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Research Paper

Effect of surfactant concentration on the spreading properties of pesticide droplets on Eucalyptus leaves

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The area wetted by 500-μm diameter droplets of pesticide and deionised water placed at different positions on *Eucalyptus urophylla* × *E. grandis* (E.u × E.g) and *Eucalyptus tereticornis* (E.t) leaves was determined at an air temperature of 30 °C and a relative humidity of 60%. Dimethyl dichlorovinyl phosphate (DDVP), and efficient cypermethrin (EC) were diluted 1000 times in deionised water. Solutions the pesticides were prepared with surfactant concentrations (SC) of 0.1%, 0.25%, 0.5%, and 1%. For comparison SC solutions with water and deionised water were also used. Droplet deposition positions were located in the interveinal area, midrib, and secondary vein on both adaxial and abaxial surfaces. Without surfactant, all droplets remained nearly spherical and did not spread on the leaf surfaces. With surfactant, the deionised water and pesticide droplets had distinct spreading properties. For deionised water, both the wetted area and spread effectiveness peaked at 0.1% SC, while for pesticide droplets the wetted area peaked at 1% SC. However, the optimum SC was 0.25%. Compared with droplets on E.u × E.g leaves, droplets spread more on E.t leaves. The adaxial surface had better wettability than the abaxial surface. For pesticide droplets, the wetted area was a minimum on the midrib and the wetted area on the secondary vein was slightly larger than that on the interveinal area.

1. Introduction

Plant leaves share a common structure consisting mainly of epidermis, mesophyll, and veins. The epidermis is covered by a thin cuticle which plays an important role in preventing excessive evaporation of water and protecting the leaves against environmental damage such as that caused by diseases, pests, and dust (Bradley, Gilbert, & Parker, 2003; Brewer,

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Nomenclature

DDVP	dimethyl dichlorovinyl phosphate
EC	efficient cypermethrin
SC	surfactant concentrations
E.u × E.g	*Eucalyptus urophylla* × *E. grandis*
E.t	*Eucalyptus tereticornis*
PPSC	Wetted area per percentage surfactant concentration
d	Droplet diameter (μm)
A	Spot area (μm^2)

Smith, & Vogelmann, 2007; Guhling, Kinzler, Dreyer, Bringmann, & Jetter, 2005; Holloway, 1993). The main two forms of epicuticular waxes on the leaf surfaces are crystalline and amorphous (Wang & Liu, 2007), both of which usually present hydrophobic characteristics and prevent the spread of droplets on leaves (Holder, 2007). When the contact angle of droplets on leaf surfaces is >90°, the leaves are hydrophobic and droplets easily roll off the surface. In contrast, when the contact angle is <90°, the leaves are hydrophilic and droplets can adhere to the leaves (Brewer & Smith, 1997; Haines, Jernstedt, & Neufeld, 1985; Wagner, Furstner, Barthlott, & Neinhuis, 2003). The cuticular membrane, trichomes, and other features form barriers to droplet deposition, spread, and uptake (Forster, Zabkiewcz, & Riederer, 2004; Pimentel, 1995).

During disease and pest control, surfactant additives are commonly used to improve the efficiency of pesticides. Several studies have found that surfactants can greatly reduce surface tension and maximise the spread, penetration, and absorption efficacy of pesticides on leaf surfaces (Hess & Foy, 2000; Ramsey, Stephenson, & Hall, 2005; Ramsey, Stephenson, & Hall, 2006). Foliar uptake and biological efficacy of the active ingredients are improved in the presence of surfactants (Brazee, Bukovac, & Zhu, 2004; Holloway & Silcox, 1985; Holloway, Wong, & Partridge, 1992; Uhlig & Wissemeier, 2000), and the amount of pesticides required can be reduced (Costa, Martins, Rodella, Duarte, & Costa, 2005; Kirkwood, 1993). De Ruiter, Uffing, Meinen, and Prins (1990) found that surfactant concentration can influence the deposition and retention of pesticide droplets, but high surfactant concentration can negatively impact pesticide efficiency. The contact characteristics of droplets following deposition on leaf surfaces have rarely been studied. When a droplet impacts a leaf surface, three outcomes are possible: adhesion, bounce, or shatter (Forster, Mercer, & Schou, 2012; Spillman, 1984; Zwertvaegher et al., 2014). Yu, Zhu, Frantz et al. (2009) and Yu, Zhu, Ozkan, Derksen, and Krause (2009) found that droplet size, leaf surface structure (waxy or hairy), relative humidity, and the chemical composition of the spray solution (water alone, pesticide and additives) greatly influenced the evaporation time and coverage area. Xu, Zhu, Ozkan, and Thistle (2010) demonstrated that the wetted area and evaporation time of droplets varied with location (interveinal area, secondary vein, or midrib) and surface (adaxial or abaxial) of leaves where the droplet was deposited, droplet diameter, and spray formulation (with or without surfactant). Xu, Zhu, Ozkan, Bagley, and Krause (2011) found that the contact characteristics of droplets on waxy or hairy leaves were greatly affected by the type and concentration of adjuvants. When droplets were deposited on common lambsquarters, purslane, and velvetleaf, there were no significant variations in the spread of distilled water droplets or solutions of primisulfuron (without adjuvant). Droplet spread was the greatest with an organosilicone surfactant, followed by a nonionic surfactant (Sanyal, Bhowmik, & Reddy, 2006).

In previous studies, distilled or deionised water has largely been used and it has been widely assumed that the physical properties of water differ little from those of pesticides. Comparative experiments on the spreading properties of deionised water and pesticide droplets with and without surfactant have not been conducted. The objective of the current work was to identify the most economic and effective surfactant concentrations for deionised water and two pesticides by determining the wetted area with solutions containing different amounts of surfactant after deposition at different positions using Eucalyptus leaves as a model surface.

2. Materials and methods

Three types of liquid were selected for the experiments: deionised water, dimethyl dichlorovinyl phosphate ($C_4H_7CL_2O_4P$, DDVP) with an active ingredient content of 77.5% (Nantong Jiangshan Agricultural Chemical Co., Ltd, Nantong, China) and efficient cypermethrin ($C_{22}H_{19}CL_2NO_3$, EC) with an effective composition of 4.5% (Nanjing Redsun Stock Co., Ltd, Nanjing, China). The DDVP and EC formulations were each diluted 1000 times with deionised water.

The surfactant used in this study was 2201 nonionic surface surfactant which has good solubility in organic solvents (Jiangsu Zhongshan Chemical Co., Ltd, Nanjing, China). Each type of spray solution was matched with four surfactant concentrations (SCs), 0.1%, 0.25%, 0.5%, and 1% (v/v surfactant/spray solution). Three spray solutions without surfactant were also tested for comparison.

Two species of Eucalyptus were chosen as the experimental materials, *Eucalyptus urophylla* × *E. grandis* (E.u × E.g) and *Eucalyptus tereticornis* (E.t). Seedlings of two plants were transplanted from the Academy of Forestry of Guangdong Province into 2.5-l pots and grown in a greenhouse at a controlled ambient temperature of 30–40 °C. Experiments were conducted during July and August 2014 in Nanjing, China.

Investigations of the spreading properties of droplets were carried out using a custom-built experimental system, comprising a droplet-generator, a relative humidity control system, a target holding chamber, and an image acquisition unit (Fig. 1).

The droplet-generator unit consisted of an air compressor, a droplet generator (Model 2405, EFD Inc., East Providence, RI, USA). The droplet generator was a microprocessor-based timed model and had an air-powered fluid dispenser. Droplet release from the microsyringe needle was initiated by use of a foot pedal. The diameter of the droplets could be controlled by setting the dispensing time, air pressure, and vacuum. A droplet diameter of 500 μm was chosen for use