Fabrication of Controlled Droplet Application for Efficient use of Pesticides

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Abstract: The impact of use of pesticides and agrochemicals in Indian agriculture has transformed the agricultural position of the country from food dependent to food reliant nation. If the credits of pesticides include enhanced economic potential in terms of increased production of food and fiber, and amelioration of vector-borne diseases, then their debits have resulted in serious health implications to man and his environment. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, because they are sprayed or spread across entire agricultural fields. The world-wide deaths and chronic diseases due to pesticide poisoning is about 1 million per year. In this paper we have made an attempt to reduce the runoff of pesticides into aquatic environments, other fields, grazing areas and even to human settlements. We observed that spraying efficiency can be drastically improved by altering spraying techniques and features of droplets of pesticides (size, speed, aiming of droplets etc.).The way it is important to use the right chemicals for agro-input; it is equally important to have right spraying equipment and nozzle to decide the right droplet size for effective application of chemicals.

Key words: droplet size, irrigation, spraying technique, atomizer

1. INTRODUCTION

Over the last few decades, there has been extensive research conducted to develop low cost and precision methodology and decision support tools necessary for application of water and plant nutrients[1]Sprinkler irrigation is a type of irrigation water similar to rainfall shower. Water is distributed through pipes which is then sprayed into the air through sprinklers so that it breaks up into small water drops. Individual sprinkler flow control can be accomplished by using a series of on-off cycles or as it has become known as 'pulsing' the sprinkler[2]. Other method for controlling irrigation water application is developed by [3]. To have an efficient and précised application of water and nutrients, it is important that the pump supply system, sprinklers and operating conditions must be designed to enable a uniform application[4]. The usual method of controlling size of droplets within fairly narrow limits is by using centrifugal-energy nozzles. The main types of centrifugal-energy nozzles are discs, cups and cylindrical sleeves or wire mesh cages and spinning brushes. This review discusses a concept and design of controlled droplet application (CDA), which is developed to address the need for greater efficiency when applying pesticide sprays at ultra-low-volume rates of application.

1.1 Pesticides Application in Agriculture

Chemicals intended for managing any pest, including vectors of human or animal disease, unwanted species of plants or animals, causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances that may be administered to animals for the control of insects, arachnids, or other pests in or on their bodies are called as pesticides[5].Pesticides can be persistent, mobile and toxic in soil, water, and air and has serious impacts on humans and wildlife through the food chain. They usually accumulate in the soil and residues reaches the surface and groundwater through leaching. Ideally a chemical pesticide must have lethal action against the targeted pests, but not against the non-target species, including human being. Unfortunately, this is not the case, so the controversy of use and abuse of pesticides has surfaced.

1.2Hazards of pesticides

The impact of pesticides consists of the effects of pesticides on non- target species. Pesticides are chemical preparations used to kill fungal or animal pests. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, because they are sprayed or spread across entire agricultural fields. Runoff can carry pesticides into aquatic environments while wind can carry them to other fields, grazing areas, human settlements and undeveloped areas, potentially affecting other species. Other problems emerge from poor production, transport and storage practices. Over time, repeated application increases pest resistance, while its effects on other species can facilitate the pest's resurgence[6]. The World Health Organization estimates that there are 3 million cases of pesticide poisoning each year and up to 220,000 deaths, primarily in developing countries[7].

1.3Pesticides Affect Soil Microbes

In a natural soil environment, a cooperative relationship exists between microbes and plants. Plants like grass, trees and food crops depend on microorganisms in the soil to obtain water, soluble nutrients, protect from pests and pathogens, prevent nutrient loss and break down compounds that could inhibit growth. The chemicals that are used to enhance plant growth can actually destroy the soil system, killing or causing mutation pressure on the soil microbes that all other organisms in the ecosystem need to survive. Pesticides include a large group of chemical agents that attempt to eliminate destructive biological forces in agriculture. These include herbicides for killing plants, insecticides for killing insects, fungicides for killing fungus and bactericides for killing bacteria. While these chemicals supposedly only target specific species, repeated use inevitably kills microbial life that is beneficial to the soil system. Microbes that survive can be genetically altered in a way that is no longer beneficial to the soil ecosystem and be resistant to the chemical intended to kill them. The destruction or alteration of first-level microbes can affect the entire soil ecosystem all the way up to the largest mammalianpredators[8].
Pesticide application plays an important role in pest management. Proper technique of application of pesticide and the equipment used for applying pesticide are vital to the success of pest control operations. The application of pesticide is not merely the operation of sprayer or duster. It has to be coupled with a thorough knowledge of the pest problem. The main purpose of pesticide application technique is to manage the targeted species with maximum efficiency and at the same time to keep the pest under control as well as minimum contamination of non-targets. The application techniques of such high-grade toxic chemicals ideally should be target oriented so that safety to the non-targets and the environment is ensured. Therefore, proper selection of application equipment, knowledge of pest behaviour and skillful dispersal methods are vital[9].

2. Sprinklers

High Pressure Impact Sprinklers:

In the 1960s, the commonly used sprinklers using center pivot irrigation systems had standard high-pressure (greater than 50 pounds per square inch) impact. When the system nozzles were properly sized and pressure variation along the lateral was within recommended limits, these sprinkler packages provided good application uniformity. During dry, windy conditions in arid and semi-arid environments, the losses from wind drift and evaporation were very high. To address this problem ,a low angle and low pressure (25 to 40 pounds per square inch) impact sprinklers were developed[9]. These were found to effectively reduce wind drift and evaporation losses, but flow rate variation caused by undulating topography still remained a significant problem. To manage such issues, flow control sprinkler nozzles and fixed pressure regulators were developed which reduced the flow rate variation due to topography to within tolerable limits. As a result, reduced-pressure impact sprinklers could be used on center pivots.

Low Pressure Impact Sprinklers

Initially, escalating energy costs made the high energy requirement of impact sprinklers a major concern among producers and the farmers. In due course, the low-pressure spray sprinklers (less than 30 pounds per square inch) for center pivots were also developed. They have a fixed-head and a part or full circle application pattern. A deflection plate was inserted to create spray by deflecting the water jet exiting the nozzle. Depending upon the type of deflection plate, water forms mist-like spray or tiny streamlets[10].

Low Energy Precision Application

A low pressure application package for center pivot systems known as LEPA (Low Energy Precision Application) was developed in the early 1980 [11,12]. A LEPA package has very-low-pressure (6 to 10 pounds per square inch) bubblers or furrow drag socks suspended on drop tubes at a height of 1 to 3 feet above the soil surface and has characteristically high application rates exceeding the water infiltration rate. Such sprinkler packages have been found to have irrigation application efficiencies of 90 to 95 % and reduced evaporation is the key reason for the efficiency of this system[11]. The spray surface area is minimized by locating the applicators very near to the soil surface or crop area.

In modern agriculture, basic sprinklers used are mainly of two types

- Spray Head
- Rotors

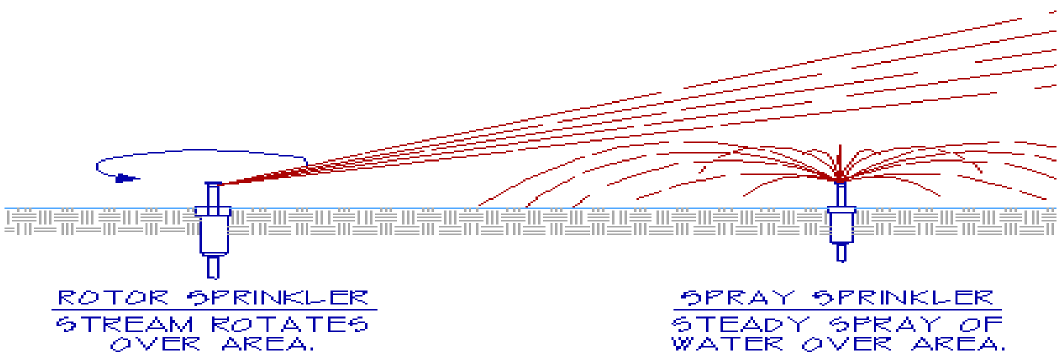

Figure-1: Types of basic sprinklers

Table-1: A sample Pressure Requirements for Sprinklers

Pressure Requirements for sprinklers		
Flow GPM	Radius Ft	Pressure PSI
2.10	10	20
2.60	12	30

The table (1) is an example of pressure requirements for sprinklers. In the given table, we can see that the considered sample at 20 PSI this sprinkler will have a radius of 10 feet and it will consume 2.10 GPM or water flow or at 30 PSI this sprinkler will have a radius of 12 feet and it will consume 2.60 GPM or water flow. This can be safely concluded that higher water pressure results in a larger radius and higher flow requirement, this relationship between pressure, radius and flow is true of most sprinklers[5].

2.1 Nozzle Size:

The nozzle and its size determine the quantity of spray applied to an area, the uniformity of application, the coverage obtained on the target surface, and the amount of potential drift. Nozzle breaks the stream of liquid into droplets, forming the spray pattern and also the spray volume at a given operating pressure, travel speed, and spacing and are instrumental in propelling the droplets in the desired direction[13]. Spray pressure and nozzle size control the drop size distribution from a sprinkler which influences the application rate pattern. Consequently, high pressure or small nozzle sizes, which tend to produce smaller droplets, increase application rates near the sprinkler while low pressure or large nozzle sizes producing larger droplets, increase application rates farther from the sprinkler[14].

2.2 Flow Rate

The nozzle flow-rate (Q) depends on the water pressure head, the diameter of the nozzle aperture and its friction coefficient.

$$Q^2 = pXdX12.5C$$

Where:

Q = Nozzle flow-rate (discharge), expressed as liters per hour (l/h)
P = Water pressure head, expressed in m (meters)
D = Nozzle nominal diameter, expressed in mm
C = Friction coefficient. Its value for small nozzles, up to 5.5 mm. = 0.95.
For medium size nozzles, 5.5-8 mm. = 0.9
For large nozzles, over 8 mm. = 0.85.
The pressure dependent flow-rate for a certain nozzle is:

$$Q_2 = Q_1\sqrt{\frac{p_2}{p_1}}$$

Where:

Q1 = The flow-rate at the P1 head.
Q2 = The flow-rate at the P2 head.

2.3 Sprinkler Droplet Kinetic Energy:

Many soils, particularly those containing significant silt fractions, are susceptible to soil-surface sealing from sprinkler droplet impact. The force of the droplets hitting the ground breaks down the surface soil structure, forming a thin compacted layer that greatly reduces infiltration rate[10]. The kinetic energy of discrete water droplets impacting a bare soil surface generally leads to a drastic reduction in water infiltration rate due to formation of a seal on the soil surface[15].

2.4 Spraying inefficiencies

In order to better understand the cause of the spray inefficiency, it is useful to reflect on the implications of the large range of droplet sizes produced by typical (hydraulic) spray nozzles. Historically, dose-transfer to the biological target (*i.e.* the pest) has been shown to be inefficient. However, relating "ideal" deposits with biological effect is fraught with difficulty, but in spite of Hislop's misgivings about detail, there have been several demonstrations that massive amounts of pesticides are wasted by run-off from the crop and into the soil, in a process called **endo-drift**[16,17]. This is a less familiar form of pesticide drift, with exon-drift causing much greater public concern. Pesticides are conventionally applied using hydraulic atomizers, either on hand-held sprayers or tractor booms, where formulations are mixed into high volumes of water[17].

Since the rate of application under low-pressure spray sprinklers can be minimized with the help of offset booms, sprinkler selection should ideally be based on drop size distribution. The drawback with small drop sizes are though they have the least droplet kinetic energy but are the highly susceptible to wind drift losses where as large drop sizes though have the highest droplet kinetic energy still they are the least susceptible to wind drift losses. Sprinklers which have an average of the two features work in most of the conditions[17]. This requirement is largely fulfilled by moving plate sprinklers that produces the drops with medium sizes and maximum wetted area.

Droplet size plays a very important role in pesticide application by minimizing environmental contamination. Pesticide sprays are generally classified according to droplet size. When drift is to be minimized, a medium or coarse spray is required irrespective of the volume applied (Table2).

Table 2: Classification of sprays according to droplet size.

V o l u m e m e d i u m diameter of droplet (μm) 1	Classification of droplet size
<50	Aerosol
51 - 100	Mist
101 - 2 0 0	Fine spray
201 - 4 0 0	M e d i u m spray
>400	Coarse spray

T h e most widely used parameter of droplet size is the volume medium diameter (Vmd) which is m e a s u r e d in micrometers (μm). 1 mic = 1/1000 m m

Different droplet sizes have dramatically different dispersal characteristics, and are subject to complex macro- and micro-climatic interactions. Greatly simplifying these interactions in terms of droplet size and wind speed, A study concluded essentially there are three sets of conditions under which droplets move from the nozzle to the target[18]. These are where:

a. Sedimentation dominates: typically larger (>100 μm) droplets applied at low wind-speeds; droplets above this size are appropriate for minimizing drift contamination by herbicides.
b. turbulent eddies dominate: typically small droplets (<50 μm) that are usually considered most appropriate for targeting flying insects, unless an electrostatic charge is also present that provides the necessary force to attract droplets to foliage.
c. Intermediate conditions where both sedimentation and drift effects are important. Most agricultural insecticide and fungicide spraying is optimized by using relatively small (say 50-150 μm) droplets in order to maximize "coverage" (droplets per unit area), but are also subject to drift[19].

Pressure also has a significant effect on the required spacing. Higher pressure allows wider spacing because of the resulting smoother application rate pattern and slight increase in the wetted area. Most spray sprinklers with low pressure results into a do nut shaped application rate pattern. As a result, closer spacing is needed in order to maintain application uniformity. Due to the high flow rates required on the outer portion of center pivots, large spacing require large nozzle sizes, which may result in excessively large drops.

3. Possible Solution for Spraying Inefficiency

3.1 Controlled Droplet Application

In essence, all of these refer to droplets produced from a liquid that is fed onto a spinning disc where it moves outwards by centrifugal force until it reaches the edge when it forms even sized droplets that are then flung off the rotating disc[19].The crux of the system is to produce small droplets of a relatively even size and with minimum spacing between droplets.

3.2 Finding Better Sprinkling Technique

a. Ideal Droplet Size
b. Plot of efficiency factor v/s wind speed

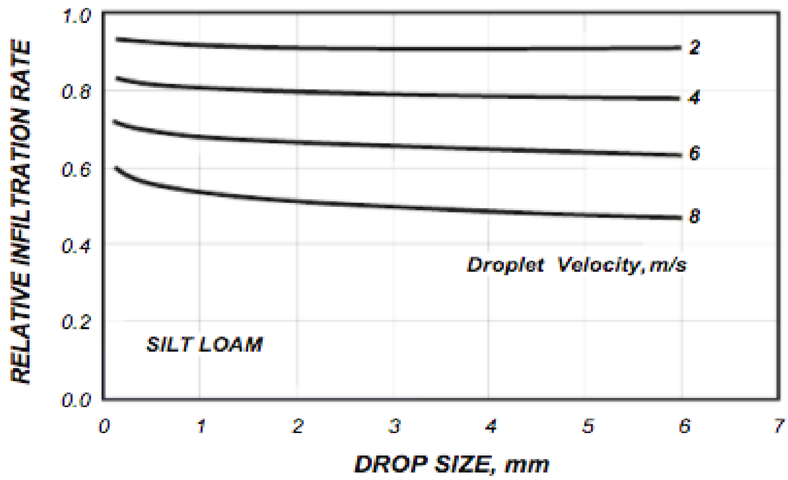

Chart 1- Plot of relative infiltration rate v/s Drop size for different Droplet Velocity

The effect of the drop size and velocity on infiltration is illustrated above with taking into account evaporation and drift of small drops. As droplet velocity is also a function of Drop Size, the tipping point for relative infiltration rate comes for relatively medium sized droplets with diameter around 0.6 to 1.3 mm[20].

4. Concept of Atomizer Sprinkler

4.1 Atomizer:

It is a three speed spinning disc rotary atomizer designed for the Controlled Droplet Application (CDA) of sprays. By efficiently producing only the spray droplet sizes appropriate for the particular application, significantly reduce spray volumes and costs and minimize the risk of environmental contamination. Droplets diameter vary with rpm of Discs and it is just inversely proportional of each other.

a. **Low Speed- 200** to 500 micron spray droplets for pre-emergent and post-emergent herbicide applications where drift avoidance is essential
b. **Intermediate Speed-**100 to 200 micron sprays droplets for most post-emergent herbicides, defoliants, foliar feeds and fungicides. It ensures good coverage of plant surfaces while minimizing any risk of uncontrolled spray drift.
c. **High Speed-**75 to 150 micron sprays droplets for insecticides and fungicides.

The low application volumes allowed by CDA mean, larger areas can be sprayed per tank load and lighter vehicles and ATVs can be used, offering impressive savings in terms of cost, time and effort. This both speeds up the spraying process and allows more spraying days, thus enabling quick and cost-effective pesticide application to be undertaken when needed[21].

4.2 Whole assembly which upholds Sprinkler Atomizer

a. It has basic triangular stand which holds the complete assembly.
b. The atomizer oscillates to and fro within the stand for uniform sprinkling.
c. The material used to make this component can be composite with reinforcement material fiber glass and epoxy resin having properties like high strength and law density.
d. After stress and strain analysis of composite material, we chose 3m length and 30 cm height of stand[8, 9].

Table- 3: Specification of sprinkler atomizer

Specification of sprinkler atomizer			
High RPM	**Intermediate RPM**	**Low RPM**	**Components**
0.6 kg	0.6 kg	0.6 kg	Weight
12DC	12DC	12DC	Power supply
12 Watts	12 Watts	12 Watts	Maximum power consumption
5000 rpm	3500 rpm	2000 rpm	Disc RPM
125-500 ml/min	250-1000 ml/min	500-3000 ml/min	Liquid feed speed
75-150 µm	**100-200 µm**	**200- 500 µm**	**Spray droplet size**
10-40 l/ha	20-80 l/ha	30-200 l/ha	Application Volume
Insects on surface and fungi	Weed control and fungi	Weed control	Possible application

And the whole setup will be driven by 12 volt motor from external battery power source.

4.3 Components of ATOMIZER

a. Motor
b. Motor Pulley
c. Drive Belt
d. Atomizer Discs
e. Atomizer Pulley
f. Mounting Bracket

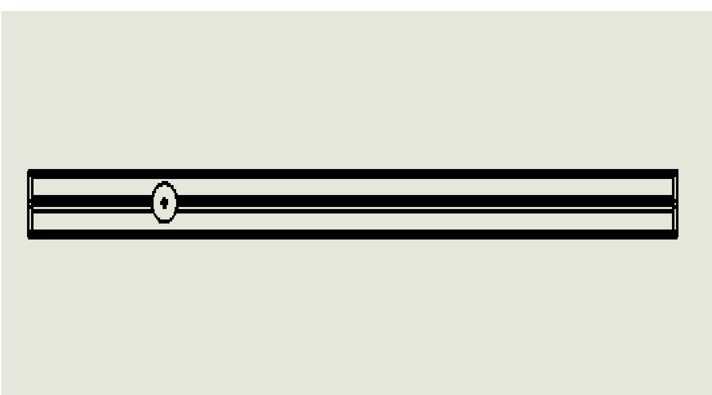

Fig-1: Top view

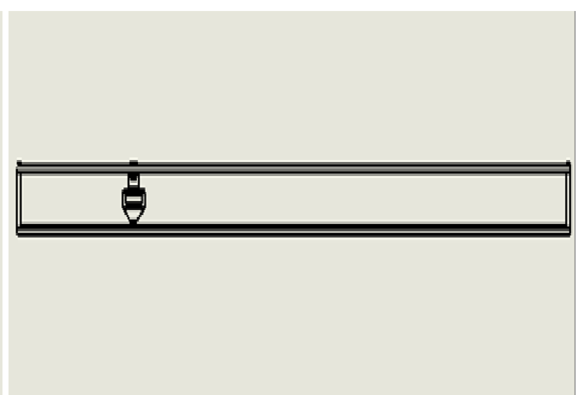

Fig-2: Side view

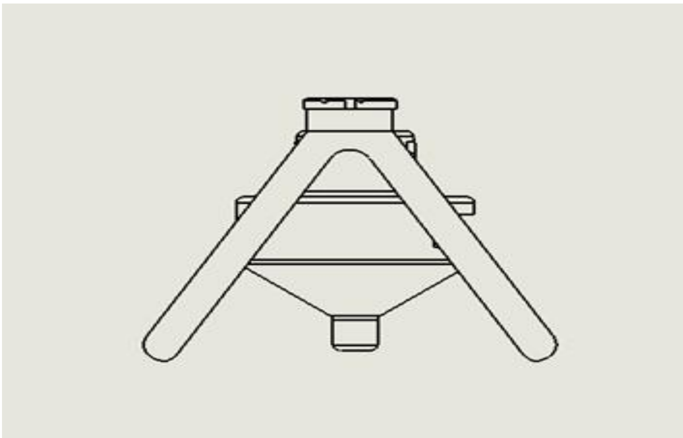

Fig-3: Front view

Fig-4: Isometric view

4.4 Distribution percent as function of distance and pressure

a. Measurements taken further from the nozzle contains a higher concentration of larger water droplets because smaller droplets have drifted (or evaporated) away.
b. As pressure increases, water atomizes and creates a higher concentration of smaller water particles.
c. Graph provides strong evidence that high pressure causes smaller water droplets that will increase water loss significantly[7].

5. Result/Conclusion

Through the development of this low cost controlled droplet application, we arrived at the conclusion that tackling spraying inefficiencies to limit the use of pesticides is an urgent need in agriculture sector. Using spraying atomizers instead of normal pest sprinklers and sprayers has come up to be best solution. We found that the key point of impact lies in the droplet size and the separation between the droplets. For aiming weed, small herbs and fungi, droplets should be in the range of 100 - 200 μm with rpm of 3500 rpm. Through this, a product model has also been developed in which the atomizer will oscillate to and fro. The results obtained give opportunities for making significant decrease in negative effects of pesticides on both soil and living creatures.

References

1. William Kranz. 2011. Monitoring irrigation water application with computerized controllers in Proceedings of the 23rd Annual Central Plains Irrigation Conference, Burlington, CO., February 22-23, 2011.
2. Karmeli, D and G. Peri. 1974. Basic principles of pulse irrigation. Journal of Irrigation and Drainage Division, ASCE 100(IR3):309-319.
3. King, B. A., and D. C. Kincaid. 2004. A variable flow rate sprinkler for site-specific irrigation management. Applied Engineering in Agriculture 20(6):765-770
4. ***http://www.fao.org/docrep/s8684e/s8684e06.htm***
5. Carolyn Randall2013. National Pesticide Applicator Certification Core Manual :National Association of State Departments of Agriculture Research Foundation, Washington, DC, Ch.1
6. George Tyler Miller 2004. Sustaining the Earth: An Integrated Approach. Thomson/Brooks/Cole. pp. 211–216. ISBN978-0-534-40088-0.
7. Muhammad Sarwar2015. International Journal of Bioinformatics and Biomedical Engineering The Dangers of Pesticides Associated with Public Health and Preventing of the Risks Vol. 1, No. 2, 2015, pp. 130-136
8. George, Rebecca; Joy, Varsha; S, Aiswarya; Jacob, Priya A. 2016. "Treatment Methods for Contaminated Soils – Translating Science into Practice". International Journal of Education and Applied Research.

9. http://niphm.gov.in/ PHE-ASO-Manual-22042013.pdf
10. Russell P. Fleming, Automatic Sprinkler System Calculations, Sectionfour , Chapter 3, NFPA
11. Kincaid, D.C. 1996. Spray drop kinetic energy from irrigation sprinklers. Trans. ASAE 39(3):847-853
12. Thompson, A.L. and L.G. James. 1985. Water droplet impact and its effect on infiltration. Trans ASAE 28(5):1506-1520
13. Subramaniam S. 2001. Statistical Modeling of Sprays Using the Droplet Distribution Function, Physics of Fluids13
14. Code of design for sprinkler systems, 2001. China planning press, Beijing, p.12.
15. King , B.A. and D.L. Bjorneberg 2010 Droplet Kinetic Energy from Center-Pivot Sprinklers in 5th National Decennial Irrigation CD-ROM Proceedings Phoenix Convention Center, 5 - 8 December 2010, Phoenix, AZ USA M. Dukes ed. St Joseph Mich: ASABE
16. Allen, R.G., J. Keller, and D. Martin. 2000. Center pivot system design. Irrigation Association, Falls Church, VA. 300 p.
17. Cramer, H. E. and D. G. Boyle. 1976. Behavior-the micrometeorology and physics of spray particles behavior, pp. 27-39. In: R. B. Roberts (Technical Coordinator). Pesticide spray application behavior, and assessment: workshop proceedings. General Technical Report PSW-15. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA
18. Dr. Russell R. Hahn 2012, Controlled Droplet Application, Pesticide Safety Education Program (PSEP), Cornell University
19. Craymer, H.E., Boyle, D.G. 1973. The micrometeorology and physics of spray particle behavior Pesticide Spray Technology Workshop, Emeryville, California, USA
20. Holterman, H.J. 2003. Kinetics and evaporation of water drops in air. IMAG report. 2003-12.
21. J.H. Combellack, The value of controlled droplet application as a spot spray technique for the control of noxious weeds in Victoria, Keith Turnbull Research Institute, Department of Crown Lands and Survey, Frankston 3199, Victoria

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