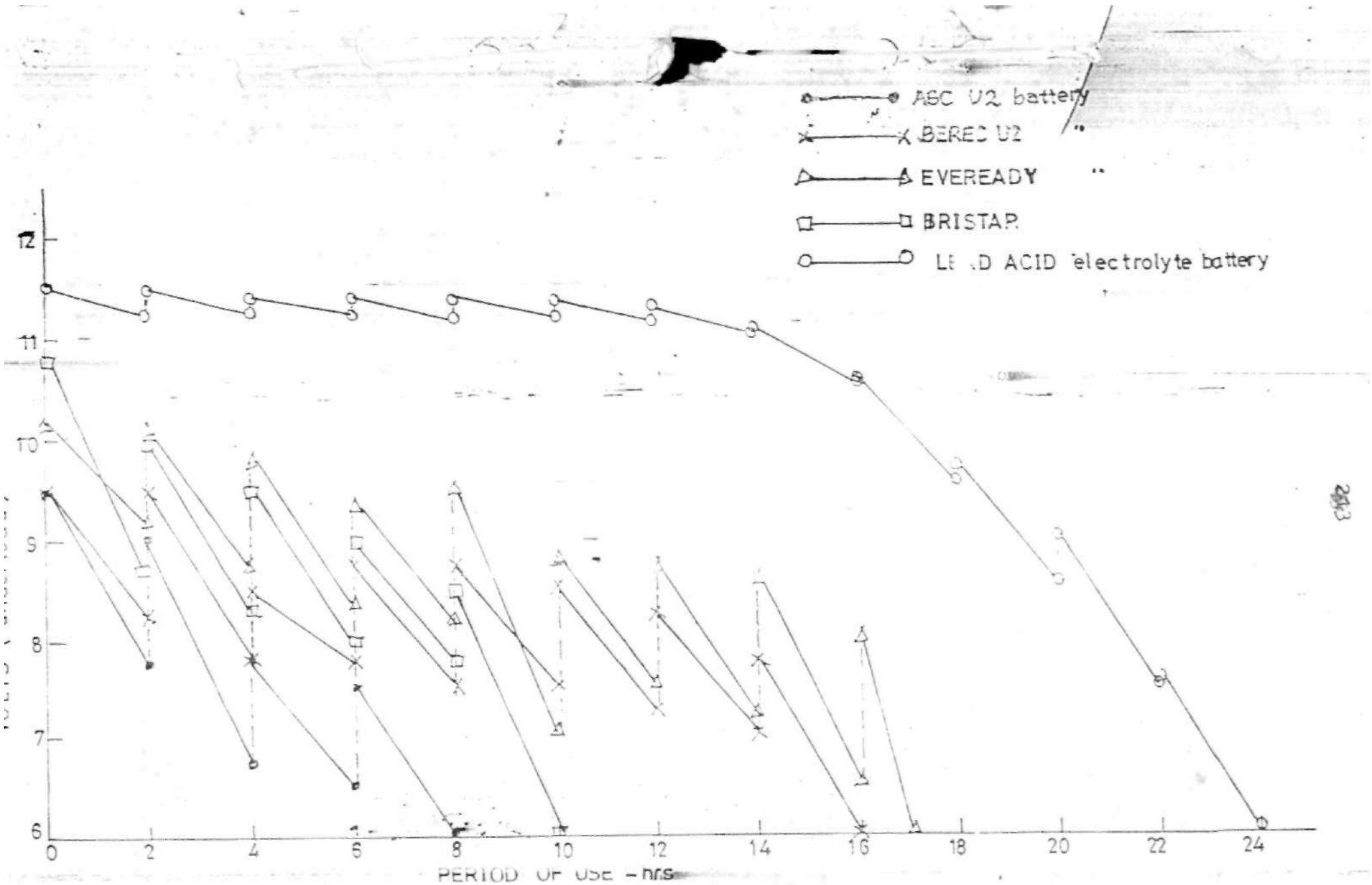


Fig. Comparison of four U2 batteries and lead acid electrolyte battery lives showing decrease in voltage for the period of use with ulva sprayer