Topics in Agricultural Entomology XIII

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Topics in agricultural entomology - XIII

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Revisão: Os autores

Dados Internacionais de Catalogação na Publicação (CIP)

T674 Topics in agricultural entomology - XIII / Joacir do Nascimento, Claudiane Martins da Rocha, Daniel Dalvan do Nascimento, et al. – Ponta Grossa - PR: Atena, 2022.

Outros organizadores
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Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-65-258-0544-3
DOI: https://doi.org/10.22533/at.ed.443220109

1. Agricultura. I. Nascimento, Joacir do (Organizador). II. Rocha, Claudiane Martins da (Organizadora). III. Nascimento, Daniel Dalvan do (Organizador). IV. Título.

CDD 338.1

Elaborado por Bibliotecária Janaina Ramos – CRB-8/9166

Atena Editora
Ponta Grossa – Paraná – Brasil
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CIÊNCIAS AGRÁRIAS

Atena Editora
Ano 2022

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DECLARAÇÃO DA EDITORA

The authors are grateful to the São Paulo Research Foundation (FAPESP) for the grant 2022/04343-9

PREFACE

The Graduate Program in Agronomy (Agricultural Entomology) at the UNESP Faculty of Agricultural and Veterinary Sciences in Jaboticabal has always been characterized by its focus on Integrated Pest Management (IPM). Since its foundation, the program has graduated 287 students with a master's degree and 148 Ph.D. students. They are now active in various areas of the public or private sector and contribute to agriculture's economic and environmental sustainability.

This e-book entitled "Topics in Agricultural Entomology - XIII" was made possible through the immense effort of the Organizing Committee, formed by MSc and Ph.D. students from all research areas of our Graduate Program. In its 14 chapters, readers will find information on the most diverse areas of IPM, with a richness of information on both the fundamental and applied aspects of IPM.

As coordinator of the 2022 edition of the Winter Workshop on Agricultural Entomology, it is my pleasure to provide event attendees with an e-book of excellent content, demonstrating the importance of our research to society.

Prof. Ricardo Antônio Polanczyk

FCAV/UNESP

PPG Entomologia Agrícola Coordinator

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CAPÍTULO 6

GOOD PRACTICES IN AGRICULTURAL SPRAYING FOR PEST MANAGEMENT

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1 I INTRODUCTION

Phytosanitary products must be applied when it comes to large-scale production. Phytosanitary applications should aim the effective control of arthropods and pathogens affecting crops and the reduction of production losses. In this sense, quality spray applications are essential to allow a successful operation.

The application technology of pesticides consists of using techniques and scientific knowledge for the correct placement of active ingredients at a target in the proper amount, economically, and with minimal environmental contamination (Matuo, 1990). As it is an interdisciplinary field, it encompasses several factors that, if disregarded, an efficient and economic deposition of a product is impaired (Contiero; Biffe & Catapan, 2018).

Most pesticides are applied via liquid application, by spraying the solution through droplets that produce greater coverage, and therefore, a greater chance of reaching the target. The efficiency of proper product deposits can decrease resistance development in pest populations, as a uniform product distribution makes pests get in contact with lethal doses of the product, decreasing the selection of resistant organisms (Volpe et al., 2012).

Thus, the objective of this chapter is to present important aspects related to the application technology of phytosanitary products aimed at pest control.

2 I THE IMPORTANCE OF SPRAY NOZZLES

Spray nozzles are the main components in sprayers, as they produce and distribute droplets that carry the active ingredient to the target. They, therefore, have a great influence on phytosanitary management quality and efficiency, such as pest arthropod control. These components are also responsible for breaking up and distributing insecticide spray solutions, determining the flow rate, size, and uniformity of droplets (Fernandes et al., 2007; Camara et al., 2008).

Poor choice of spray nozzles will hardly be fixed by changing working pressure, application flow, spray bar height, nozzle spacing, application speed, or even using adjuvants in the solution.

Such a mistake may cause economic losses to farmers, low insect control efficiency, contamination of non-target organisms, and damage to the environment. Therefore, application success starts by selecting a proper spray nozzle to be used for a given situation.

Determining factors for a proper spray nozzle selection are desired droplet size, application speed and rate, weather conditions during application, working pressure, and formulation of the phytosanitary products composing spray solution (Miller; Butler Ellis, 2000). In addition to these, biological factors related to the crop are also important, such as the phenological stage and target to be reached, which considers the preferred location of the target insect.

Droplets are formed by pressure-aided passing of spray liquid through a small outlet orifice in spray nozzles, with sufficient speed and energy to spread the liquid. In this process, a thin liquid sheet is formed, which disintegrates into different droplet sizes. Thus, the droplet spectrum constitutes the amplitude among the droplet sizes produced by nozzles during spraying (Matthews; Bateman & Miller, 2014).

Droplet spectrum is determined by a set of factors such as uniformity coefficient (Relative Span), which indicates uniformity in droplet size; volumetric median diameter (VMD), which is the droplet diameter that 50% of the sprayed liquid volume consists of smaller droplets than it; and droplet volume percentage of droplets smaller than 100 μm, which stands for drift-susceptible droplets. A droplet diameter is considered appropriate when it provides maximum pest control, with a minimum amount of pesticide and ecosystem contamination (Himel, 1969).

Overall, droplets larger than 400 μm have a low capacity to penetrate the plant canopy and increase product runoff from plants. Although they may provide reduced surface coverage, these droplets are less likely to be lost by drift and evaporation. Conversely, droplets smaller than 200 μm provide increased surface coverage, but also have higher drift and evaporation risks (Figueiredo et al., 2007).

For insect control by contact insecticides, droplet sizes between Fine (136 to 177 μm) and Medium (177 to 218 μm) are recommended (Asabe, 2013). As contact products require a large surface coverage, Fine droplets increase the chances of active ingredients reaching lower plant strata (Cunha; Marques & Alvezs, 2016). On the other hand, systemic insecticides demand Medium and Coarse droplets. The systemic action of products requires less surface coverage, thus reducing the risk of drift and evaporation.

There are several spray nozzle models available on the market, which have been developed specifically to meet application needs. The nozzles mostly used by farmers are those that use hydraulic energy to form droplets. The main hydraulic nozzle models are those of flat and conical spray jets.

Flat fan spray nozzles, produce single plane spray jets and are recommended for a variety of applications, especially for pre-emergent herbicide and systemic post-emergence herbicide applications. There are models recommended for soil insecticide application, which vary with the target to be reached, applying droplets of larger size classes, such as Extremely Coarse and Ultra-coarse (Román, et al., 2009).

3 I DRIFT CONTROL

An effective insect control application must consider the maximum reduction of spray losses as possible. Drift reduction, besides improving spraying effectiveness, reduces the risk of environmental contamination and intoxication of sensitive crops, humans, and animals. Incidents of pollinator mortality, for example, have been reported due to pesticides drift, directly affecting pollination-dependent crops, with yield losses of up to 24% (Garibaldi et al., 2016).

Spray drift can be defined as the volume of spray solution droplets diverted from the target area by wind action (Matthews; Miller & Bateman, 2014). The spray solution amount drifting off the target can also reach the soil, which is a result of high application volumes or large droplets applied in the same direction (Al Heidary et al., 2014; Zhang; Luo & Goh, 2018).

Drift control strategies include correct sprayer setup, use of proper spray nozzle and working pressure to produce ideal droplet sizes, proper boom or flight altitude (in case of aerial spraying), proper spray jet direction, selection of optimal sprayed band, application speed control, use of adjuvants and other technologies such as electrostatic sprayers, pulse width modulation (PWM), and air-assisted equipment, in addition to spraying under suitable weather conditions.

Overall, the smaller the droplet size, the greater the drift potential by evaporation and wind drag (Al Heidary et al., 2014; Miranda et al., 2010). This way, to reduce losses by drift and evaporation of products at the time of application, larger droplets and evaporation reducers are used. However, in such cases, droplet potential for coverage and penetration into the crop canopy can be reduced (Garcerá et al., 2017).

Boom height and nozzle spacing are also part of the sprayer configuration and may directly impact spray liquid distribution uniformity and hence its drift (Benez et al., 2016). The higher the boom height, the greater the drift potential. Higher boom heights tend to increase droplet exposure to wind, thus increasing the risk of evaporation and off-target drag (Al Heidary et al., 2014). In aerial sprays, the distance between nozzles and targets can reach several meters away; therefore, flight height should be properly selected. By decreasing flight height from 6.7 to 2.4 m, for example, reductions of up to 2.5 times in drift can be observed (Matthews; Miller & Bateman, 2014).

Directed spray applications can also improve drift control. Band applications with the use of inter-row directed spraying nozzles, for example, have been effective to control pests such as the root spittlebug, *Mahanarva fimbriolata* (Hemiptera: Cercopidae) in sugarcane (Peixoto et al, 2009). Directed applications sprays have been effective in fruit trees and generated great savings in application volume, without adversely affecting leaf coverage and significantly reducing drift losses (Carvalho, 2014; Andrade; Ferreira & Martinelli, 2014).

Effective spray swath must also be determined regardless of spraying mode, as it directly affects distribution uniformity over the target. In the case of aerial sprays, air turbulence generated by aircraft movement, especially at the wingtip, directly impacts distribution profile, effective deposition range, and drift potential. Effective spray swath smaller than 75% of the aircraft wingspan are recommended to reduce the vortex effect on droplets, thus reducing the risk of drifts (Teske et al., 1998, Matthews; Miller; & Bateman, 2014). Another alternative for decision making for drift reduction includes decreasing working speed. Reductions from 12 to 6 km h^{-1}, for example, reduced drift by up to 77% (Van De Zande et al., 2004).

The addition of adjuvants to the spray solution is another alternative to minimize drift potential. The use of lecithin in applications with very fine droplets, for example, significantly reduces the potential for drift (Griesang et al., 2017). Such changes in droplet size, which allow reducing the volume with smaller droplets, more prone to being dragged by the wind, can also be related to adjuvant inclusion into agrochemical formulations (Costa et al., 2017).

Regarding the adoption of different technologies with drift reduction potential, one can mention electrostatic systems. The transfer of electrical charges to droplets formed in spraying induces an electric field that generates a force of attraction between droplet and plant (Chaim & Wadt, 2015). This attractive force increases droplet speed and deposition. Another technology, known as PWM (Pulse Width Modulation), makes it possible to increase or decrease nozzle flow without changing working pressure. It, therefore, causes no droplet size changes, thereby better controlling the risk of drift. In addition, air-assisted spray boom is another technology that allows drift reduction by increasing droplet transport speed using a wind sheet.

Among the weather conditions that can affect drift during agricultural spraying, wind speed is the most relevant (Nuyttens et al., 2005). According to FAO (1998), wind speed limits for pesticides applications are up to 10 km h^{-1}. However, in most farming areas in Brazil, wind may exceed this limit, thus, other methods need to be adopted to enable applications outside the recommended conditions. Accordingly, using larger droplets as well as all other techniques discussed here (spray nozzle, boom/flight height, directed spray application, application swath, application speed, adjuvants and others) should be considered to reduce effects from wind or other meteorological conditions (relative humidity and temperature), aiming to reduce drift and effectiveness of phytosanitary control.

4 I SPRAY SOLUTION PREPARATION

One of the several factors influencing the quality of agricultural sprays is incorrect spray solution preparations, which includes water quality for product dilution. Water physical quality in terms of the number of suspended sediments has been much discussed nowadays. Such a factor can cause several damages to sprays such as clogging of filters and nozzles, reducing the longevity of sprayers and pumps, hence impairing applications (Ramos; Araújo, 2006; Contiero; Biffe & Catapan, 2018). Studies on the physical-chemical properties of water have shown that some factors such as hardness, pH, and suspended sediments, interfere with the integrity of phytosanitary products, negatively affecting the effects of active ingredients and expected control (Queiroz; Martins & Cunha, 2008).

Apart from the physical factor, chemical water quality has been another factor interfering with the action of crop protection products. Water hardness, which refers to concentrations of alkaline-earth cations (Ca^{+2}, Mg^{+2}, Sr^{+2}, and Ba^{+2}), can negatively affect the efficiency of spray solutions by generating product incompatibility. This process includes the occurrence of precipitates and flocculation, which can clog filters and spray nozzles. An example of this is the presence of Fe^{+3} and Al^{+3}, which can react with phytosanitary products and reduce their effectiveness (Ramos & Araujo, 2006; Petter et al., 2013).

Another factor that may be associated with the incompatibility of spray mixtures is the pH, which indicates potential changes in the chemical characteristics of mixtures (Ramos & Araújo, 2006). The interference of pH with spray efficiency varies with an active ingredient that requires a different pH range. Higher pH values in spray solutions can accelerate degradation by alkaline hydrolysis. In this case, the pH of agrochemical mixtures in the tank must be below 7.0, which delays hydrolysis, maintaining the composition of molecules for a longer time. Thus, attention must be paid to the appropriate pH range of each product (Cunha; Alves & Marques, 2017).

Another factor to consider is electrical conductivity in spray solutions. This water property refers to ions and their concentrations and valences, which vary according to the products used and/or their mixtures (Cunha; Alves & Marques, 2017). Furthermore, this parameter can also alter the biological action of agrochemicals (Carlson & Burnside, 1984).

A practice that has been commonly used not only in Brazil but also in other countries, is spraying solution preparation with more than one product, to widen the spraying action spectrum, reducing the number of applications and hence costs (Guimarães, 2014; Oliveira, 2014 & Krause, 2014). To control pests, diseases, and weeds all at once, and even to nourish plants together, farmers mix several products. This practice, however, can generate problems for applications. The preparation using more than one product results in interactions between them, promoting physical/chemical or biological changes in spray solutions, which may not promote the expected effects (Damalas, 2004).

Gazziero (2015) surveyed farmers and asked about issues arising from tank mixtures; they listed excess foam, poor homogenization, decantation, hydraulic clogging, and increased crop phytotoxicity, among other problems. Moreover, these tank mixtures can generate challenges due to product loss and consequent environmental risks (Vale et al. 2019).

In addition to mixing various chemical and biological products, another key factor for preparing solutions is the sequence in which products are added to the sprayer tank. Proper order of addition can avoid problems related to phytotoxicity and control ineffectiveness (Cessa et al., 2013). When mixing different formulations, the most suitable addition sequence should be followed, thus avoiding potential problems. As an example, water-dispersible granule formulations (WG) are added first because their specific surface is smaller than those based on powder (WP). Thus, the order of mixtures is based on each formulation's affinity with water. In short, first insoluble products are added, then suspensions and emulsions, and finally, soluble formulations (Costa & Polanczyk 2019).

Still, several are the exceptions to that rule as there is a wide range of formulations available, which are individually designed, as well as variations in their uses in terms of the amount of water for dilution. Therefore, the most recommended is to prepare mixtures thoroughly and on a small scale for each farm, ensuring solution stability. Another crucial recommendation is to apply the prepared spray solution over a pilot area to verify its control effectiveness.

Among the precautions for the preparation of spray solutions, stirring is a key factor for homogenization and must be carried out continuously from the addition of the first product until the end of spraying in the field (Costa & Polanczyk, 2019). It is also recommended pre-dilution in a smaller container, to be later poured into the spray tank. This pre-mix container must allow a proportion of 1 kg or L of product to at least 3 liters of water (Miguela & Cunha, 2010).

A good alternative that has been used to mitigate incompatibilities in spray solutions is the use of agricultural adjuvants. These can modify the physicochemical properties of spray solutions. Thus, such additives make the products of a mixture compatible, hence improving solution characteristics such as viscosity, surface tension, contact angle, pH, electrical conductivity, and droplet retention and deposition (Prado et al., 2016; Cunha et al., 2017).

5 I USE OF ADJUVANTS

Adjuvants are substances added to phytosanitary formulations or spray solutions. They can increase or change the efficiency of products against their targets and physicochemical properties of spray solutions, minimizing potential problems in applications. Among their functions are product compatibility in-tank mixing, drift reduction, increased target coverage and wetting, better product efficiency, greater droplet spreading on leaves, and faster absorption of the active ingredient, all of which often allow operational performance gains.

To properly select adjuvants as a function of application needs, their specificities should be well known, which are: foam reducers, volatilization, evaporation and drift, dispersants, emulsifiers, spreaders, wetting agents, adhesives, acidifiers, and buffers (Hunsche et al., 2006; Kraemer et al, 2009, Griesang et al., 2017). In other words, adjuvants must be selected according to their functions. Notably, a single product will hardly be able to perform well all necessary corrections for an efficient and safe application (Tu & Randall, 2003). Moreover, the effectiveness of active ingredients cannot be impaired either by mixing active ingredients in a tank or by adding adjuvants to the solution.

Adjuvants can change physicochemical properties inherent to spray solutions, depending on their chemical composition and formulation (Iost & Raetano, 2010). Thus, some authors have reported adjuvants acting to break water surface tension (Iost & Raetano, 2010; Barrêto, 2011), change volumetric median diameter (Mota, 2011; Checheto & Antuniassi 2012), modify pH and electrical conductivity in *Bacillus thuringiensis*-based solutions (Santos et al., 2019), and reduce the percentage of drift-susceptible droplets (<100 μm) (Matthews, 2000), thus contributing to the correct placement of the product on the target (Ferreira et al., 2003).

One of the primary and relevant functions of adjuvants is to reduce spray solution surface tension, and hence the contact angle between droplets and the applied surface. Accordingly, the spread and coverage of droplets over the desired target tend to increase. Furthermore, solution pH and electrical conductivity can alter the degradation and leaf absorption of phytosanitary products. However, crop leaves may have different affinities with adjuvants, making its recommendation difficult (Cunha, 2017).

Adjuvants are classified into two groups according to their role in phytosanitary products and spray solutions. The first group comprises the activators, which increase the quality of active ingredients and can be further classified as surfactants (reduce the surface tension of solutions to spread droplets on leaf surfaces); oils (increase the active ingredient penetration into leaves by diluting leaf waxy layer, besides reducing evaporation); and silicone derivatives (work as adhesive agents, reducing evaporation and run-off losses, as well as foam formation) (Kissmann, 1998). The second group includes the modifiers (also known as special-purpose adjuvants), which alter the physicochemical properties of solutions/formulations and can be further classified as humectants (reduce the surface tension of solutions and increase the contact of active ingredients with water); compatibilizers (avoid the chemical interaction between products, thus reducing incompatibilities); solution conditioners (used in water with lots of salts [cations]); pH buffering (balance pH and improve compatibility between products); defoaming agents (reduce the foaming during preparation, improving dilution and reducing spillage); drift control agents (increase the droplet sizes and decrease the number of droplets susceptible to drift); and thickening agents (increase the solution viscosity, most used in aerial applications) (Kissmann, 1998). Thus, in short, it can be concluded that a proper adjuvant selection is vital to ensure a good performance of the phytosanitary products and spray safety.

The quality of application of phytosanitary products must undoubtedly be maintained to obtain the expected economic results, with lower environmental risks. The information and technologies discussed in this chapter, if well implemented, are capable of contributing to this objective.

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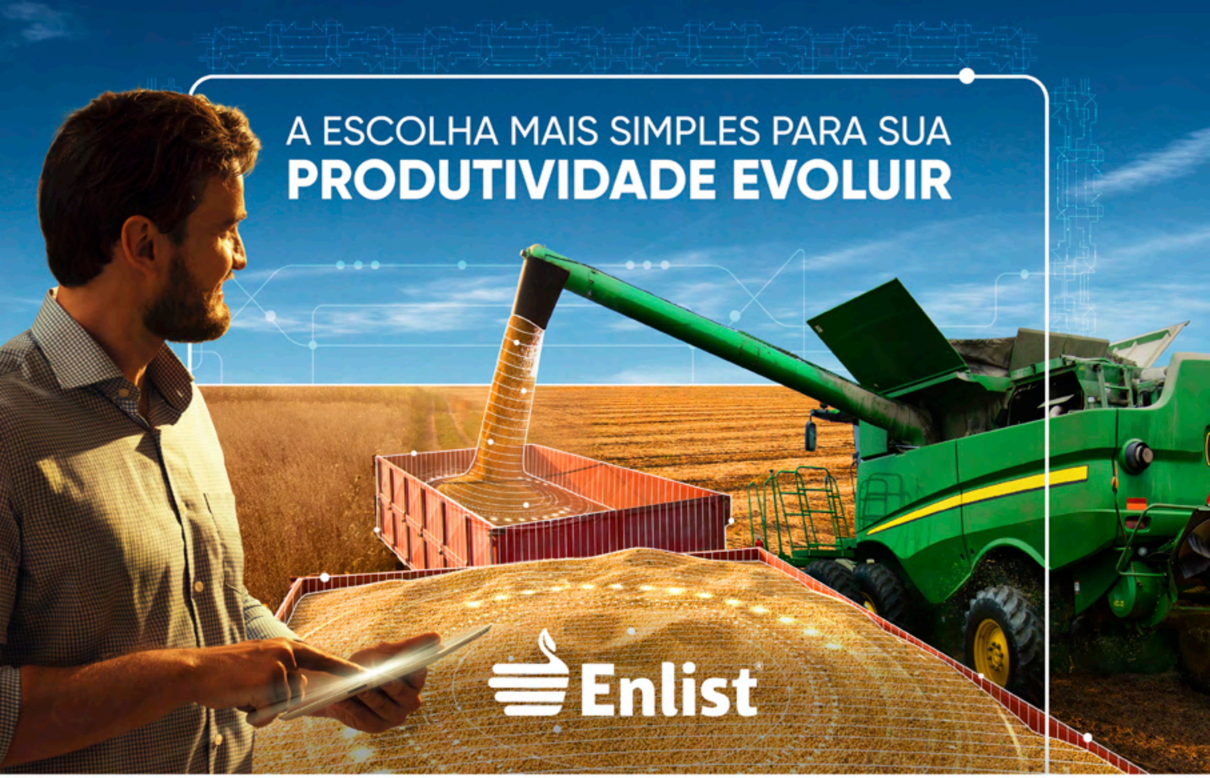

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