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The Effects of Sprayer Speed and Droplet Size on Herbicide Burndown Efficacy

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The Effects of Sprayer Speed and Droplet Size on Herbicide Burndown Efficacy

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Abstract

An Apache AS1220 self-propelled boom sprayer with a 27.4 m (90 ft) boom was equipped with different sizes (02, 04 and 06) and types (TeeJet AI, XR, AIXR and TTI) of nozzles to achieve medium, very coarse and ultra coarse droplet sizes traveling 11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph). These combinations of speed and droplet size were evaluated for percent coverage of the spray and percent control of targeted weeds 3, 7, and 15 days after treatment (DAT). Four replications were conducted for each speed and droplet size combination except for at 19 km/h (12 mph) where only three replications were used (35 plots). Significant ($p < 0.05$) differences were found in percent coverage by travel speed ($F(2) = 16.15$, $p = <.0001$) and by droplet size ($F(2) = 5.09$, $p = 0.01$) but not by the interaction of travel speed and droplet size. A travel speed of 18 mph ($M = 9.35$, $SD = 0.94$) and a very coarse droplet size ($M = 8.71$, $SD = 1.30$) were found to have the highest mean percent coverage among the groups. Significant ($p < 0.05$) differences were found in percent control by travel speed and droplet size but not the interaction of travel speed and droplet size at 3 and 7 DAT. No significant ($p < 0.05$) differences were found 15 DAT. A travel speed of 11 km/h (7 mph) ($M = 77.58$, $SD = 10.58$) and a medium droplet size ($M = 76.63$, $SD = 11.46$) were found to have the highest mean percent control at 3 DAT. A travel speed of 29 km/h (18 mph) ($M = 88.33$, $SD = 6.15$) and a medium droplet size ($M = 89.09$, $SD = 4.90$) were found to have the highest mean percent control at 7 DAT. Results suggest that an applicator planning to operate at increased field speeds, should consider selecting a nozzle that will produce a larger droplet when combined with their chosen travel speed. Moreover, no significant ($p < 0.05$) differences were found 15 DAT, suggesting that applicators should select a nozzle based on its ability to control drift at a given travel speed.

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I would also like to thank my father, Jon Carroll. This study could not have happened without your patience and willingness to cooperate. Thank you for supporting me in all my academic endeavors and providing a resource of knowledge and love.

Dedication

This thesis is dedicated to my parents, Jon and Jana, and my fiancé Paige. Thank you for your love and support throughout my entire college career. I love you all very much and I am blessed to have such positive influences in my life.

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Chapter 1: Introduction

Need for the Study

Pesticides are an important tool in an integrated pest management system for row crop production. As defined by the Federal Insecticide, Fungicide, and Rodenticide Act (2013), a pesticide is “(1) any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest, (2) any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant, and (3) any nitrogen stabilizer” (U.S. Environmental Protection Agency, 2015). Pesticides and their application rank among the top production expenses in American agriculture. In 2014 agricultural chemical expense in the United States totaled $15.8 billion (United Stated Department of Agriculture [USDA], 2015).

With the advent of new chemical compounds, pesticide resistant crop varieties, and increasing public concern about chemical use in food production, there is a renewed emphasis on proper pesticide application (Knoche, 1994). Two specific areas of concern are the reduction of application rate errors and spray drift. Application rate errors occur when the actual application rate is either higher or lower than the target application rate. Under-application errors result in low pesticide efficacy and lower yield due to weed competition (Luck et al. 2010a) while over-application errors result in increased production costs and potential environmental degradation (Porter, Rascon, Shi, Taylor & Weckler, 2013). Spray drift occurs when the wind carries pesticide spray droplets outside of the intended target area, potentially resulting in a negative impact on other crops, wildlife, or human health (Blomquist, 1995).

In order to maximize use of time, pesticide applicators in a row crop setting tend to travel faster than recommended, resulting in less effective application and possible pesticide drift.

Little is known about how this increase in speed affects the droplet spectra of pesticides and their effectiveness at killing targeted weeds.

Overview of the Literature

Pesticide use in row crop production is a vital part of sustaining high yielding crops to feed our growing population. According to Matthews (2000),

"Without modern technology (including the use of pesticides) tripling the world crop yield between 1960 and 1992, an additional 25-30 million square kilometers of land would have had to be cultivated with low-yield crops to feed the increased human population (p. 1)."

Pesticides allow farmers to control weeds, diseases, and insects from damaging their crop and ultimately reducing their yield. Due to the decreased yield without pesticide use, farmers would need to cultivate more land to plant more crops in order to equal the yield of crops where pesticide was used.

Unfortunately, errors are made in chemical application far too often on row crop operations. Most commonly, these errors involve a deviation in the rate of chemical applied per unit of area in the field. Application rate errors come in many forms including skipped-application, multiple applications, over and under application, or unintentional-application on environmentally delicate areas (Porter et al., 2013).

A study by Grisso, Dickey and Schulze (1989) of 103 private herbicide applicators in 12 Central and Eastern Nebraska counties found that only 30% of applicators were applying within 5% of their intended application rate, with the average cost of over application more than $570 per application. Additionally, field surveys conducted in Nebraska and Western Iowa showed that out of 152 private and commercial pesticide applicators, only one out of every four were applying pesticides within 5% of their estimated application rate (Rider & Dickey, 1982). Overall, chemical application errors can produce negative consequences for an individual's row crop operation.

Yield loss, increased production costs, and environmental contamination are all potential effects of chemical application errors. Under-application can result in yield loss to weed pressure, whereas over-application inhibits crop growth and increases production expenses. Environmental contamination is also a possibility when over applying pesticide due to the runoff produced when the pesticide mixes with irrigation water and exits the field.

According to TeeJet (2016b), "One of the most overlooked factors that can dramatically influence the effectiveness of a given crop production chemical is spray distribution. The uniformity of the spray distribution across the boom or within the spray swath is an essential component to achieving maximum chemical effectiveness with minimal cost and minimal non-target contamination." (p. 147). A number of factors affect the distribution quality of a spray boom, they include nozzle type, nozzle pressure, spray pattern quality, flow rate, pressure losses, boom height, boom stability, environmental conditions and sprayer speed (TeeJet, 2016).

Statement of the Problem

The literature presents many variables that affect the efficacy of pesticides. Although most of these variables have been researched, they have been primarily studied for their effects on spray drift (Wolf, Harrison, Hall & Cooper, 2000; Nuyttens, De Schampeleire, Verboven, Brusselman & Dekeyser, 2009; Knoche, 1994). Few studies have looked at sprayer speed or droplet size and their individual and combined effects on pesticide efficacy. Most recommendations for equipment operating conditions to achieve uniform spray deposits are largely based on laboratory data, and are not always compatible with field operation (Krishnan, Gal, Kemble & Gottfried, 1993). For practical application recommendations to be made to row crop producers, data is needed on how speed and droplet size affect pesticide efficacy and coverage.

Purpose, Objectives and Null Hypothesis

The purpose of this study is to determine the effects of travel speed and spray droplet size on herbicide coverage and efficacy. The objectives of this study are:

1. Determine the effect of travel speed [11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph)] on the coverage and efficacy of a burn-down herbicide [Gramoxone SL 2.0] on targeted weeds;
2. Determine the effect of droplet size (medium, very coarse, and ultra coarse) on the coverage and efficacy of a burn-down herbicide on targeted weeds; and
3. Determine the combined effects of travel speed [11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph)] and droplet size (medium, very coarse, and ultra coarse) on the coverage and efficacy of a burn-down herbicide on targeted weeds.

These three objectives were formulated as two null hypotheses for statistical testing:

Ho_1: There will be no significant ($p < 0.05$) difference in mean spray coverage on targeted weeds by travel speed, droplet size, or the interaction of travel speed and droplet size.

Ho_2: There will be no significant ($p < 0.05$) difference in herbicide burn down efficacy on targeted weeds at (a) 3 days after treatment, (b) 7 days after treatment, and (c) 15 days after treatment by travel speed, droplet size, or the interaction of travel speed and droplet size.

Chapter 2: Literature Review

This chapter will review the literature on general agricultural pesticide application information in row crops, common errors in agricultural pesticide application in row crops, the process of developing agricultural pesticide application recommendations, and the effects of selected application variables on pesticide efficacy.

Overview

As defined by the Federal Insecticide, Fungicide, and Rodenticide Act (2013), a pesticide is "(1) any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest, (2) any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant, and (3) any nitrogen stabilizer" (U.S. Environmental Protection Agency, 2015). Generally, pesticides consist of herbicides, used for weed control, insecticides, used for insect control, and fungicides, used for control of plant pathogens (U.S. Environmental Protection Agency, 2015).

Crop producers in the U.S. use an assortment of practices to reduce yield loss due to pests such as field scouting to determine whether pesticide application is needed and when it should be applied. Producers also implement genetically engineered (GE) crops that are insect-resistant and herbicide-tolerant to help maximize yield with a limited amount of land. These practices, along with crop rotation and preservation of natural enemies, make up integrated pest management (IPM) strategies that help producers increase crop yield and minimize environmental adverse effects.

Pesticides' large impact on the farming industry is undeniable. Over the previous 50 years there have been considerable changes in the amount of and trend of use of pesticides. In the first 20 years, the tendency was toward rapid growth of pesticide use, stalling in 1981

(Fernandez-Cornejo et al., 2014). An analysis of pesticide use on 21 different crops carried out by the United States Department of Agriculture (USDA), showed an increase from 196 million pounds of pesticide active ingredients in 1960 to 632 million pounds in 1981 (Fernandez-Cornejo et al., 2014). Since the 80's, improvements in the modes of action of pesticides along with agricultural practices, including GE crops, and technological innovations in IPM systems, have resulted in a descending trend in pesticide use to 516 million pounds of active ingredient in 2008 (Fernandez-Cornejo et al., 2014). According to the USDA, pesticide expenditures in U.S. agriculture totaled nearly $12 billion in 2008, a drastic increase since 1960, but well under the $15.4 billion peak reached in 1998 (Fernandez-Cornejo et al., 2014). In 2014 agricultural chemical expense in the United States totaled $15.8 billion (USDA, 2015).

History

The development of pesticides in the early 1800's drove researchers to develop efficient methods to properly apply them. In 1869, C.V. Riley developed the "cyclone nozzle" and is effectively the pioneer of the first efficient liquid atomizer for application purposes (Combellack, 1981). The discovery of selective herbicides in the late 1890s provided the impetus needed to develop a more suitable application method, and although "boom" sprayers were being used in the United States as early as 1888, by 1894 they were being further developed for spraying low growing vines in France (Combellack, 1981). Improvement continued in the late 1890's into the early 1900's with the addition of a motorized pump (Combellack, 1981). When phenoxyacetic herbicides, one of the early precedents to modern pesticides, were introduced in the mid-1940s, units were adapted to be used with tractors' three-point linkage as well as the P.T.O to drive gear or piston pumps (Combellack, 1981). With more research being conducted on atomizer design, by the late 1950s the fan atomizer was widely adopted for broad acre boom spraying. The

1960's saw improvements centered around wider booms, plastic tank construction, and increasing adoption of diaphragm pumps (Combellack, 1981). Large selectivity in the earlier developed pesticides played a major role in the lack of design specificity of sprayers.

Being relatively inexpensive and largely effective at a wide range of rates, pesticide use was increasing, however, by the 1960's those outside of conventional agriculture became concerned with its widespread use (ASABE, 2007). During the latter part of the 1960's, costs in the development of pesticides began to increase along with the specificity of the pesticides, but, excluding extensive applications with aircraft, little was said about the application process (ASABE, 2007). By the late 1970's the "computer" sprayer was introduced, which used a ground wheel to drive a positive displacement pump in order to vary spray volume directly with variation in ground speed. Although new to improved machines, this concept was originally developed in the late 1890's (Combellack, 1981). During the 1970's and 80's equipment development began trending toward accuracy of application through improvement of existing sprayer components, namely the interest in using rotary atomizers instead of hydraulic nozzles on sprayers, which allowed application at much lower volumes of water (ASABE, 2007). Although rotary atomizers were never widely adopted, the idea of low application rates continued. Many new application technologies were introduced between the 1970's and 1990's, such as ultra-low volume, rotary atomization, and electrostatics, but the basic chemical application method using hydraulic nozzles has not changed significantly since the beginning of the technology (ASABE, 2007). In part, this is due to new technology not being consistently efficient in applying the wide array of pesticide compounds, but also because applicators are not using conventional equipment with maximum efficiency (ASABE, 2007).

Boom Sprayer Operation

The most commonly used type of pesticide application equipment is the boom sprayer: about 90% of all pesticides are formulated to be sprayed (NASDA, 2014). Hydraulic sprayers use water or other liquid transferors to carry the pesticide to the desired application site. Large agricultural boom sprayers come in several forms, tractor mounted sprayers, pull-type sprayers and self-propelled ground sprayers, each with multiple-nozzle booms. No matter what the type, a pump is used push the liquid through hoses on the boom and atomize the spray mix at the nozzle (NASDA, 2014). Due to the fact that water is used to dilute and carry pesticides, a tank is necessary to hold the spray mix, where it is in contant agitation to maintain uniform mixture resulting in an even application of the chemical. A pump is used for the agitation as well as for pushing the liquid to the spray nozzles. Almost all current ground sprayers have automatic rate controllers, which control the spray liquid pressure by opening and closing a bypass valve. The applicator inputs the boom width and the rate controller measures flow rate from a flow meter as well as sprayer speed from GPS or radar methods (Wolf, n.d.). Once the sprayer is calibrated, the applicator inputs the desired application volume (rate) and the controller sets the pressure accordingly (Wolf, n.d.).

$$\text{l/ha} = \frac{60{,}000 \times \text{l/min (Per Nozzle)}}{\text{km/h} \times \text{W}}$$

Figure 1. The formula used for sprayer calibration, the rate is expressed in liters per hectare. TeeJet Technologies. (2016b). *Spray Application: Overview.* Retrieved December 2016, from TeeJet: http://www.teejet.com/literature_pdfs/catalogs/C51A-M/technical_information.pdf

As shown in Figure 1, sprayers must be calibrated according to three variables that affect the rate of pesticide applied: nozzle flow rate, ground speed of the sprayer, and width of the spray per nozzle (NASDA, 2014). Nozzle flow rate varies according to the size of the nozzle, the spraying pressure, and density of the spray liquid. A nozzle's size is the indicator of the droplet size produced by the nozzle at a given pressure. Nozzles for agricultural purposes can be classified as producing fine, medium, coarse or very coarse dropelts. Course or very course droplet sizes are usually selected to minimize off-target drift, whereas a fine droplet is needed to obtain optimal surface coverage of the target plant (TeeJet, 2016b).

Figure 2. The complete spectrum of droplet sizes arranged from smallest to largest: Extra Fine(XF), Very Fine(VF), Fine(F), Medium(M), Coarse(C), Very Coarse(VC), Extra Course(XC), Ultra Course(UC). TeeJet Technologies. (2016a). *Catalogs and Bulletins.* Retrieved January 2017, from TeeJet: http://www.teejet.com/literature_pdfs/bulletins/B124_Spray_Nozzle_Rate_Droplet_Size_Chart_20-inch.pdf

Spray pressure affects nozzle flow rate, the spray pattern (fan angle) and the spray droplet size spectra. The relationship between pressure and nozzle flow rate is shown in Figure 2.

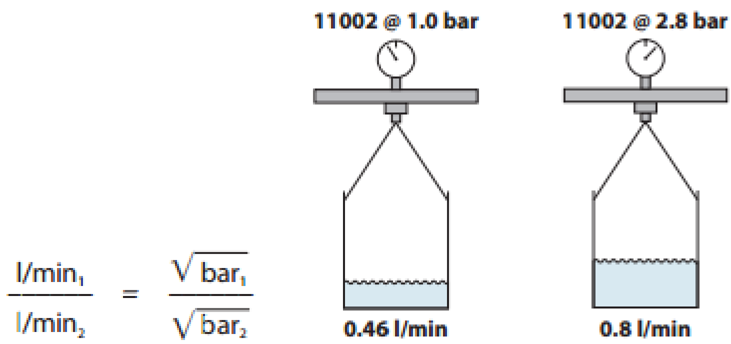

Figure 3. The relationship between nozzle flow rate and boom pressure expressed in liters per minute (flow rate) and bar (pressure). TeeJet Technologies. (2016b). *Spray Application: Overview.* Retrieved December 2016, from TeeJet: http://www.teejet.com/literature_pdfs/catalogs/C51A-M/technical_information.pdf

Basically, to double the nozzle flow rate, the pressure has to increase four fold. Raising the pressure not only increases flow rate, but influences droplet size and orifice wear rate. As pressure increases, droplet size decreases and orirfice wear increases (TeeJet, 2016b). Spray pressure also has a significant impact on spray angle and spray distribution quality. Figure 3 shows how lowering the pressure produces a smaller spray angle and reduction in spray coverage.

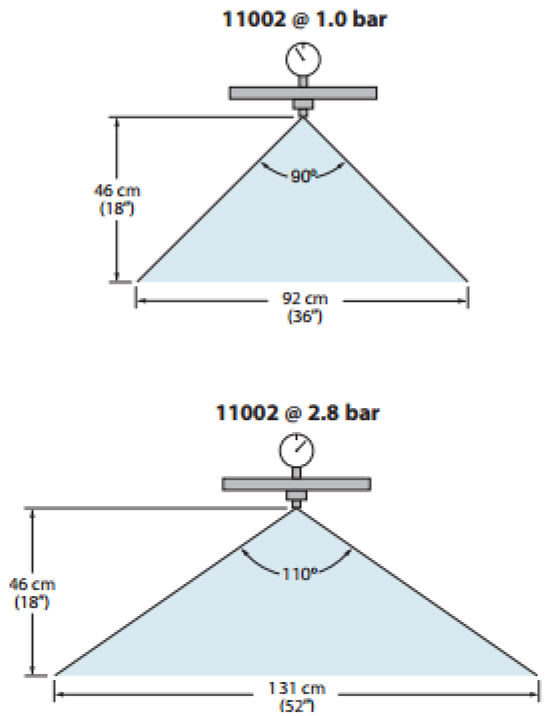

Figure 4. The relationship between pressure and spray angle/coverage expressed in degrees/centimeters (angle/coverage) and bar (pressure). TeeJet Technologies. (2016b). *Spray Application: Overview.* Retrieved December 2016, from TeeJet: http://www.teejet.com/literature_pdfs/catalogs/C51A-M/technical_information.pdf

It is critical to size nozzles correctly in order to apply the correct amount of pesticide in the appropriate speed range. Spray application rate varies inversely with ground speed, doubling the ground speed cuts the application rate in half, if pressure is held constant. The only way application rate remains constant is by a pressure increase from the rate controller in repsonse to the higher travel speed. Doubling the effective width sprayed per nozzle decreases the application rate by one-half (NASDA, 2014).

Application Errors and Traffic Patterns

Application rate errors caused by a variety of factors can be categorized as static or dynamic errors. Static errors include chemical mixing, sprayer and nozzle calibration, and pressure or ground speed readings, whereas dynamic errors include sprayer overlap, velocity difference across the boom during turning, pressure change across the boom during actuation, and boom height change from rolling terrain (Porter et al., 2013). Sprayer calibration as well as chemical mixing errors can be mitigated with proper training and maintenance. Certain devices and methods have been developed for assistance in proper sprayer calibration such as the device created by Salyani and Serdynski using a bucket and lid with a manifold attachment (1993). On the other hand, once static errors are minimized, the attention turns to dynamic errors. Studies have shown that application rate errors can result from factors such as irregular field shapes and traffic patterns. Luck et al. (2010a), shows that an additional application equal to 15-17% of the field area can be caused by irregular shaped fields. Lower field efficiencies can be directly attributed to the higher number of turns associated with contoured fields as opposed those with straight rows. Increasing the number of turns will also increase the opportunity for overlapping application as well as application rate error due to irregular field patterns within the turns and dynamic reactions of the boom of the equipment during turns (Grisso, Jasa & Rolofson, 2002; Grisso, Kocher, Adamchuk, Jasa & Schroeder, 2004). To help mitigate these errors, variable rate and section control technology was developed. By accounting for specific needs in different areas with variable rate technology, chemical can be applied more evenly in an effort of environmental stewardship. Most self-propelled ground sprayers in this day and age come equipped with boom section control technology that allows different boom sections to be controlled individually to avoid multiple or undesired application. Several studies have been executed (Luck et al. 2010a, 2010b; Luck, Pitla, Zandonadi, Sama & Shearer, 2011; Sharda, Fulton, McDonald, Zech & Brodbeck, 2008; Sharda et al., 2010) to assess dynamic boom response during field operations such as turning and responsiveness of section control (Porter et al., 2013). The effects of controller response and turning movements on application rate uniformity studied by Luck et al. (2011) found that only 25-36% of the area in the field tested received application rates within ±10% of the target rate.

Currently, hydraulic spray atomization techniques are the predominant agricultural crop protection practices used. While these techniques have their inefficiencies, they offer simple, reliable operation as well as consistent biological results (Wolf et al., 2000). Spray interception by non-target organisms is a common, coincidental event, mostly out of the control of the applicator (Wolf et al., 2000). Off-target losses such as spray drift are also a major concern among applicators, as they may contribute to damaging of non-target crops as well as decreased efficacy at the intended application site. To help control spray drift, applicators can alter several key variables such as carrier volume in the tank, droplet size, and travel speed. There have been some alterations to hydraulic application to improve spray targeting. One such improvement is the advent of the pulse-width modulation technique. Pulse-width modulation is a variable rate application system that was developed using a solenoid to pulse the sprays from a standard nozzle, by controlling frequency and duty cycle of the solenoid, the application rate of a standard tip can be altered to allow for a larger turndown ratio (Lang, 2013).

Droplet Size

Although improvements have been made, general recommendations still hold true in most herbicide applications made with a ground vehicle. Generally speaking, smaller droplet sizes are recommended for better coverage and spray retention (Wolf et al., 2000; Wolf, Friedli & Laver, 2009). However, larger droplet sizes lower the potential for spray drift (Wolf et al., 2000). In addition, optimal carrier volumes can increase the efficacy of the application of several herbicides (Knoche, 1994). Knoche (1994) states "generally, increasing coverage by decreasing droplet size or increasing carrier volume improved performance", while also recognizing, "coverage was not the only critical factor affecting herbicide performance and that other factors were also involved." (p. 167). Droplet sizes can be altered most easily by changing operating pressure but is also affected by nozzle size. Increasing the pressure at which the spray is applied not only yields finer spray droplets, but also increases the velocity of droplets. Moreover, increasing initial droplet velocity decreases drift distances, while at the same time making the spray finer and increasing the tendency for drift (Nuyttens et al., 2009). It has been found that an increase in pressure is not directly associated with increased drift, and some nozzle designs may even see a decrease in drift due to the dominance of the effect of droplet velocity (Nuyttens et al., 2009).

Spray Boom Motion

In order to help maximize the efficacy of pesticides the operator must control the spray uniformity to the best of their ability. One of the main factors affecting spray uniformity is the motion of the spray boom during application. Unsteady boom movement has been recognized as a limitation to precise application of pesticides (Jeon, Womac & Gunn, 2004). The majority of self-propelled sprayers control the average height of the boom as well as managing overall boom motion with passive boom suspension systems.

There have been several studies that investigated boom movement and its relation to spray distribution. Womac, Etheridge, Seibert, Hogan & Ray (2001) studied the effects of nozzle height and driving speed on spray distribution uniformity from venturi as well as extended-range elliptical-orifice nozzles under field conditions. Although percent coverage was mostly uniform across all driving speeds compared to the control, the coefficient of variation (CV) of spray distribution was 5-17% for a static boom and 6-37% for a moving boom (6-26 km/h). Langenakens, Ramon and De Baerdemaeker (1995) built a model for measuring the effect of tire pressure and driving speed on horizontal sprayer boom movements and spray pattern. They found that driving speed had a much larger influence on sprayer boom movements than tire pressure, stating "After increasing the driving speed of the tractor from 4 to 12 km/h, the amplitude of the boom movements almost quadruples. When tire pressure were changed from 60 to 180 kPa, the boom vibrations increased less than 10%." (p. 72). Jeon, Womac and Gunn (2004) investigated dynamic effects on sprayer booms as they related to application uniformity. Using extended-range elliptical-orifice fan nozzles as well as ultra-plus low-drift venturi nozzles, a sprayer was run on level field with an earthen bump installed as well as a dip in opposite wheel tracks. The maximum coefficient of variation (CV) of spray coverage on the track was 53.4% for the extended-range nozzles and 39.4% for the ultra-plus low-drift nozzles. Droplet density and spray coverage were correlated with vertical acceleration of the boom.

Forward Travel Speed

Travel speed of the sprayer is critical in achieving the desired application rate (ASABE, 2016). While most studies focus on how travel speed affects spray drift potential, little research has been done on the effect of travel speed on the efficacy of spray applications. Forward speed of the ground sprayer affects spray through the movement of the boom and the turbulence of the air as it passes by the nozzles. The amount of spray particles that reach their intended target are reduced when driving speed is increased. Increasing driving speeds bends and distorts the vertical air jet and leads to the smallest droplets escaping out of the spray into the downwind atmosphere of the sprayer (Nuyttens, De Schampeleire, Baetens & Sonck, 2007). The range of sprayer speeds will, in part, determine the nozzle flow rate necessary for the desired application rate, higher travel speed means higher nozzle flow rate to achieve the desired application rate

(ASABE, 2016). Spray drift is a major concern when increasing travel speed during pesticide application due to the increased spray pressure and in turn, increased nozzle flow rate. Although opposed to popular belief, increasing pressure does not force spray droplets deeper into the plant canopy, but instead increases the risk of spray drift (ASABE, 2016). There are several studies that show spray particle drift is increased when driving speeds are increased from 4 km/h to 8 km/h as well as 7 km/h to 10 km/h (Miller & Smith, 1997; Taylor, Anderson & Cooper, 1989; Nuyttens et al., 2007). Inherently, spray drift affects the efficacy of the pesticide being applied by lowering the intended application dose to the site. Ghosh and Hunt (1998), investigated dynamics of spray jets in a cross-flow as it related to droplet dispersion. They found that air flow patterns and droplet dispersion where quite different depending on the ratio of air speed into the air induction nozzle to the relative cross wind speed or tractor speed.

While the majority of these studies have focused on identifying the sources of application error involving dynamic properties of a sprayer and quantifying them in the field, very few studies have evaluated best use recommendations for application. Even fewer studies have identified thresholds of common application variables involved in row crop spraying. While many studies have evaluated how application variables affect spray drift, few studies have looked specifically at appropriate travel speed and droplet size combinations that can be used to make proper application recommendations for maximum efficacy of widely used pesticides.

Industry Incongruences

Another less recognized incongruity in best management practices for pesticide application using boom sprayers is the difference in application method in the development of recommendations and typical on-farm application practices. General information on equipment-operating conditions are, for the most part, based on lab data and, in some cases, are not aligned with field operation (Krishnan et al., 1993). According to University of Arkansas weed scientist, Dr. Bob Scott, “Efficacy from a weed science standpoint is evaluated in the field with a back pack type sprayer, whereas nozzle recommendations are usually made in labs with a few field tests to verify” (personal communication, January 30, 2017). Accordingly, the physics of application and the actual effectiveness of the herbicide are rarely tested together to investigate their relationship from a practical application perspective. The variable effects that can happen when traveling at speeds too fast for certain droplet spectrums have not been widely investigated in a field setting. “The incongruence between how herbicides are recommended to be applied and how they are actually applied is usually that the applicator is driving too fast.” (Bob Scott, personal communication, January 30, 2017).

Summary

With agriculture chemicals and their application among the top agriculture production expenses, it is crucial that they are being applied effectively. Added pressure from the public to decrease chemicals in food production makes practical recommendations for pesticide application crucial in order for producers to be economically and environmentally sustainable. As the need increases for timely application of pesticides on growing farm sizes, the spraying capacity is most often managed by sprayer speed increasing (van de Zande, Stallinga, Michielsen & van Velde, n.d.).

One variable that largely contributes to pesticide efficacy is droplet size. General recommendations include smaller droplet size for increased coverage and performance, however coverage is not the only factor affecting performance (Wolf et al., 2000; Wolf, Friedli & Laver, 2009; Knoche, 1994). While smaller droplets increase coverage, as droplet size decreases, drift potential increases (Nuyttens et al., 2009). Most recommendations include a medium sized droplet in order to decrease drift while maintain coverage and performance. While much research has been done investigating effects of droplet size on spray drift, little research has looked at how droplet size affects pesticide efficacy, particularly when coupled with increasing travel speed.

A second variable that not only affects pesticide coverage and efficacy, but also spray drift is sprayer speed. Driving faster than recommended by the pesticide manufacturer can bend and distort the vertical air jet and can lead to the smallest droplets escaping out of the spray into the downwind atmosphere of the sprayer (Nuyttens et al., 2007). As boom sprayers increasingly gain better suspension systems to allow higher application speeds with little boom movement, applicators speed up in an effort to maximize the use of their time and money (van de Zande, n.d.). However, little is known about how these increasingly faster speeds can affect the spray distribution and ultimately the spray efficacy.

Statement of the Problem

Recent public concern over pesticide in food production as well as high production expenses causes the need for row crop producers to get the most out of their pesticide applications. These applications are affected by many variables. Although most of these variables have been researched, few studies have looked at sprayer speed, droplet size, and the relationship between them. Most recommendations for equipment operating conditions to achieve uniform spray deposits are largely based on laboratory data, and are not always compatible with field operation (Krishnan et al., 1993). For practical application recommendations to be made to row crop producers, data is needed on these two critical variables to prevent money loss to over spraying as well as environmental contamination.

Defined by the needs associated with this literature review, the purpose of this study was to examine how spray efficacy is affected by application variables associated with ground sprayers. This study specifically looked at how spray efficacy was impacted by droplet size, forward travel speed, and the interaction of droplet size and forward travel speed.

Chapter 3: Methods and Materials

Statement of the Purpose

The purpose of this study was to examine how spray efficacy and coverage are affected by forward travel speed and droplet size. This study specifically looked at how spray efficacy and coverage were impacted by droplet size, forward travel speed, and the interaction of droplet size and forward travel speed.

Design of the Study

This study was an experimental, split plot design testing the individual and combined effects of two independent variables, droplet size and forward travel speed. This study measured two dependent variables, percent coverage of spray and percent kill of targeted weeds.

Research Variables

Two independent variables were used in the study. The first independent variable was droplet size. The three droplet sizes chosen were medium (M), very coarse (VC), and ultra coarse (UC). Generally speaking, the bigger the droplet size, the lower potential for chemical drift (Wolf et al., 2000). For that reason, the three droplet sizes chosen are within the common range used by applicators today with medium being the smallest size, ultra-coarse being the largest size, and very coarse being intermediate. The second independent variable was forward travel speed. The three travel speed chosen were 11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph). Speeds were chosen not only for volume but are common industry recommended speeds. Although the 11 km/h (7 mph) speed is less commonly used by applicators, it was chosen as the lowest speed because it is one of the highest speeds achievable on the smaller plot sprayers used in standard weed science plots. With this commonality in speeds we are able to compare data with industry standard experimental plot designs. We varied nozzles, pressures, and speeds to hold volume at a constant 10 gallons per acre (GPA), while also getting an accurate representation across the listed droplet sizes on the TeeJet Technologies spray nozzle rate and droplet size chart (TeeJet, 2016).

Instrumentation & Data Collection Preparation

An Apache AS1220 self-propelled boom sprayer with a 4,524 L (1,200 gal) mixing tank and 27.4 m (90 ft) spray boom was the ground sprayer used to make all herbicide applications. Speed was calibrated using dealer installed Raven GPS (Sioux Falls, SD). Flow was calibrated by performing a nozzle catch test on TeeJet AIXR, AI, and TTI size 02 nozzles and TeeJet AIXR, XR, and TTI 04 and 06 size nozzles (University of Arkansas Cooperative Extension Service, 2017). The plots were randomly assigned via the ARM data management software (Gylling Data Management Inc., 2017). Each plot was 15.2 m (50 ft) long, spaced 4.5 m (15 ft) apart horizontally and grouped in two rows with 3.4 m (100 ft) between the two rows of plots as seen in Figure 5.

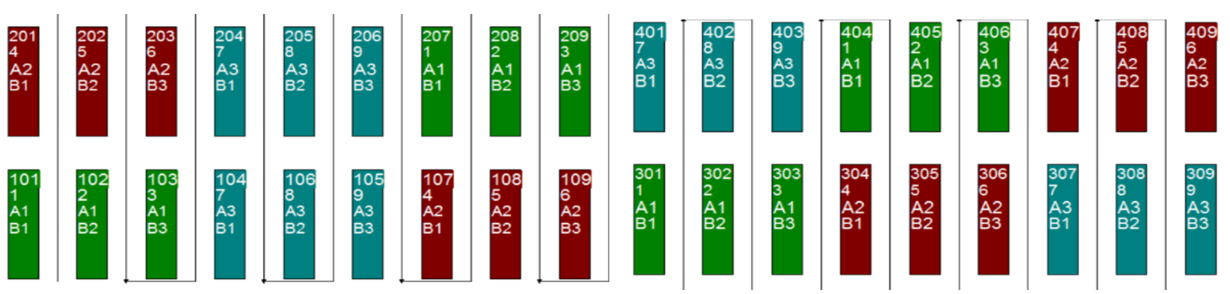

Figure 5. The physical layout of plots in the field is shown. Different colors denote the different speed, each with four randomly assigned repetitions

Pressure was calibrated by on-board pressure gauges and verified with nozzle body pressure gauges. Due to short spraying passes, the sprayer was put into a manual mode in order to self-adjust boom pressure to ensure accuracy during each pass. TeeJet XR, AIXR, AI, and TTI nozzles were used in order to maintain the proper droplet size and volume (gal/ac) across all forward travel speeds. Nozzle sizes and pressures used were 02 at 413.6 kPa (60 psi), 04 at 275.7 kPa (40 psi), and 06 at 275.7 kPa (40 psi). These combinations of sizes and pressures were chosen in order to keep a consistent 93.5 L/ha (10 gal/ac) spray volume across all three of the forward travel speeds. The on-board Raven GPS measured travel speed, flow, and application rate. The pesticide used was Gramoxone SL 2.0 mixed with water used as the carrier as well as ionic surfactant. Gramoxone SL 2.0 is a paraquat dichloride herbicide with a contact mode of action, meaning that it essentially desiccates green plant tissue in the presence of light and causes rapid decolorization of the plant (Dodge, 1971). Nozzles were separated into three 6 m (20 ft.) sections with 4.5 m (15 ft.) of space between where no nozzles were placed and no chemical was applied to facilitate easier visual comparison of efficacy and prevent cross contamination of treatments. To evaluate percent coverage of the spray distribution, 2” x 3” TeeJet water-sensitive spray cards, such as the ones in Figure 6, were used. Water-sensitive spray cards are yellow, rigid paper that are specially coated to be stained a dark blue color when in contact with aqueous droplets (Syngenta, 2017). They are commonly mounted on stakes to mimic crop/weed height and orientation.

Figure 6. Water sensitive spray cards were used to capture percent coverage readings of liquid carried sprays.

Conditions of Testing

Data were collected in environmental condition ranges aligning with the best management practices for boom spraying (ASABE, 2016). All coverage data were collected on Thursday March 23, 2017 between 1:00-3:00 P.M. Wind speeds were 3.6 to 10.9 mph, measured by a WeatherFlow WINDmeter (Scotts Valley, CA), while temperature was 70-80ºF. Field surfaces were smooth with even vegetative coverage of the targeted weed, henbit (Lamium amplexicaule), across all sprayed plots. Henbit is a winter annual, broadleaf weed found in moist soil conditions usually in early spring. The target pesticide application volume was 93.5 L/ha (10 gal/ac) for the entire study. Average temperature between initial application and 15 DAT was 80 degrees Fahrenheit with no significant rainfall above one inch (The Weather Channel, 2017).

Procedures for Data Collection

The Apache AS1220 mixing tank was washed and rinsed thoroughly prior to mixing in the pesticide. The tank was filled with approximately 1135.6 L (300 gal) of water along with 67.1 L (17.75 gal) of Gramoxon SL 2.0 at a rate of 2300 mL/ha (32 oz/ac) as well as the appropriate amount of surfactant recommended for Gramoxon SL 2.0. Half of the recommended rate of Gramoxone SL 2.0 was applied at 2300 mL/ha (32 oz/ac) in order to prevent total control of the targeted weed so quickly in order to facilitate easier visual ratings. TeeJet AIXR, AI, and TTI number 02 sized nozzles were placed onto the boom in three, 6 m (20 ft) sections respectively, one nozzle type per section as shown in Figure 7. The sprayer was driven to the testing site and boom height was set to 50.8 cm (20 in). All computer systems were turned on to monitor sprayer output and speed. Spray pressure was set to 413.6 kPa (60 psi). TeeJet water-sensitive spray cards were placed on wooden stakes that were placed in three different orientations; one in front of the stake, one in back of the stake, and one laying horizontally on the ground (108 total cards). Three water sensitive spray cards were placed in each treatment across all replications as shown in Figure 6.

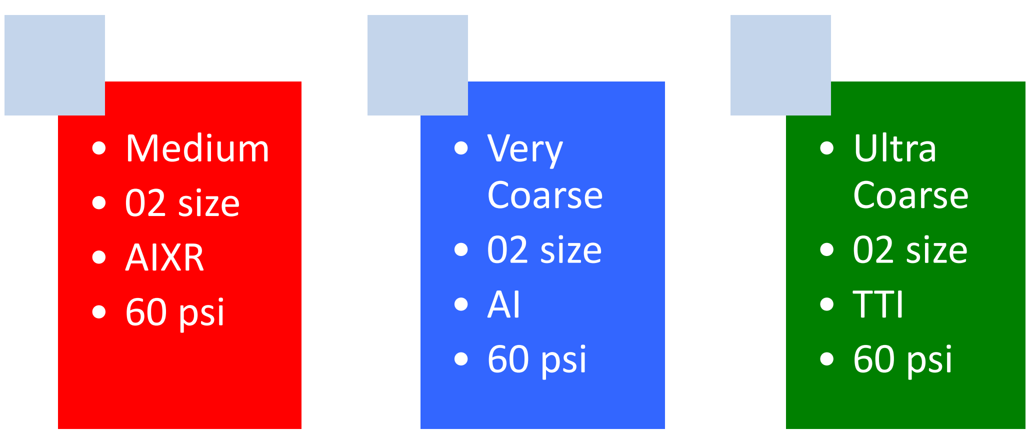

Figure 7. Boom setup for all passes sprayed at the 11 km/h (7 mph) travel speed. Spraying section widths were 6 m (20 ft.) with 3 m (10 ft.) unsprayed between each section

Four passes were sprayed with all 02 size nozzles at a target travel speed of 11 km/h (7 mph). The sprayer was lined up for the next pass and all 02 size nozzles were replaced with TeeJet XR, AIXR, and TTI 04 size nozzles. Spray pressure was set to 275.7 kPa (40 psi) and the four pass procedure was repeated at 19 km/h (12 mph). After all passes had been sprayed with the 04 nozzle size, the sequence of tests was repeated with TeeJet XR. AIXR, and TTI 06 size nozzles at a spray pressure of 40 psi and a target travel speed of 29 km/h (18 mph). All passes were driven by the same applicator in the same east-to-west direction. Travel speeds were held as consistent as possible but variation still occurred during testing.

After all tests concluded, the water-sensitive spray cards were collected and scanned using the SnapCard app (Kingston, Australia) to determine percent coverage readings. Visual ratings of pesticide efficacy were conducted by Tom Barber, a weed scientist with the University of Arkansas Cooperative Extension Service and his graduate student, 3 and 7 days after treatment (DAT). Dr. Ford Baldwin, former weed scientist with the University of Arkansas Cooperative Extension Service, conducted 15 DAT visual ratings. Visual raters were not aware of treatments, only plot numbers. Visual ratings were rated by percent control of targeted weeds 3, 7 and 15 DAT because these are standard weed science rating periods used in experimental plot work (Jhala, Sandell & Kruger, 2014). Percent coverage readings and percent control ratings were input into a Microsoft Excel workbook.

Data Analysis

As the spray cards were scanned, their coverage readings were input into Microsoft Excel along with the visual efficacy ratings. Data were analyzed using SAS® 9.3. Descriptive statistics along with a 3 X 3 factorial analysis of variance (ANOVA) ($p < 0.05$) procedure were used to analyze the data.

Chapter 4: Results

This chapter includes results that will display and describe significant ($p < 0.05$) differences found in percent coverage of spray and percent kill of targeted weeds for each travel speed, droplet size and combination of travel speed and droplet size.

Purpose, Objectives and Null Hypothesis

The purpose of this study is to determine the effects of travel speed and spray droplet size on herbicide coverage and efficacy. The objectives of this study are:

1. Determine the effect of travel speed [11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph)] on the coverage and efficacy of a burn-down herbicide [Gramoxone SL 2.0] on targeted weeds;
2. Determine the effect of droplet size (medium, very coarse, and ultra coarse) on the coverage and efficacy of a burn-down herbicide on targeted weeds; and
3. Determine the combined effects of travel speed [11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph)] and droplet size (medium, very coarse, and ultra coarse) on the coverage and efficacy of a burn-down herbicide on targeted weeds.

These three objectives were formulated as two null hypotheses for statistical testing:

Ho_1: There will be no significant ($p < 0.05$) difference in mean spray coverage on targeted weeds by travel speed, droplet size, or the interaction of travel speed and droplet size.

Ho_2: There will be no significant ($p < 0.05$) difference in herbicide burn down efficacy on targeted weeds at (a) 3 days after treatment, (b) 7 days after treatment, and (c) 15 days after treatment by travel speed, droplet size, or the interaction of travel speed and droplet size.

Field Spraying Conditions

Environmental and testing conditions were monitored and logged during the entire application period. Data was collected on March 23, 2017 from 1:00 to 3:00 P.M. Throughout all applications, environmental conditions were within best management practices for boom spraying (ASABE, 2016). Forward travel speeds were held as close as possible to target travel speeds for the short passes completed. Because this could not be attained in one set of plots in the 19 km/h (12 mph) target speed group, that data was not analyzed, resulting in only three replications for all data in the 19 km/h (12 mph) speed group. Wind speed was below the recommended 16-19 km/h (10-12 mph) threshold, while pressure at the boom was held as constant as possible to target pressures. Variations in boom pressure were not recorded until the start of the 19 km/h (12 mph) applications. Table 1 provides summary statistics of all field spraying conditions during application.

Table 1.

*Means (*M*) and Standard Deviations (*SD*) of Field Spraying Conditions*

Target Travel Speed (km/h)	Droplet Size	Actual Travel Speed (mph)		Wind Speed (mph)		Boom Pressure (psi)	
		M	*SD*	*M*	*SD*	*M*	*SD*
11 (7 mph)	Medium	6.95	0.19	8.25	3.19	60.00[a]	-
11 (7 mph)	Very Coarse	6.95	0.19	8.25	3.19	60.00[a]	-
11 (7 mph)	Ultra Coarse	6.95	0.19	8.25	3.19	60.00[a]	-
19 (12 mph)	Medium	12.13	0.15	7.23	2.36	38.33	7.37
19 (12 mph)	Very Coarse	12.13	0.15	7.23	2.36	38.33	7.37
19 (12 mph)	Ultra Coarse	12.13	0.15	7.23	2.36	38.33	7.37
29 (18 mph)	Medium	17.82	0.20	8.17	1.74	38.00	1.41
29 (18 mph)	Very Coarse	17.82	0.20	8.17	1.74	38.00	1.41
29 (18 mph)	Ultra Coarse	17.82	0.20	8.17	1.74	38.00	1.41

Note. Means based on four replications per speed excluding the 12 mph target speed, which is based on three replications. [a]Variability in boom pressures denoted by letters were not logged, therefore have no standard deviation.

Mean actual travel speeds ranged from 6.95 mph (*SD* = 0.19) to 17.82 mph (*SD* = 0.20) across all droplet sizes. Mean wind speeds ranged from 7.23 mph (*SD* = 2.36) to 8.25 mph (*SD* = 3.19) across all droplet sizes. Mean boom pressures ranged from 38 psi (*SD* = 1.41) to 60 psi (*SD* = 0) across all droplet sizes.

Percent Coverage

To evaluate percent coverage of the spray distribution, 2” x 3” TeeJet water-sensitive spray cards were used. The cards were placed to collect spray droplets in three different orientations (front of vertical stake, back of vertical stake, horizontal stake) to mimic different plant heights and leaf orientations as seen in Figure 5. Means and standard deviations of percent coverage were calculated by speed and droplet size individually as well as by the interaction of speed and droplet size. Overall mean percent coverage by speed ranged from 6.19% (*SD* = 1.70%) at 19 km/h (12 mph) to 9.35% (*SD* = 0.94%) at 29 km/h (18 mph). Table 2 provides the means and standard deviations of percent coverage data by speed.

Table 2.

*Means (*M*) and Standard Deviations (*SD*) for Percent Card Coverage by Travel Speed*

Target Travel Speed (km/h)	Percent Card Coverage							
	Front		Back		Horizontal		Overall	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
11 (7 mph)	6.59	3.45	1.31	0.75	14.24	2.75	7.38	1.65
19 (12 mph)	7.55	3.03	1.64	1.02	9.38	3.01	6.19	1.70
29 (18 mph)	13.45	3.19	1.07	0.43	13.52	3.57	9.35	0.94

Note. Means based on four replications per speed excluding the 12 mph target speed, which is based on three replications

Overall mean percent coverage by droplet size ranged from 7.03% (*SD* = 1.87%) using an ultra coarse droplet to 8.71% (*SD* = 1.30%) using a very coarse droplet. Table 3 provides the means and standard deviations of percent coverage data by droplet size.

Table 3.

Means (M) *and Standard Deviations* (SD) *for Percent Card Coverage by Droplet Size*

Droplet Size	Percent Coverage							
	Front Card		Back Card		Horizontal Card		Overall	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Medium	7.86	4.56	1.24	0.55	13.62	3.65	7.57	2.21
Very Coarse	10.80	2.97	1.00	0.44	14.34	3.14	8.71	1.30
Ultra Coarse	9.39	5.43	1.70	1.01	10.00	2.81	7.03	1.87

Note. Means based on three replications per droplet size

Overall mean percent coverage by the interaction of speed and droplet size ranged from 5.72% (*SD* = 2.29%) at 19 km/h (12 mph) with an ultra coarse droplet to 9.97% (*SD* = 1.19%) at 29 km/h (18 mph) using a very coarse droplet. Table 4 provides the means and standard deviations of percent coverage by the interaction of speed and droplet size.

Table 4.

Means (M*) and Standard Deviations* (SD) *of Percent Coverage by Travel Speed and Droplet Size*

Target Travel Speed (km/h)	Droplet Size	Percent Coverage							
		Front Card		Back Card		Horizontal Card		Overall	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
11 (7 mph)	Medium	7.05	4.95	1.10	0.21	15.15	2.57	7.76	2.35
11 (7 mph)	Very Coarse	8.25	2.26	0.87	0.37	15.35	3.00	8.15	0.74
11 (7 mph)	Ultra Coarse	4.47	2.01	1.97	0.99	12.22	1.97	6.25	1.07
19 (12 mph)	Medium	4.97	0.91	2.12	0.91	10.85	3.91	5.98	1.79
19 (12 mph)	Very Coarse	10.62	1.93	1.12	0.67	13.65	5.10	8.46	1.46
19 (12 mph)	Ultra Coarse	7.43	1.71	1.96	1.67	7.76	3.80	5.72	2.29
29 (18 mph)	Medium	11.15	4.29	1.02	0.66	15.60	2.61	9.25	0.88
29 (18 mph)	Very Coarse	13.45	1.63	0.95	0.20	15.52	2.43	9.97	1.19
29 (18 mph)	Ultra Coarse	15.77	1.44	1.25	0.36	9.45	0.97	8.82	0.40

Note. Means based on four replications per speed and droplet size excluding the 12 mph target speed, which is based on three replications

Null hypothesis one stated there would be no statistically significant ($p < 0.05$) difference in mean percent spray coverage on targeted weeds by travel speed, droplet size or the interaction of travel speed and droplet size. Data for null hypothesis one were analyzed using a 3 X 3 factorial analysis of variance (ANOVA). The analysis indicated that both travel speed and droplet size had significant effects on mean spray coverage. The interaction of travel speed and droplet size was not significant ($p < 0.05$). Null hypothesis one was rejected. These results are summarized in Table 5.

Table 5.

Factorial ANOVA for Percent Coverage by Travel Speed and Droplet Size

Source	*df*	*SS*	*MS*	*F*	*p*	R^2
Travel Speed	2	54.14	27.07	16.15	<.0001	0.46
Droplet Size	2	17.05	8.52	5.09	0.01	0.14
Travel Speed*Droplet Size	4	6.71	1.67	1.00	0.42	0.06

The Tukey post-hoc test indicated mean percent coverage was significantly higher at the 29 km/h (18 mph) travel speed than at either the 19 km/h (12 mph) or 11 km/h (7 mph) travel speeds. The Tukey post-hoc test also indicated the very coarse droplet size resulted in significantly greater mean coverage than did ultra-coarse droplet size. Descriptive statistics and significant differences in mean percent coverage by travel speed and droplet size are presented in Table 6.

Table 6.

Means, Standard Deviations, and Tukey post-hoc Results for Mean Percent Spray Coverage by the Main Effects of Travel Speed and Droplet Size

Main Effect	Percent Coverage	
Travel Speed (km/h)	*M*	*SD*
11 (7 mph)	7.38^{a}	1.65
19 (12 mph)	6.19^{a}	1.70
29 (18 mph)	9.35^{b}	0.94
Droplet Size		
Medium	7.57^{ab}	2.21
Very Coarse	8.71^{b}	1.30
Ultra Coarse	7.03^{a}	1.87

Note. Means within each main effect that do not share a letter are significantly ($p < .05$) different by the Tukey post-hoc test.

Percent Control

To determine herbicide efficacy each plot was evaluated for percent control at 3 days after treatment (DAT), 7 DAT and 15 DAT. Percent control was defined as control of targeted weeds as compared to the untreated check plots. Means and standard deviations of percent control were calculated for each period after treatment by speed, droplet size as well as the interaction of speed and droplet size. Mean percent control by speed ranged from 50% (*SD* = 18.54%) 3 DAT, traveling 19 km/h (12 mph) to 88.33% (*SD* = 6.15%) 7 DAT, traveling 29 km/h (18 mph). Table 6 provides the means and standard deviations of percent control by speed at 3. 7, and 15 DAT.

Table 7.

Means (M) *and Standard Deviations* (SD) *for Percent Control by Travel Speed*

	Percent Control					
Target Travel Speed (km/h)	3 Days After Treatment		7 Day After Treatment		15 Days After Treatment	
	M	*SD*	*M*	*SD*	*M*	*SD*
11 (7 mph)	77.58	10.58	84.10	8.21	85.41	2.57
19 (12 mph)	50.00	18.54	76.66	9.01	82.22	6.18
29 (18 mph)	62.91	16.84	88.33	6.15	86.25	6.78

Note. Means based on four replications per speed excluding the 12 mph target speed, which is based on three replications

Figure 8 displays the trends in mean percent control by travel speed at 3, 7, and 15 DAT. As shown, the largest differences in mean percent control by speed occurred at 3 DAT and decreased at both 7 DAT and 15 DAT. The declining amount of percent control from 7 DAT to 15 DAT at 18 mph is attributed to different rater's opinions at the different times of rating. This could also be influenced by the ability of a small amount of the targeted weed to green back up from the initial burn of the herbicide application.

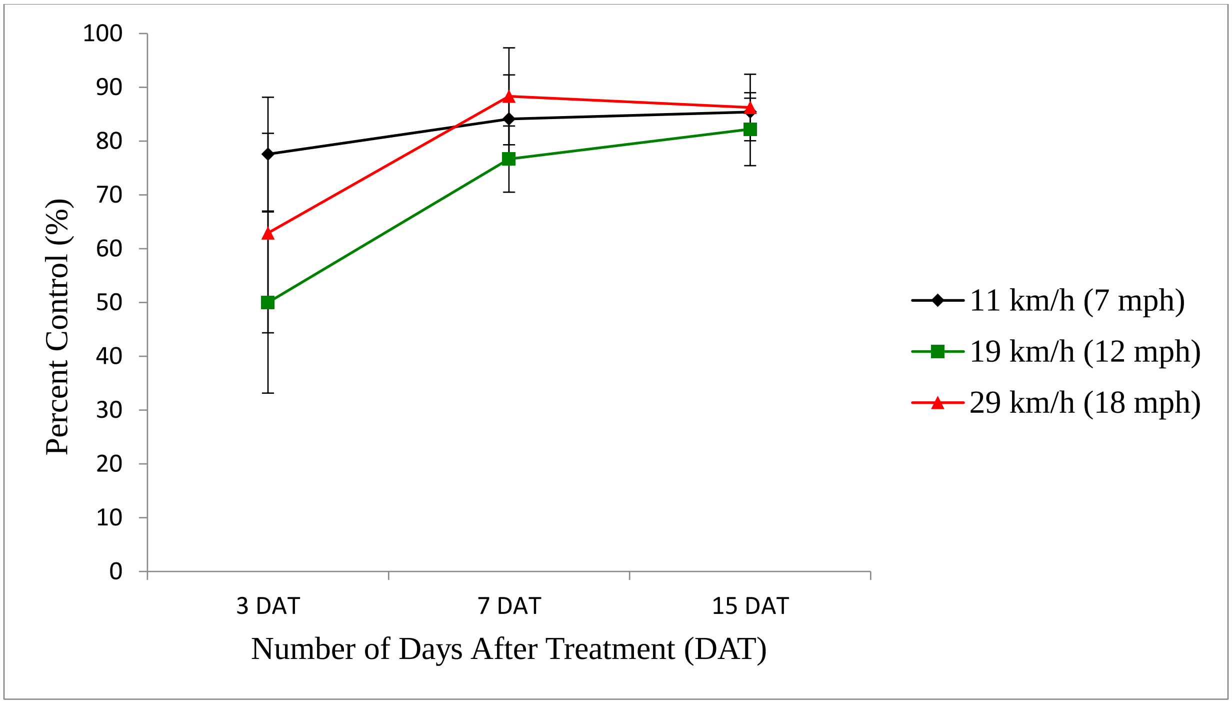

Figure 8. Mean percent control (+1 *SD*) by travel speed at 3, 7, and 15 days after treatment.

Mean percent control by droplet size ranged from 52.72% (*SD* = 19.28%) 3 DAT, using an ultra coarse droplet to 89.09% (*SD* = 4.90%) 7 DAT, using a medium droplet. Table 8 provides the means and standard deviations of percent control by droplet size.

Table 8.

Means (M) *and Standard Deviations* (SD) *of Percent Control by Droplet Size*

	Percent Control

Droplet Size	3 Days After Treatment		7 Day After Treatment		15 Days After Treatment	
	M	*SD*	*M*	*SD*	*M*	*SD*
Medium	76.63	11.46	89.09	4.90	86.36	5.51
Very Coarse	64.81	17.04	84.09	8.00	85.00	5.47
Ultra Coarse	52.72	19.28	77.72	9.58	83.18	5.60

Note. Means based on three replications per droplet size

Figure 9 displays the trends in mean percent control by droplet size at 3, 7, and 15 DAT. As shown, the largest differences in mean percent control by droplet size occurred at 3 DAT and decreased at both 7 DAT and 15 DAT.

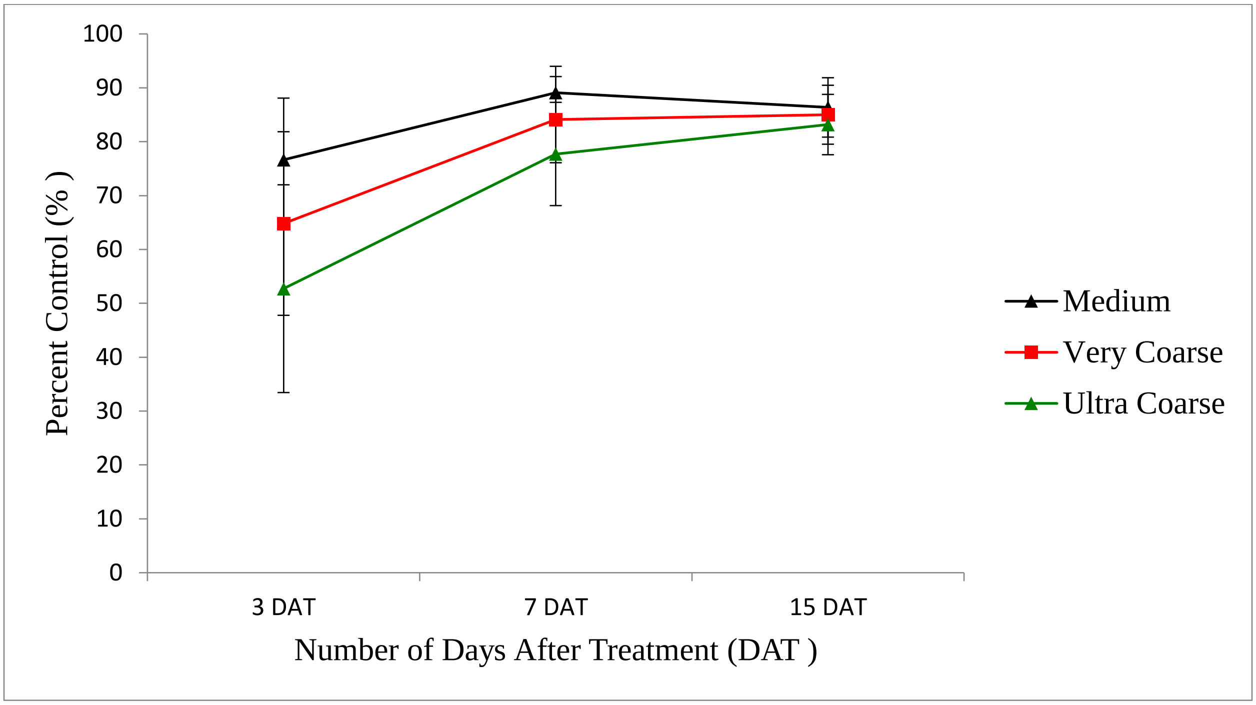

Figure 9. Mean percent control (±1 *SD*) by droplet size at 3, 7, and 15 days after treatment.

Mean percent control by the interaction of speed and droplet size ranged from 33.33% (*SD* = 11.54%) 3 DAT, traveling 19 km/h (12 mph) using an ultra coarse droplet to 92.50% (*SD* = 2.88%) 7 DAT, traveling 29 km/h (18 mph) using a medium droplet. Table 8 provides the means and standard deviations of percent control for each combination of speed and droplet size.

Table 9.

Means (M) *and Standard Deviations* (SD) *of Percent Control by Travel Speed and Droplet Size*

Target Travel Speed (km/h)	Droplet Size	Percent Control					
		3 Days After Treatment		7 Days After Treatment		15 Days After Treatment	
		M	*SD*	*M*	*SD*	*M*	*SD*
11 (7 mph)	Medium	84.50	3.31	90.00	0.00	86.25	2.50
11 (7 mph)	Very Coarse	79.50	7.37	88.75	4.78	86.25	2.50
11 (7 mph)	Ultra Coarse	68.75	13.14	73.75	2.50	83.75	2.50
19 (12 mph)	Medium	71.25	16.50	87.25	9.14	87.50	9.57
19 (12 mph)	Very Coarse	60.00	21.98	82.25	12.78	87.50	6.45
19 (12 mph)	Ultra Coarse	33.33	11.54	70.00	10.00	78.33	7.63
29 (18 mph)	Medium	77.50	9.57	92.50	2.88	88.75	7.50
29 (18 mph)	Very Coarse	60.00	14.71	85.00	8.16	83.75	8.53
29 (18 mph)	Ultra Coarse	51.25	16.00	87.50	5.0	86.25	4.78

Note. Means based on four replications per speed excluding the 12 mph target speed, which is based on three replications

Null hypothesis two stated there would be no significant ($p < 0.05$) difference in herbicide burn down efficacy on targeted weeds at (a) 3 DAT, (b) 7 DAT, and (c) 15 DAT by travel speed, droplet size, or the interaction of travel speed and droplet size. Data testing null hypothesis two were analyzed using a 3 X 3 factorial analysis of variance (ANOVA). The analysis indicated that both travel speed and droplet size had significant effects on mean percent control, 3 DAT. The interaction of travel speed and droplet size was not significant. These results are summarized in Table 10.

Table 10.

Factorial ANOVA of Percent Control by Travel Speed and Droplet Size 3 Days After Treatment

Source	*df*	*SS*	*MS*	*F*	*p*	R^2
Travel Speed	2	3974.71	1987.35	13.10	0.0001	0.36
Droplet Size	2	3256.86	1628.43	10.73	0.0005	0.29
Travel Speed*Droplet Size	4	319.81	79.95	0.53	0.71	0.03

The interaction of travel speed and droplet size was not statistically significant, $F(4) = 0.53$, $p = 0.71$ which indicated no significant interaction between the two variables. When looking at each individual variable, travel speed indicated $F(2) = 13.10$, $p = 0.0001$ which was significant along with droplet size $F(2) = 10.73$, $p = 0.0005$. Therefore, null hypothesis two part (a) was rejected by travel speed and droplet size individually but not by the interaction of travel speed and droplet size.

The Tukey post-hoc test indicated mean percent control was significantly higher at the 11 km/h (7 mph) travel speed than at either the 19 km/h (12 mph) or 29 km/h (18 mph) travel speeds at 3 DAT. The Tukey post-hoc test also indicated the medium droplet size resulted in significantly greater mean percent control than did the ultra coarse droplet size. Descriptive statistics and significant differences in mean percent control by travel speed and droplet size 3 DAT are presented in Table 11.

Table 11.

Means, Standard Deviations, and Tukey post-hoc Results for Mean Percent Control by the Main Effects of Travel Speed and Droplet Size 3 Days After Treatment

Main Effect	Percent Control	
Travel Speed (km/h)	*M*	*SD*
11 (7 mph)	77.58[a]	10.58
19 (12 mph)	50.00[b]	18.54
29 (18 mph)	62.91[b]	16.84
Droplet Size		
Medium	76.63[a]	11.46
Very Coarse	64.81[ab]	17.04
Ultra Coarse	52.72[b]	19.28

Note. Means within each main effect that do not share a letter are significantly ($p < .05$) different by the Tukey post-hoc test.

Visual rating data were collected again at 7 DAT to determine percent control among the plots. The analysis indicated that both travel speed and droplet size had significant effects on mean percent control. The interaction of travel speed and droplet size was not significant. Therefore, null hypothesis two part (b) was rejected by travel speed and droplet size individually but not by the interaction of travel speed and droplet size. Table 12 shows ANOVA results for percent control by travel speed and droplet size, 7 DAT.

Table 12.

Factorial ANOVA for Percent Control by Travel Speed and Droplet Size 7 Days After Treatment

Source	*df*	*SS*	*MS*	*F*	*p*	R^2
Travel Speed	2	705.30	352.65	10.98	0.0004	0.28
Droplet Size	2	720.41	360.20	11.22	0.0004	0.29
Travel Speed*Droplet Size	4	323.86	80.96	2.52	0.06	0.13

The Tukey post-hoc test indicated mean percent control was significantly higher at the 7 mph and 18 mph travel speeds than at the 12 mph travel speed at 7 DAT. The Tukey post-hoc test also indicated the medium and very coarse droplet sizes resulted in significantly greater mean percent control than did the ultra coarse droplet size. Descriptive statistics and significant differences in mean percent control by travel speed and droplet size 7 DAT are presented in Table 13.

Table 13.

Means, Standard Deviations, and Tukey post-hoc Results for Mean Percent Control by the Main Effects of Travel Speed and Droplet Size 7 Days After Treatment

Main Effect	Percent Control	
Travel Speed (km/h)	*M*	*SD*
11 (7 mph)	84.10[a]	8.21
19 (12 mph)	76.66[b]	9.01
29 (18 mph)	88.33[a]	6.15
Droplet Size		
Medium	89.09[a]	4.90
Very Coarse	84.09[a]	8.00
Ultra Coarse	77.72[b]	9.58

Note. Means within each main effect that do not share a letter are significantly ($p < .05$) different by the Tukey post-hoc test.

Visual rating data were collected for a final time at 15 DAT to determine percent control among the plots. There were no significant interactions among variables at 15 days after treatment. Therefore, null hypothesis part (c) was not rejected. Table 14 shows ANOVA results for percent control by travel speed and droplet size, 15 DAT.

Table 14.

Factorial ANOVA of Percent Control by Travel Speed and Droplet Size 15 Days After Treatment

Source	*df*	*SS*	*MS*	*F*	*p*	R^2
Travel Speed	2	89.52	44.76	1.44	0.25	0.09
Droplet Size	2	62.22	31.11	1.00	0.38	0.06
Travel Speed*Droplet Size	4	82.82	20.70	0.67	0.62	0.09

Chapter 5: Conclusions and Recommendations

The conclusions and recommendations regarding the results from this study and their implications are discussed in this chapter. Recommendations are made in the context that applicators will be using similar travel speeds and droplet sizes that were used in the study.

Statement of the Problem

Recent public concern over pesticide in food production as well as high production expenses causes the need for row crop producers to get the most out of their pesticide applications. These applications are affected by many variables. Although most of these variables have been researched, few studies have looked at sprayer speed, droplet size, and the relationship between them. Most recommendations for equipment operating conditions to achieve uniform spray deposits are largely based on laboratory data, and are not always compatible with field operation (Krishnan et al., 1993). For practical application recommendations to be made to row crop producers, data is needed on these two critical variables to prevent money loss to over spraying as well as environmental contamination.

Purpose, Objectives and Null Hypothesis

The purpose of this study is to determine the effects of travel speed and spray droplet size on herbicide coverage and efficacy. The objectives of this study are:

1. Determine the effect of travel speed [11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph)]on the coverage and efficacy of a burn-down herbicide [Gramoxone SL 2.0] on targeted weeds;
2. Determine the effect of droplet size (medium, very coarse, and ultra coarse) on the coverage and efficacy of a burn-down herbicide on targeted weeds; and

3. Determine the combined effects of travel speed [11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph)] and droplet size (medium, very coarse, and ultra coarse) on the coverage and efficacy of a burn-down herbicide on targeted weeds.

These three objectives were formulated as two null hypotheses for statistical testing:

Ho_1: There will be no significant ($p < 0.05$) difference in mean spray coverage on targeted weeds by speed, droplet size, or the interaction of speed and droplet size.

Ho_2: There will be no significant ($p < 0.05$) difference in herbicide burn down efficacy on targeted weeds at (a) 3 days after treatment, (b) 7 days after treatment, and (c) 15 days after treatment by travel speed, droplet size, or the interaction of speed and droplet size.

Summary of Study

An Apache AS1220 self-propelled boom sprayer with a 27.4 m (90 ft) boom was equipped with different sizes (02, 04 and 06) and types (TeeJet AI, XR, AIXR and TTI) of nozzles to achieve medium, very coarse and ultra coarse droplet sizes traveling 11 km/h (7 mph), 19 km/h (12 mph), and 29 km/h (18 mph). These combinations of speed and droplet size were evaluated for percent coverage of the spray and percent control of targeted weeds. Four replications were conducted for each speed and droplet size combination (36 plots). Significant ($p < 0.05$) differences were found in percent coverage by travel speed ($F(2) = 16.15$, $p = <.0001$) and by droplet size ($F(2) = 5.09$, $p = 0.01$) but not by the interaction of travel speed and droplet size. A travel speed of 18 mph ($M = 9.35$, $SD = 0.94$) and a very coarse droplet size ($M = 8.71$, $SD = 1.30$) were found to have the highest mean percent coverage among the groups. Significant ($p < 0.05$) differences were found in percent control by travel speed and droplet size but not the interaction of travel speed and droplet size at 3 and 7 DAT. No significant differences were found 15 DAT. A travel speed of 11 km/h (7 mph) (M = 77.58, SD = 10.58) and a medium droplet size (M = 76.63, SD = 11.46) were found to have the highest mean percent control at 3 DAT. A travel speed of 29 km/h (18 mph) (M = 88.33, SD = 6.15) and a medium droplet size (M = 89.09, SD = 4.90) were found to have the highest mean percent control at 7 DAT.

Conclusions

This section describes the results from Chapter 4. It also describes how they relate to other similar studies as well as their implications for spray applicators.

Percent Coverage

Results indicated a significant ($p < 0.05$) difference in percent coverage by travel speed and droplet size individually, with a travel speed of 29 km/h (18 mph) (M = 9.35, SD = 0.94) and a very coarse droplet size (M = 8.71, SD = 1.30) having the highest mean percent coverage among the groups. This could be attributed to the larger size of the droplet holding a consistent pattern at higher speeds. Coverage was likely highest with this larger droplet size due to the decreased propensity for drift, which is consistent with Wolf et al. (2000).

Although generally speaking, smaller droplet sizes are recommended for better coverage and spray retention (Wolf et al., 2000; Wolf, Friedli & Laver, 2009), this increase in coverage by a larger droplet size could be due to the manner in which coverage is measured with water-sensitive spray cards. The larger droplets at higher speeds create larger spots on the card than do the smaller droplet sizes, increasing the percent coverage measured by the SnapCard app. Therefore, it was concluded that general weed scientists recommendations hold true in a real world application and that nozzle selection should be focused around minimizing off target drift based upon the planned travel speed. If an applicator plans to operate at increased field speeds, they should consider selecting a nozzle that will produce a larger droplet when combined with their chosen travel speed.

Percent Control

Results indicated a significant ($p < .05$) difference in percent control by travel speed and droplet size individually at 3 DAT as well as 7 DAT. There were no significant differences in percent control by 15 DAT. This indicates that for a burndown application with a contact killing mode herbicide, like the one used in the study, 15 DAT herbicide efficacy is not affected by the travel speed, droplet size or any combination of travel speed and droplet size. As mentioned earlier, based on these results an applicator should make nozzle and speed selections based upon their ability to control drift.

A medium sized droplet and a travel speed of 11 km/h (7 mph) seemed to be a highly effective combination at controlling the targeted weed at 3 DAT (M = 84.50, SD = 3.31) and 7 DAT (M = 90.00, SD = 0.00) when using half the recommended rate of Gramoxone. In a situation where weather delays burndown applications until later into the planting season, quicker weed control may be needed in which case an applicator should use the full application rate of their chosen chemical as opposed to the half rate used in the study. However, in cases where the applicator has enough time before planting begins or the field being sprayed will undergo tillage of some kind prior to planting, the results indicate that any combination of speed and droplet size studied will provide proper control of targeted weeds when using a contact herbicide.

Recommendations

Mean spray coverage was significantly ($p < 0.05$) higher at a travel speed of 29 km/h (18 mph) with a very coarse droplet size. Based on these results, it is recommended that applicators pair larger droplet sizes with higher speeds when applying contact herbicide in a burndown situation. However, in a situation where neighboring fields could be adversely affected by off-target application of the contact herbicide, slower speeds are recommended (Nuyttens et al., 2007).

No significant ($p < 0.05$) difference was found in percent control of targeted weeds by 15 DAT. Therefore, it is recommended that applicators choose nozzle type and size based upon the recommended droplet size for the pesticide they are spraying. If spraying a contact herbicide with a similar sprayer setup with a boom width of 27.4 m (90 ft) and drift is not a concern, an applicator will be able to cover the most amount of acres in the least amount of time by traveling 29 km/h (18 mph) with confidence the chemical will be as effective as possible using a nozzle such as an 06 TeeJet AIXR.

This study only investigated two variables involved in applying contact herbicide in a burndown situation, percent coverage and percent control. Although drift may not be a large concern during an early season burndown application, its effects may not be desirable when applying herbicide during the growing season. Therefore, it is recommended that future research also investigate drift in conjunction with coverage and efficacy of herbicide applications.

While previous literature states that increased field travel speeds bend and distort the vertical air jet and lead to the smallest droplets escaping the spray pattern (Nuyttens et al., 2007), this study did not find that to be true. The mean percent coverage traveling 29 km/h (18 mph)

(*M* = 9.35, *SD* = 0.94) was significantly ($p < 0.05$) greater than the mean percent coverage traveling 11 km/h (7 mph) (*M* = 7.38, *SD* = 1.65). Further research should be conducted to investigate these discrepant findings.

Contact herbicides are a widely used mode of weed control, however applicators are also recommended to use systemic herbicides, especially when the crop itself is being sprayed. Future research should investigate the effects of travel speed and droplet size when applying systemic herbicides in-season where crop canopy penetration is involved.

In our study the plots were evenly covered with the broadleaf henbit and visual ratings were made based on the percent control of this weed. Henbit is relatively easy to control using both contact and systemic herbicides, especially in the presence of warm weather. Further research should examine weeds that are more difficult to control in conjunction with any variables affecting spray performance in the field.

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