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The Effect of Droplet Size and Sprayer Type on Physical Drift

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By

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The effect of droplet size and sprayer type on physical drift

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With the development of transgenic crops resistant to auxin herbicides will come an increase in the use of these herbicides for weed control. This new technology will greatly aid growers that have glyphosate-resistant weeds such as Palmer amaranth (*Amaranthus palmeri* S. Wats) in their fields. A challenge will be with farmers that choose not to use this new technology and have susceptible crops on their farm or adjoining farms. Auxin herbicides such as 2, 4-D and dicamba are well-documented as being very injurious to susceptible crops, even at low doses. It is for this reason that research is being conducted to compare the differences in the amount of particle drift with hooded boom sprayers compared to open boom sprayers. Along with this research, various droplet sizes will also be analyzed and compared between the two sprayers.

DEDICATION

I would like to dedicate this work to my family who has helped me throughout my life to make it possible for me to accomplish this great achievement. To my father, Clay, who instilled a strong work ethic and showed me what it means to be a leader. To my mother, Lana, who taught me how to care for others and always do what is right. To my two sisters, Courtney, and Noelle, for all the support and concern as well. I would also like to thank my wife, Meg, for all her support during this process. Most of all I would like to dedicate this work, along with everything else I do in my life, to God. I have truly been blessed and I hope that everything I do is pleasing in Your sight.

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CHAPTER I

INTRODUCTION

For many years, producers had very few options to manage troublesome weed populations. With the introduction of synthetic herbicides in the 1950's, growers gained additional methods for weed management. The introduction of 2, 4-D led to a tremendous increase in herbicide discovery and by 1970, there were 75 synthetic herbicides on the market. The next revolution in weed management came with the introduction of glyphosate-tolerant crops. Glyphosate-resistant soybeans were the first transgenic herbicide tolerant crop to be commercially introduced in 1996. After introduction, there was a rapid adoption of the new technology. Adoption of the new technology was rapid because it provided a simple and effective weed management strategy that was relatively inexpensive compared to other means of weed control.

With the introduction and quick adoption of this new technology, overuse of glyphosate led to repeated exposure to many weeds leading to glyphosate-resistant weeds. Resistance occurred because of the overdependence on glyphosate and the lack of incorporating multiple modes of action (MOA) with herbicide applications. The International Survey of Herbicide Resistant Weeds lists 14 glyphosate-resistant (GR) weed species currently affecting U.S. crop-production areas (Heap 2014). Soybean growers who had reported a decline in the effectiveness of glyphosate as of 2012 received lower total ($55.65/hectare) returns than soybean growers who had not reported such a decline (Livingston et al. 2015).

Some of the most troublesome glyphosate-resistant weed species are from the pigweed family: tall waterhemp (*Amaranthus tuberculatus (Moq.)* Sauer), and Palmer amaranth (*Amaranthus palmeri* S. Wats). The reason pigweeds are so troublesome is because of their rapid growth, aggressive competition, high seed production, and almost constant germination throughout the growing season. To effectively manage aggressive species like tall waterhemp and palmer amaranth, multiple modes of action should be incorporated into weed management practices for better control. Dicamba and 2, 4-D are auxin herbicides that effectively control glyphosate resistant weeds; however, use of these herbicides are often associated with off target movement to non-crop susceptible plants.

Instead of trying to develop a new mode of action, scientists have discovered how to develop tolerance in previously susceptible crops. These crops will include tolerance to auxin herbicides such as 2, 4-D and dicamba. Scientists at the University of Nebraska-Lincoln inserted the gene dicamba monooxygenase (DMO) into plant species which produces an enzyme capable of breaking the dicamba molecule into the inactive compound 3, 6-dichlorosalicylic acid (DCSA) (Weeks et al. 2006). This will allow use of dicamba directly to crops that were once susceptible, such as soybeans (Sciumbato et al. 2004).

Monsanto purchased the rights to this new technology to develop crop species with tolerance to dicamba. Monsanto has coupled the tolerance to dicamba with glyphosate tolerance to better control a wide range of weed populations. The new dicamba technology is being marketed under the trade name Roundup Ready 2 Xtend System™ and is available for use in the 2017 growing season. Dow AgroSciences has also developed genetically modified crops capable of metabolizing 2, 4-D as a part of their new Enlist™ cropping system.

By incorporating these new technologies, producers can better control weed populations, especially those that have evolved resistance to other herbicides. The problem lies with producers that choose not to use the new technology. Since many plant species are sensitive to dicamba and 2, 4-D, keeping the herbicides within the target area is critical. The movement of these auxin herbicides will need to be mitigated as much as possible to prevent damage to non-target species and crops that are not tolerant to these chemistries.

With an increase in the number of acres using auxin-tolerant crops, there will be an increase in the number of drift event. Herbicide drift that injures neighboring crops will lead to crop injury, yield loss, and litigation. This was a problem in 2016 with the release of the Roundup Ready 2 Xtend crops prior to the availability of an approved formulation of a dicamba labeled for use in these crops. States across the south including Arkansas, Missouri, Tennessee, and Mississippi faced drift related issues in the 2016 season. Because of the inherent risk involved, it is essential to fully understand when, where, why and how drift occurs.

There are four major factors that influence particle drift: environmental conditions, boom height, spray particle size, and distance from susceptible vegetation. Wind speed has the greatest impact on spray drift. Regardless of droplet size, boom height, or distance from susceptible vegetation, if the wind velocity is high enough there will be drift (Wolf et. al, 1993).

Generally, a light wind is desirable to avoid temperature inversions. A temperature inversion occurs when the air at the ground level is cooler than the air above it. This occurs naturally and is a part of a daily atmospheric cycle, occurring in the early morning hours when the ground cools the air layer immediately above it. These conditions can cause small droplets to remain suspended in the air until the inversion subsides (Fishel and Ferrel 2010). A light wind could prevent an inversion and minimize the potential for drift.

Humidity and temperature are two other factors that should be noted before an application is made. When the relative humidity is below 50 percent and the temperatures are high, the spray droplets evaporate quickly and become more susceptible to wind forces (Fishel and Ferrel 2010; Thistle 2004). The environmental conditions during herbicide application are the most influential because they are beyond human control. It is up to the operator to make wise decisions to minimize the occurrence of drift.

Spray boom height at the time of application is another factor that can influence the amount of drift because it determines the distance the herbicide travels to reach the target area. The greater the interval between application and deposition, the more susceptible the droplets are to environmental conditions. Generally, a spray boom should be kept 45 to 60 cm above the crop canopy. This can be reduced by using a wider fan angle. The problem with a wider fan angle is that it creates smaller droplets which are more likely to drift. The proper boom height should be based on nozzle selection. To reduce the potential for drift, applications should be made at the proper boom height.

Droplet size is an important factor affecting drift potential. Smaller droplets remain suspended in the air for longer periods of time leading to a higher drift potential. Droplets are found to have an extreme potential for drift when the diameter is 100 to 200 micrometers or less (Wolf et al., 1993). Spray pressure and nozzle selection determine the size of the droplet being produced (Fishel and Ferrel 2010; Ramsdale and Messersmith 2001). An increase in pressure will generally decrease droplet size.

Droplet size is also a factor when an applicator is deciding what to spray. Contact herbicides are more effective if there is a larger coverage area with smaller droplets. Likewise, systemic herbicides do not require as much coverage and can be applied with larger droplets (Henry et al. 2004). With the new auxin resistant cropping system, coverage is not necessarily as important due to the systemic activity of auxin herbicides. This will be beneficial if an applicator wants to use the sprayer interchangeably, between herbicide and insecticide applications. Many of the insecticides are contact chemicals that require smaller spray droplets for maximum coverage.

Viscosity is another factor that can affect droplet size. Increasing the viscosity of the spray will reduce the number of small droplets (<150m). Drift retardants can be used to increase the viscosity There are several drift retardants on the market with various degrees of efficacy, but they cannot be relied on solely to eliminate drift (Fishel and Ferrel 2010; Ozkan et al. 1993).

The final factor affecting herbicide drift is the distance from susceptible vegetation. The incorporation of buffer zones could be a possibility if a producer is certain of what crops are planted in adjacent fields. The difficulty for the applicator is determining the size of the buffer zones needed for adequate protection. In past studies, it was suggested that buffer zones 20 m wide should give adequate protection to adjacent land (Marrs et al., 1993). The problem with incorporating buffer zones is that most producers may not be willing to give up 20 m on each side of the field to mitigate the effects of drift.

Adoption of the new herbicide tolerant crops will provide producers with the opportunity to apply herbicides that in the past were not a viable option. The acreage planted with the new cropping technology is likely to increase rapidly, with regulatory approvals. However, it is unlikely that all producers will choose to incorporate this technology into their management plan. This will likely lead to many hectares of susceptible crops interspersed with auxin resistant crops thus increasing the likelihood of a drift event occurring. There have been numerous studies evaluating the effects of dicamba and 2, 4-D have on soybean. One study looked at soybeans response to dicamba when applied at the vegetative and reproductive growth stages (Griffen et al. 2013). Soybeans at stages V3/V4 or R1 were treated with diglycolamine salt of dicamba. They found that soybean injury increased from 20 to 89% as dicamba rate increased from 4.4 to 280 g ae ha^{-1} at seven DAT (days after treatment). At 14 DAT, soybean injury at 4.4 to 140 g ha^{-1} had increased 15 to 19 percent since the earlier evaluation, but increased only 8 percent for the 280 g ae ha^{-1} application. The study concluded that greater soybean yield loss occurred with dicamba applied during the early reproductive stage versus the V2 to V4 stage (Griffin et al. 2013).

Studies have also been conducted to determine cotton response to simulated drift. One study observed cotton response to 2, 4-D amine, 2, 4-D ester, clopyralid, picloram, fluroxypyr, triclopyr, and dicamba applied to cotton in the six- to eight-leaf stage. The greatest visual injury 14 DAT was observed with the two 2, 4-D formulations. All rates of 2, 4-D, along with the highest rate of picloram, caused greater than 60% flower abortion. Fiber yield reduction was also greatest with the two formulations of 2, 4-D, followed by picloram. This study shows that cotton is extremely susceptible to the low rates of 2, 4-D and picloram (Marple et. al, 2007).

Applicators spraying soybean or cotton early in the growing season for soybeans and cotton with the auxin herbicides should be cautious of application conditions and try to mitigate the effects of drift to reduce injury to susceptible crops. There have been many studies investigating spray application technology to mitigate herbicide drift. One study looked at the incorporation of shields to reduce spray drift. The experiment was conducted in a wind tunnel with nine different shield designs. The distance to center of mass was the unit used to measure spray distribution and evaluate shields for their effectiveness against spray drift. They concluded that all nine shields effectively reduced spray drift by directing smaller spray droplets to the ground. Even the porous shield reduced drift by 13%. The double-foil shield produced the best performance by reducing drift 59% (Ozkan et al. 1997).

Smith et al. conducted experiments to quantify the effects of mechanical and pneumatic shields on drift. Experiments were conducted under both laboratory and field conditions. The laboratory experiment indicated the shielded boom reduced downstream deposits by 35.7 to 70%. The field experiment concluded that the mechanical shield reduced drift deposits by 65%, but in another circumstance (different sprayer/wind speed) caused 81% more drift deposits compared to the conventional boom (Smith et al. 1982). This was due to different environmental conditions between experiments. Comparisons of a simple shield, mounted vertically in front of a boom with conventional nozzles with an air-assist system were conducted to determine the viability of shields. The conclusion was that shields, even simple mounted shields, are reliable ways to reduce drift (Furness 1991).

Studies have also been conducted with standard and shrouded booms using flat-fan nozzles. Two approximate volumetric mean diameters were used for the droplet sizes (320 µm and 100 µm) to evaluate changes in drift deposits with a change in droplet size. Fehringer and Cavaletto concluded that the hooded boom sprayer reduced drift 1.8 to 2.75 times compared to the standard sprayer (Fehringer and Cavaletto 1990).

Other studies have been conducted evaluating the effectiveness of shields in reducing off-target movement. Sprayer booms ranging from 10 to 13.5 m and equipped with commercial shields were used in wheat fields with wind speeds ranging from 10 to 35 km/h^{-1}. The results showed that shields used in the experiment reduced drift compared to the conventional sprayer. Wolf et al. (1993) indicated that shields which cover the entire boom reduce visibility and access to the nozzles, as well as possible contamination of susceptible crops by wiping herbicide residue onto the susceptible crop. However, this exposure would not be as detrimental to the susceptible crop compared to a drift event. Wiping of herbicide residues can be mitigated with proper cleanout of the sprayer before and after application.

The incorporation of shields has proven to reduce drift, but nozzle selection is also important when trying to reduce drift. One study observed the influence of droplet size on efficacy with Engenia™, Roundup PowerMax®, and Liberty®. Treatments included glufosinate at 594 g ai ha^{-1}, glyphosate at 867 g ae ha^{-1}, dicamba at 560 g ae ha^{-1}, glufosinate plus dicamba, glyphosate plus dicamba, and glufosinate plus glyphosate plus dicamba. The nozzles used included TeeJet (TeeJet Technologies, Springfield, IL) 11004 Turbo TeeJet (TT), Air Induction Extended Range (AIXR), and Turbo TeeJet Induction (TTI) nozzles. The TeeJet TT, AIXR, and TTI 11004 nozzles are designated as producing coarse, extremely coarse, and ultra-coarse droplets at 276 kPa, respectively. The results show that smaller droplets had improved control over larger droplets for glufosinate alone on both monocot and dicot species. As the volumetric mean diameter increased from TT nozzles to the TTI nozzles, efficacy decreased for most treatments. The results also showed that the VMD relative to water decreased for Liberty alone and when tank-mixed with Engenia or Roundup PowerMax. Meyer et al. concluded that nozzle selection will play a key role in maximizing the efficacy of POST applications in dicamba-resistant crops (Meyer et al. 2015).

Proper application technology selection will be a key factor in providing control of the persistent weed problems we face today. The objective of this research was to examine different nozzle types with and without a hooded boom to determine which combination is most effective at reducing physical herbicide drift.

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CHAPTER II

THE COMPARISON OF OFF-TARGET MOVEMENT OF VARIOUS SIZE SPRAY DROPLETS WHEN APPLIED WITH AN OPEN BOOM SPRAYER VERSUS A HOODED BOOM SPRAYER

Abstract

Field experiments were conducted at Brooksville, MS and North Platte, NE, in 2015 and 2016, to compare the drift potential of various size spray droplet profiles from two sprayer types. A Redball® open boom sprayer and a Redball® hooded boom sprayer was used to apply four different droplet sizes: fine, medium, very coarse, and ultra-coarse. Roundup PowerMax and a tracer dye (PTSA dye for NE location; rhodamine dye for MS location) were applied to each treatment, and replicated four times. Mylar cards were placed downwind of the treated area to measure the amount of particle drift for each sprayer and droplet size combination. These data indicate that regardless of droplet size, the use of a hooded boom sprayer decreased the amount of particle drift out to 32 m. The use of a hooded boom can be used as an additional tool for applicators to mitigate drift. The use of a hooded boom alone should not be used as a solution to drift. Proper environmental conditions and good judgement should also be used to minimize physical particle drift.

Nomenclature: glyphosate.

Key words: Drift, herbicide, nozzle selection, sprayer type.

Introduction

The development of transgenic crops has revolutionized the agricultural industry. One of the most popular lines of transgenic crops adopted are glyphosate resistant. Glyphosate resistant crops make up approximately 80% of the total area planted with herbicide-resistant crops as of 2009 (Duke & Powles 2009). The widespread adoption of glyphosate-resistant crops is due to the cost and effectiveness of glyphosate for weed control (Gianessi 2008). Many weed species are susceptible to glyphosate because it is a non-selective herbicide. Many weed species are controlled with fewer properly timed applications. However, since the introduction of glyphosate-resistant crops, there has been very little incorporation of other weed control methods. Two-thirds of the total volume of glyphosate applied since its introduction in 1974 has occurred in the last decade (Meyers et al. 2016). This recent increase in glyphosate use is likely due to increasing use of transgenic crops that allow producers to spray the herbicide in the crop without injury. Regardless of the cause, farmers depend heavily on glyphosate for weed control.

An overdependence on glyphosate and under reliance on multiple weed control methods that has brought about glyphosate-resistant weed species. This overdependence on the glyphosate technology placed high selection pressure on weed populations and has led to weed species that are either poorly controlled by glyphosate or completely resistant to the herbicide (Vencill et al. 2012). There have been multiple accounts of weed species resistant to glyphosate in the U.S. including Palmer amaranth (*Amaranthus palmeri* S. Wats), tall waterhemp (*Amaranthus tuberculatus (Moq.)* Sauer), common ragweed (*Ambrosia artemissifolia L.*), giant ragweed (*Ambrosia trifida L.*), and horseweed

(*Conyza Canadensis (L.)* Cronq.) (Heap 2009). Weeds from the Amaranthus family are some of the most troublesome due to rapid growth rates and prolific seed production. Palmer amaranth reduced corn (Zea mays L.) yields 11 to 91% with 0.5 to 8 plants m^{-1} of row (Massinga et al. 2001) and reduced soybean yield 17 to 68% with 0.33 to 10 plants m^{-1} of row (Klingaman and Oliver 1994). Tall waterhemp has been shown to reduce soybean yields 44% and corn yields 15% with 20 or more plants per 0.1 square meters (Steckel and Sprague, 2004). Results are variable as to how much yield is lost to the pigweed species due to environmental conditions, herbicide application types and timing. One certainty is that the control of resistant weed species such as Palmer amaranth and tall waterhemp will be critical in years to come.

In response to the need for new technology in weed management, scientists have developed crops resistant to two auxin herbicides. This will allow growers to apply auxin herbicides post-emergence for the control of glyphosate-resistant weeds. This will be beneficial because relatively few weeds have evolved resistance to auxin herbicides, despite its widespread use in cereal and non-crop environments going back to the 1940's.

The effectiveness of auxin herbicides creates a problem for applicators in an era of auxin-resistant crops. Research estimates that more than 28 million ha^{-1} will be planted with auxin-resistant varieties by 2025 (Mortensen et al. 2012). This will increase the amount of auxins applied and increase the potential for off-target movement. Off-target movement can occur through many ways such as sprayer contamination, vapor drift and particle drift. These are issues that must be considered in the future.

Studies show that as little as 0.01% of the labelled rate of dicamba can result in observable symptomology and yield reductions of 13 to 42% in soybeans (Griffin et al.

2013; Auch and Arnold 1978; Wax et al. 1969; Steckel et al. 2010). Many of the southern states experienced the movement potential of dicamba in the 2016 growing season. More than 200 official complaints were filed in the mid-south alone. In the upcoming growing season, growers will be allowed to legally spray dicamba over the top of Roundup Ready 2 Xtend soybeans and cotton for weed control. The U.S. Environmental Protection Agency has set forth rules on how to properly apply dicamba such as spray tip selection, wind velocity and direction limitation and ground speed application limits. There may still be a great risk of injury or yield loss to susceptible plants on the farm or adjoining farms.

Because of these concerns, a study was conducted in Brooksville, MS and North Platte, NE in 2015 and 2016 to compare the off-target movement of various spray qualities when applied with an open spray boom versus a hooded spray boom. The objective of this research was to examine different nozzle types with and without a hooded boom to determine which combination is most effective at reducing physical herbicide drift.

Materials and Methods

Experimental Layout

This experiment was conducted at the Blackbelt Research Station in Brooksville, Mississippi and the West Central Research and Extension Center in North Platte, Nebraska in 2015 and 2016. For the Brooksville location, the field was made up of a Brooksville silty clay with 7% sand, 48% silt, 45% clay, pH of 5.7, and 1.59 organic matter. Asgrow 4632 soybeans were planted as the non-dicamba-tolerant soybean variety for both years and locations, except for the 2016 field year in North Platte. A fallow field that was previously planted to corn was used due to the timing of the application in North Platte in 2016. Soybean row spacing was 96 cm for both years and locations. The treated area was 183 m in 2015 for both locations, and 168 m in 2016. The width of the treated area was 5.5 m wide. The layout of the field was one pass (183 m in 2015, 168 m in 2016) down the field with one line of mylar cards placed downwind from the center of the treated area (Figure 2.1). Small mylar cards (52 mm by 72 mm) were placed at positions 2, 4, 6, 14, 30, 43 and 59 m downwind from the treated area and perpendicular to the spray pass. Large mylar cards (104 mm by 144 mm) were placed 73, 89 and 104 m downwind. A small mylar card was placed upwind of the treated area as a control for each replication. Three petri dishes (ø 150mm) were also placed within the treated area.

Herbicide Treatment and Application

Each treatment consisted of glyphosate (Roundup PowerMax®, Monsanto Company, St. Louis, MO) at 1.26 kg ae ha^{-1}, rhodamine dye (Cole-Parmer, Vernon Hills, IL) at 0.2% vv^{-1} for the Brooksville location, and 1 3 6 8-pyrene tetra sulfonic acid tetra sodium salt (PTSA) at 1,321 mgL^{-1} for the North Platte location both years. AI 11002, XR 11002 and XR 11003 nozzles (Teejet Technologies, Springfield, IL) were used to apply the eight treatments. Four treatments were made with a Redball® hooded boom 8 - row sprayer (Wilmar Manufacturing, Wilmar, MN) and a Redball® open boom 8 – row sprayer (Wilmar Manufacturing, Wilmar, MN) calibrated to deliver 141 L ha^{-1} spray volume at 207, 414, and 300 KPa at 8.0, 11.3, and 12.9 kph, respectively (Table 2.1). These tip, pressure, and speed combination were used to produce droplet distributions representing fine (F), medium (M), very coarse (VC), and ultra-coarse (UC) as described by ANSI/ASAE S 572.1 standard (ASABE 2017). The application in Brooksville, MS was on August 12th, 2016. The application for North Platte, NE was on August 3rd, 2015, and August 9th, 2016. The target wind speed for application was between 6.4 to 13 kph. Applications were applied only when the environmental conditions were met within the tolerance ranges for this study. Both sprayers were primed away from the experimental field. Each treatment was replicated four times. The nozzles were 48 cm from the top of the canopy for all locations. Nozzle spacing was 31 cm for each boom at each location.

Data Collection

The meteorological conditions were recorded by an on-site weather station (WatchDog 2000 Series Weather Station, Spectrum Technologies, Aurora, IL) as well as a handheld Kestrel wind meter (Kestrel 3000 Pocket Weather Meter, Kestrel Meters, Minneapolis, MN). Conditions were recorded during the applications, as well as 48 hr after the experiment. These conditions were recorded on 30 sec intervals during the experiment. Mylar cards were collected 2 min after each application to allow sufficient time for deposition of the smaller droplets. To prevent contamination, mylar card collectors replaced gloves after each replication to prevent contamination to the mylar cards during collection. Start time, stop time, wind speed, wind direction, relative humidity and temperature were recorded. The mylar cards and petri dishes were taken to a laboratory to extract and analyze dye concentrations. Reagent alcohol (Fisher Scientific, Fair Lawn, NJ) was diluted with distilled water to a final concentration of 10%. Forty ml of the alcohol solution was added to a bag containing a small mylar card. The bag was vigorously shaken to remove the dye from the mylar card and a 1 ml aliquot was taken and placed in a glass cuvette. Sixty ml of the alcohol solution was added to a bag containing the large mylar cards and petri dishes to wash the dye from the surface. A

1 ml aliquot was taken from the wash solution of the large mylar cards and petri dishes and placed into a glass cuvette. Fluorescence data were collected using a fluorometer (Model T200, Turner Designs) for each location and year.

Logic would dictate that the smallest droplets (Fine) originating from an open boom would have the greatest propensity to drift and thus would represent the worst case scenario of those evaluated. The values obtained from the fluorometer were in relative fluorescence units (RFU). To normalize the data among site-years and dye types, the data were transformed and expressed as a percentage of the RFU value for the "Fine" droplet distributions represents the worst case scenario and was expressed as 100%. All other RFU values were expressed as a percentage of the worst case scenario observed with the "Fine" droplets originating from an open boom.

Two methods were used to analyze the data. In the first method, an asymptotic non-linear regression model was conducted to regress the data over distance of movement. In the second method, the data were subjected to ANOVA to test for main effects and interactions using the agricolae package in R (version 0.98.1091). Where significant effects were observed, means were separated using Fisher's protected LSD test (α=0.05).

The asymptotic non-linear regression model is shown in Equation 2.1.

$$Y = Yasym[1-\exp(-aI/Yasym)] \qquad \text{(Eq. 2.1)}$$

Y = response variable (drift percentage)
I = explanatory variable (distance from boom)
A = (initial slope of the curve at low I values)

Results and Discussion

In the asymptotic model an arbitrary value of 5% was chosen, thus the model predicts the distance at which the dye concentration would be 5% or less of that observed with the "Fine" spray quality from an open boom. The amount of tracer dye was greater for the Redball® open boom sprayer, regardless of droplet size (Table 2.2, Figure 2.2 – 2.5). This model predicts that concentration of dye of 5% or greater would be found to distances of 20, 19, 7, and 8 m for F, M, VC, and UC spray quality, respectively, when applied with an open spray boom. With the Redball hooded boom sprayer 5% or greater concentrations of the dye were found 6, 5, 4, and 0 meters for F, M, VC, and UC spray quality, respectively. The model indicated that the combination of UC spray quality and a Redball hooded boom sprayer resulted in less than 5% of the drift observed with the F spray quality originating from an open boom sprayer at all distances evaluated. Particle drift observed downwind decreased at a greater rate with the incorporation of a hooded boom sprayer, compared to the open boom sprayer. Without the use of a Redball® hooded boom sprayer, 5% solution was found at 8.2 m from the treated area with the UC spray quality.

When analyzed by droplet size with ANOVA, the hooded boom sprayer resulted in less drift than the open boom sprayer at 2 m regardless of spray quality (Table 2.4 and Figures 2.2 – 2.5). When evaluating the worst case scenario of an open boom sprayer with a F spray quality the use of a hooded boom sprayer reduced drift out to 31 m. Similarly, the use of a hooded boom sprayer reduced the movement of M spray quality out to 14 m. As the droplet size became larger the use of the hooded boom sprayer had less of an affect. The VC and UC spray qualities were only reduced with a hooded boom sprayer out to 2 m indicating that the effectiveness of a hooded boom sprayer occurs over greater distances for smaller droplet sizes.

The data shown in Table 2.4 and Figure 2.6 demonstrates the effect of droplet size on drift from an open boom sprayer at each of the evaluation intervals used in this experiment. These data show that droplet size influences movement out to 43 m after which dye concentrations were the same. Although the data show that differences occurred between the F and M spray qualities at three of the evaluation intervals, for the most part they performed similarly. The VC and UC spray qualities did not differ in their performance regardless of the distance evaluated. The VC and UC spray qualities generally had less drift than the M and F spray qualities at all distances out to 43 m. Furthermore, these data would indicate that drift beyond the 34 m buffer requirement for dicamba use in Xtend crops (Unglesbee 2017) is affected little by droplet size. That is not to say that drift is not occurring beyond that distance, but the spray qualities evaluated did not differ beyond that distance. These data clearly demonstrate the effect of spray droplet size on drift where the larger droplets moved less than the F and M spray qualities at distances less than 43 m.

The use of a Redball hooded boom sprayer reduced the drift with the F and M spray qualities to the same as a VC and UC spray qualities, regardless of the distance from the point of application (Table 2.5 and Figure 2.7). These data show that the use of a hooded boom sprayer can result in reduced movement of F and M spray qualities resulting in deposition concentration equivalent to those observed when using VC and UC spray qualities. This corresponds similarly to previous data conducted (Henry et al. 2014)

Conclusion

In conclusion, these data indicate that the incorporation of a hooded boom sprayer can decrease the amount of particle drift, regardless of droplet size. They also show that past 32 m downwind, droplet size is not a factor in the amount of particle drift observed. Interactions between sprayers did play a role in the amount of particle drift. The spray hoods can provide additional drift mitigation concerning particle drift, especially with the auxin herbicides. Proper application techniques, environmental conditions, and good judgement should also be incorporated to ensure particle drift is minimized.

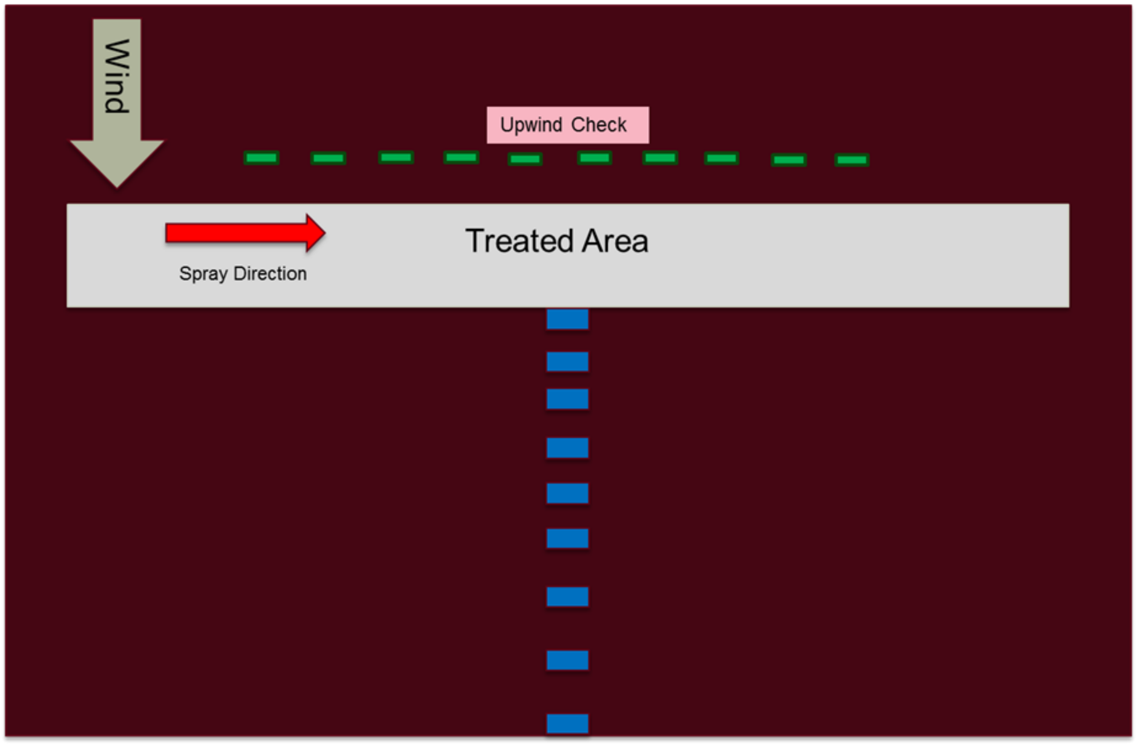

Figure 2.1 Experimental layout for 2015 and 2016 growing seasons in Brooksville, MS and North Platte, NE.

The layout of the field was one pass (183 m in 2015, 168 m in 2016) down the field with one line of mylar cards placed downwind from the center of the treated area. Small mylar cards (52 mm by 72 mm) were placed at positions 2, 4, 6, 14, 30, 43 and 59 m downwind from the treated area and perpendicular to the spray pass. Large mylar cards (104 mm by 144 mm) were placed 73, 89 and 104 m downwind. A small mylar card was placed upwind of the treated area as a control for each replication. Three petri dishes (ø 150mm) were also placed within the treated area.

Table 2.1 Treatment table for sprayer comparison with various spray qualities[a]

Boom type	Nozzle type	kPa	kph	Droplet Size
Open	XR11002	414	11	Fine (F)
Open	XR11003	300	13	Medium (M)
Open	AI11002	414	11	Very coarse (VC)
Open	AI11002	207	8	Ultra-coarse (UC)
Hooded	XR11002	414	11	Fine (F)
Hooded	XR11003	300	13	Medium (M)
Hooded	AI11002	414	11	Very coarse (VC)
Hooded	AI11002	207	8	Ultra-coarse (UC)

[a]Four spray qualities were produced to test variation among sprayer types. Pressure, speed and nozzle type vary to produce the desired droplet sizes.

Table 2.2 Average environmental conditions during experiment comparing a Redball® hooded boom sprayer and a Redball® open boom sprayer[a]

Sprayer	Spray quality[b]	Wind speed[c]	Temperature[d]	Relative humidity[e]
		KPH	C	---- % ----
Open	Fine (F)	12	32	48
Open	Medium (M)	15	33	48
Open	Very coarse (VC)	15	32	49
Open	Ultra-coarse (UC)	15	33	48
Hooded	Fine (F)	13	33	48
Hooded	Medium (M)	15	33	50
Hooded	Very coarse (VC)	14	32	49
Hooded	Ultra-coarse (UC)	15	33	49

[a]These values are averaged over the Brooksville, MS and North Platte, NE locations in 2015 and 2016.
[b]Spray classifications are defined using ASABE S572.1
[c]Wind speeds in kilometers per hour.
[d]Temperature in degrees Celsius.
[e]Relative humidity expressed as a percent.

Table 2.3 Asymptotic non-linear regressional analysis of the normalized data for each treatment.[a]

Sprayer	**Spray quality[b]**	**Asymptote**	**R0[c]**	**LRC[d]**	**DR_5[e]**
Open	Fine (F)	5.87	74.2	-0.61	20.4 (±38) [f]
Open	Medium (M)	4.66	38	-0.72	19 (±30.5)
Open	Very coarse (VC)	3.1	16.7	-0.58	6.8 (±11.1)
Open	Ultra-coarse (UC)	3.45	11.1	-0.663	8.2 (±16.2)
Hooded	Fine (F)	1.68	4.4	-0.7	5.8 (±7.3)
Hooded	Medium (M)	2.5	3.2	-1.3	5.2 (±7)
Hooded	Very coarse (VC)	1.95	5.5	-0.64	4 (±3.6)
Hooded	Ultra-coarse (UC)	0.3744	1.1	-1.5	X[g]

[a]The incorporation of a hooded boom sprayer decreased the asymptote value for all spray qualities compared to the open boom sprayer. The Y-intercept was also found to be less for all spray qualities with the hooded boom sprayer compared to the open boom sprayer.
[b]Spray classifications are defined using ASABE S572.1
[c]Y-intercept
[d]Logarithmic Rate Constant (represents the slope of the line)
[e]DR_5 = distance at which 5% drift is found, expressed as meters downwind from spray boom.
[f]Parentheses represent 95% confidence interval.
[g]5% tracer dye was not found.

Table 2.4 Deposition amounts determined as a normalized percent of the applied rate for each nozzle tested in 2015 and 2016 with a Redball® open boom sprayer and a Redball® hooded boom sprayer.[a]

Droplet Size[b]	Boom	Distance downwind (m)									
		2	4	6	14	31	43	59	73	89	104
Fine (F)	Hooded	18a	9a	7a	4a	2a	2b	2b	1b	1b	1b
	Open	100b	49b	34b	20b	12b	7b	6b	4b	2b	2b
Medium (M)	Hooded	18a	9a	6a	5a	3b	2b	2b	2b	1b	1b
	Open	61b	35b	24b	12b	8b	5b	4b	3b	2b	2b
Very coarse (VC)	Hooded	8a	5b	4b	3b	3b	3b	2b	1b	1b	1b
	Open	19b	10b	9b	6b	4b	3b	3b	2b	2b	2b
Ultra-coarse (UC)	Hooded	4a	3b	2b	2b	2b	2b	1b	1b	1b	1b
	Open	14b	9b	7b	6b	4b	4b	4b	3b	3b	2b

[a]Means followed by the same letter in each column are not different according to Fisher's LSD test at $P \leq 0.05$.
[b]Spray classifications are defined using ASABE S572.1.

Table 2.5 Deposition amounts determined as a normalized percent of the applied rate for each nozzle with the Redball® open boom sprayer.

Droplet Size[b]	Distance Downwind (m)									
	2	4	6	14	31	43	59	73	89	104
Fine	100a[a]	49a	34a	20a	12a	7a	6a	4a	2a	2a
Medium	61b	35a	24b	12b	8a	5a	4a	3a	2a	2a
Very coarse	19c	10b	8b	6c	4bc	3a	3a	2a	2a	2a
Ultra-coarse	14cd	9b	7b	6c	4bc	4a	4a	3a	3a	2a

[a] Means followed by the same letter in each column are not different according to Fisher's LSD test at $P \leq 0.05$
[b] Spray classification are defined using ASABE S572.1.

Table 2.6 Deposition amounts determined as a normalized percent of the applied rate for each nozzle with the Redball® hooded boom sprayer.

Droplet Size[b]	Distance Downwind (m)									
	2	4	6	14	31	43	59	73	89	104
Fine	18a	9a	7a	4a	2a	2a	2a	1a	1a	1a
Medium	18a	9a	6a	5a	3a	2a	2a	2a	1a	1a
Very coarse	8a	5a	4a	3a	3a	3a	2a	1a	1a	1a
Ultra-coarse	4ab	3a	2a	2b	2a	2a	1a	1a	1a	1a

[a] Means followed by the same letter in each column are not different according to Fisher's LSD test at $P \leq 0.05$.
[b]Spray classifications are defined using ASABE S572.1.

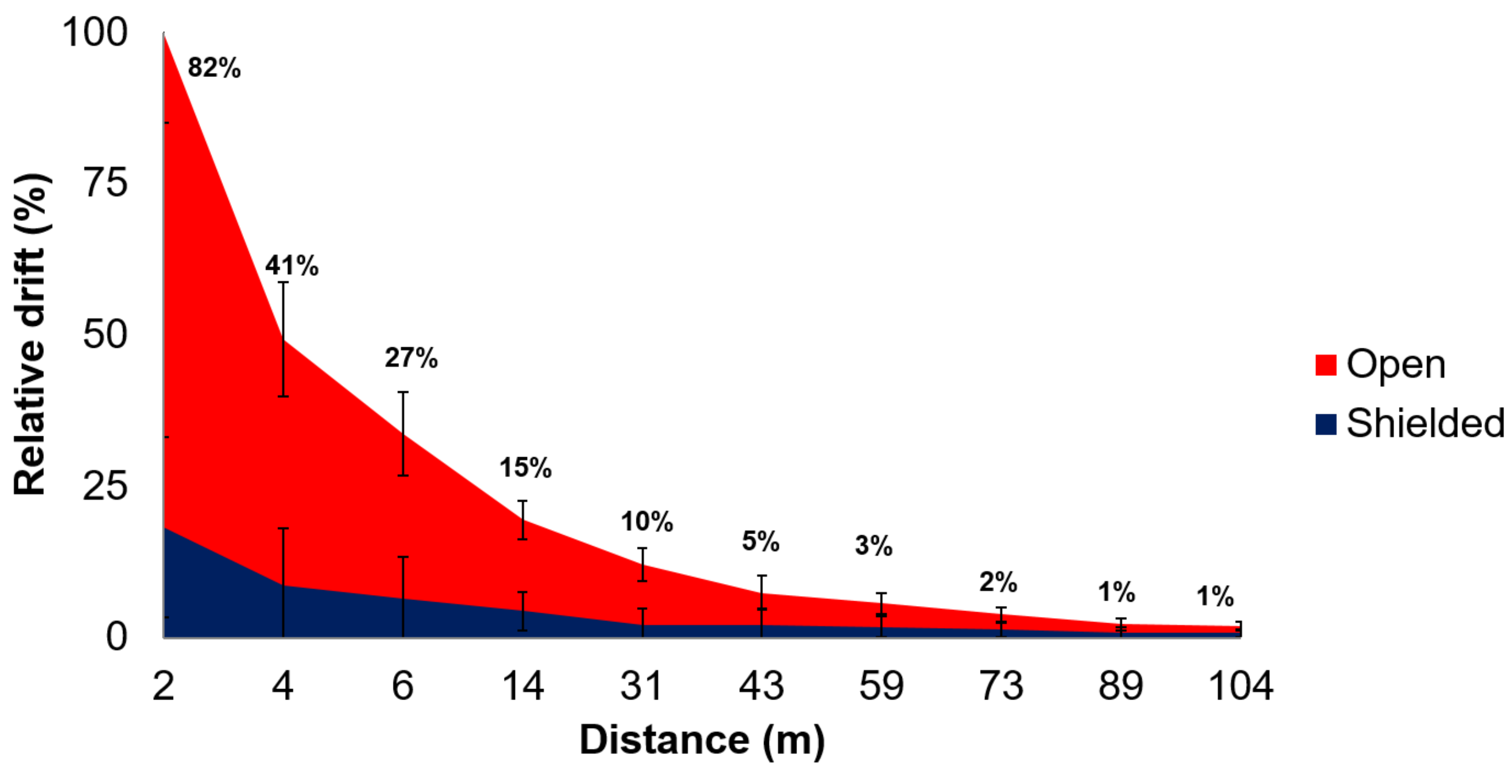

Figure 2.2 Distance to where there is no difference using a Fine spray quality applied with a Redball® open boom sprayer and a Redball® hooded boom sprayer.

Data were subjected to ANOVA to determine interactions between sprayer types at each distance. The percent difference can be seen at each distance. The drift values are relative to the most extreme drift value found in the experiment (Fine spray quality at 2 m). Wind speeds of 12 kph were observed with the open boom sprayer and 13 kph for the hooded boom sprayer.

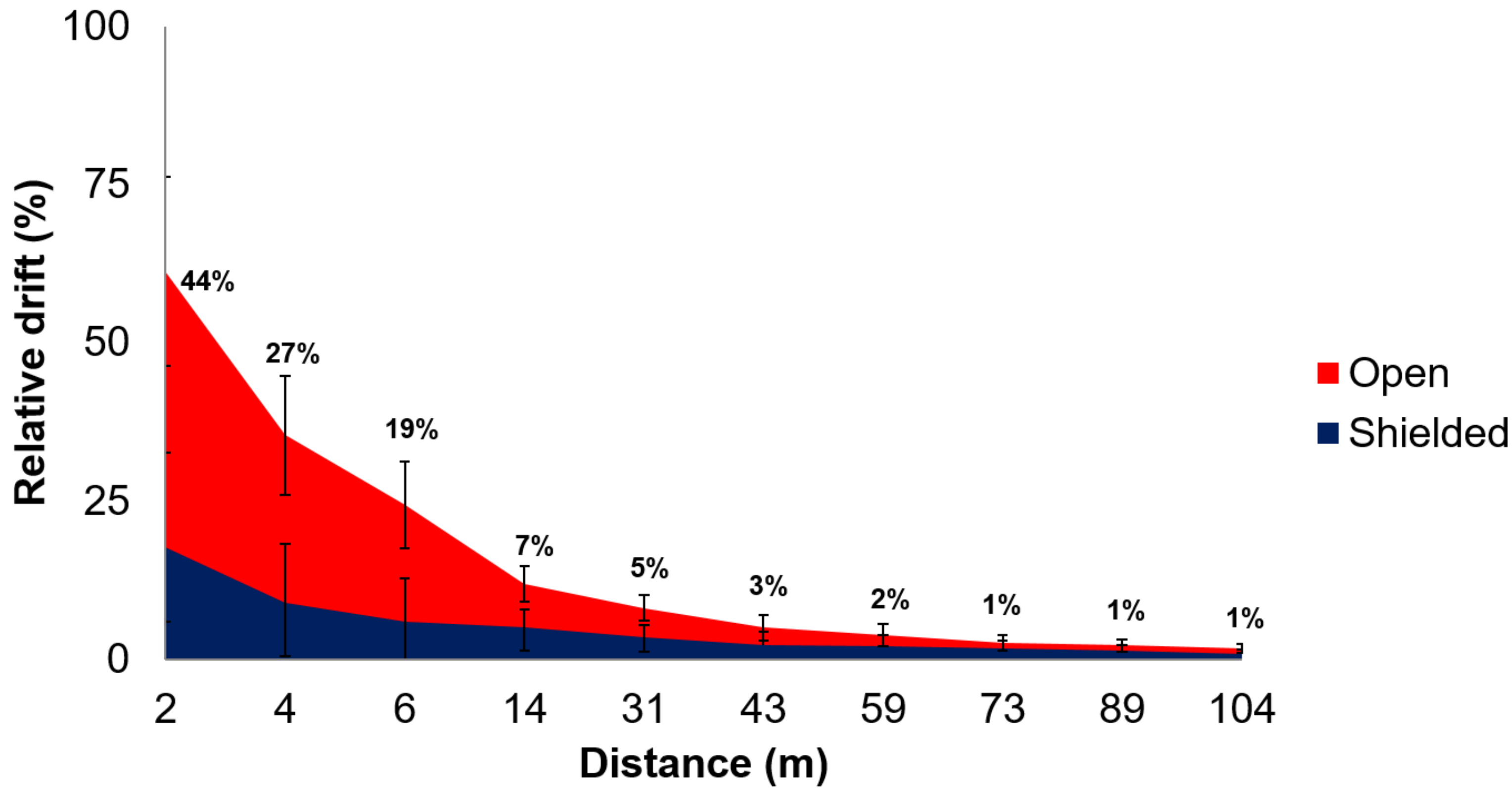

Figure 2.3 Distance to where there is no difference using a Medium spray quality applied with a Redball® open boom sprayer and a Redball® hooded boom sprayer.

Data were subjected to ANOVA to determine interactions between sprayer types at each distance. The percent difference can be seen at each distance. The drift values are relative to the most extreme drift value found in the experiment (Fine spray quality at 2 m). Wind speeds of 15 kph were observed with the open boom sprayer and 15 kph for the hooded boom sprayer.

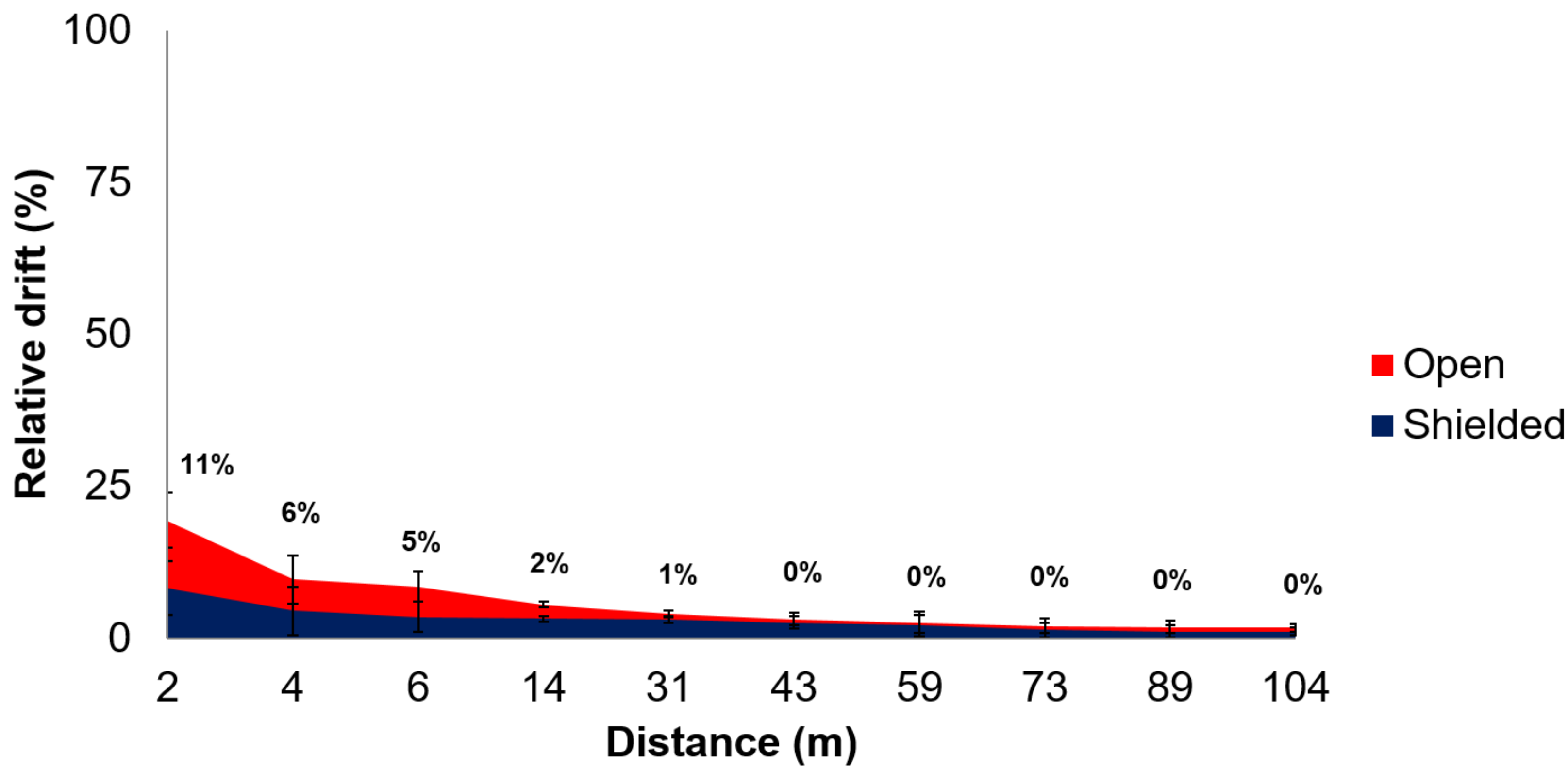

Figure 2.4 Distance to where there is no difference using a Very coarse spray quality applied with a Redball® open boom sprayer and a Redball® hooded boom sprayer.

Data were subjected to ANOVA to determine interactions between sprayer types at each distance. The percent difference can be seen at each distance. The drift values are relative to the most extreme drift value found in the experiment (Fine spray quality at 2 m). Wind speeds of 15 kph were observed with the open boom sprayer and 14 kph for the hooded boom sprayer.

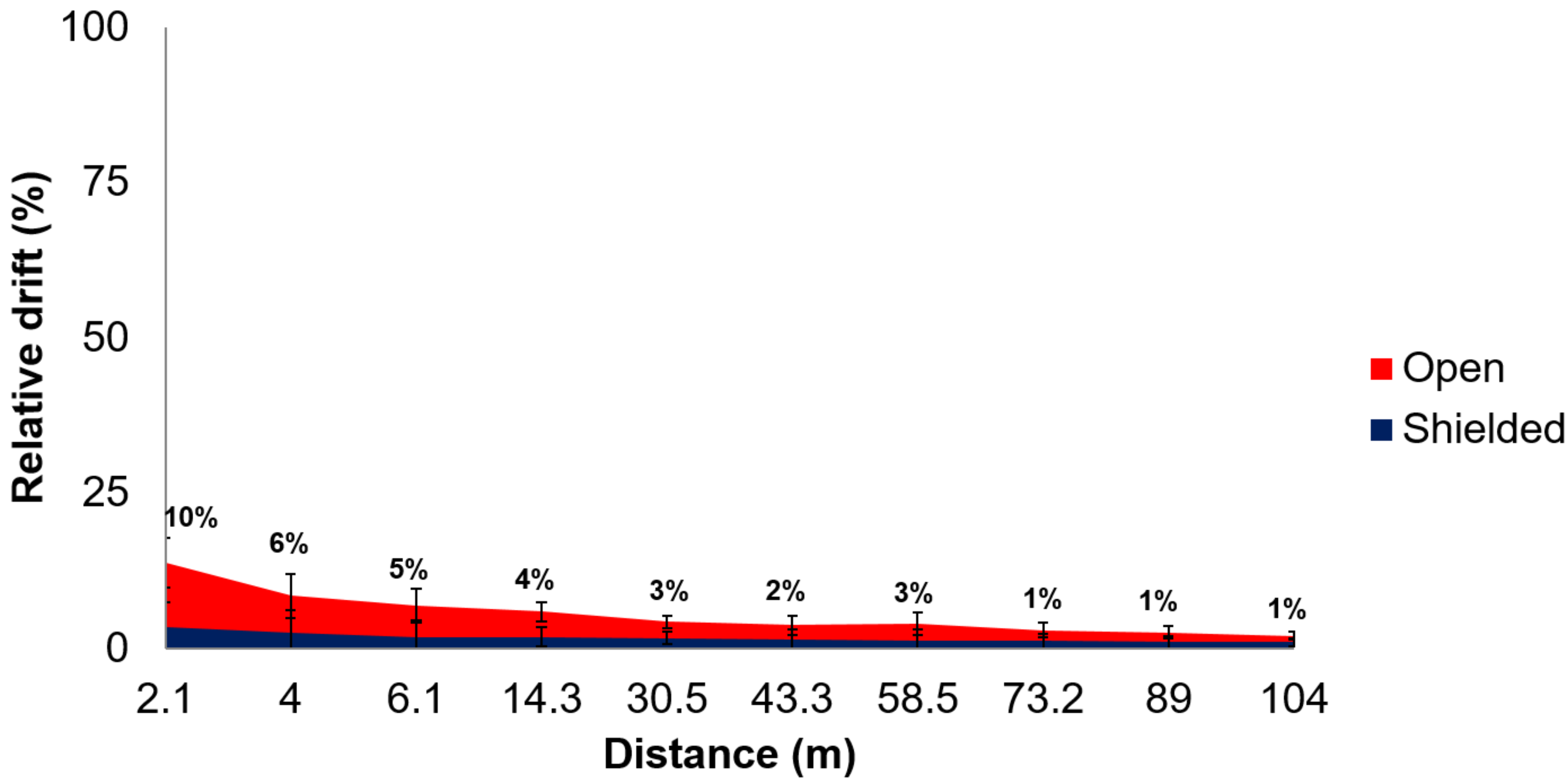

Figure 2.5 Distance to where there is no difference using an Ultra-coarse spray quality applied with a Redball® open boom sprayer and a Redball® hooded boom sprayer.

Data were subjected to ANOVA to determine interactions between sprayer types at each distance. The percent difference can be seen at each distance. The drift values are relative to the most extreme drift value found in the experiment (Fine spray quality at 2 m). Wind speeds of 15 kph were observed with the open boom sprayer and 15 kph for the hooded boom sprayer.

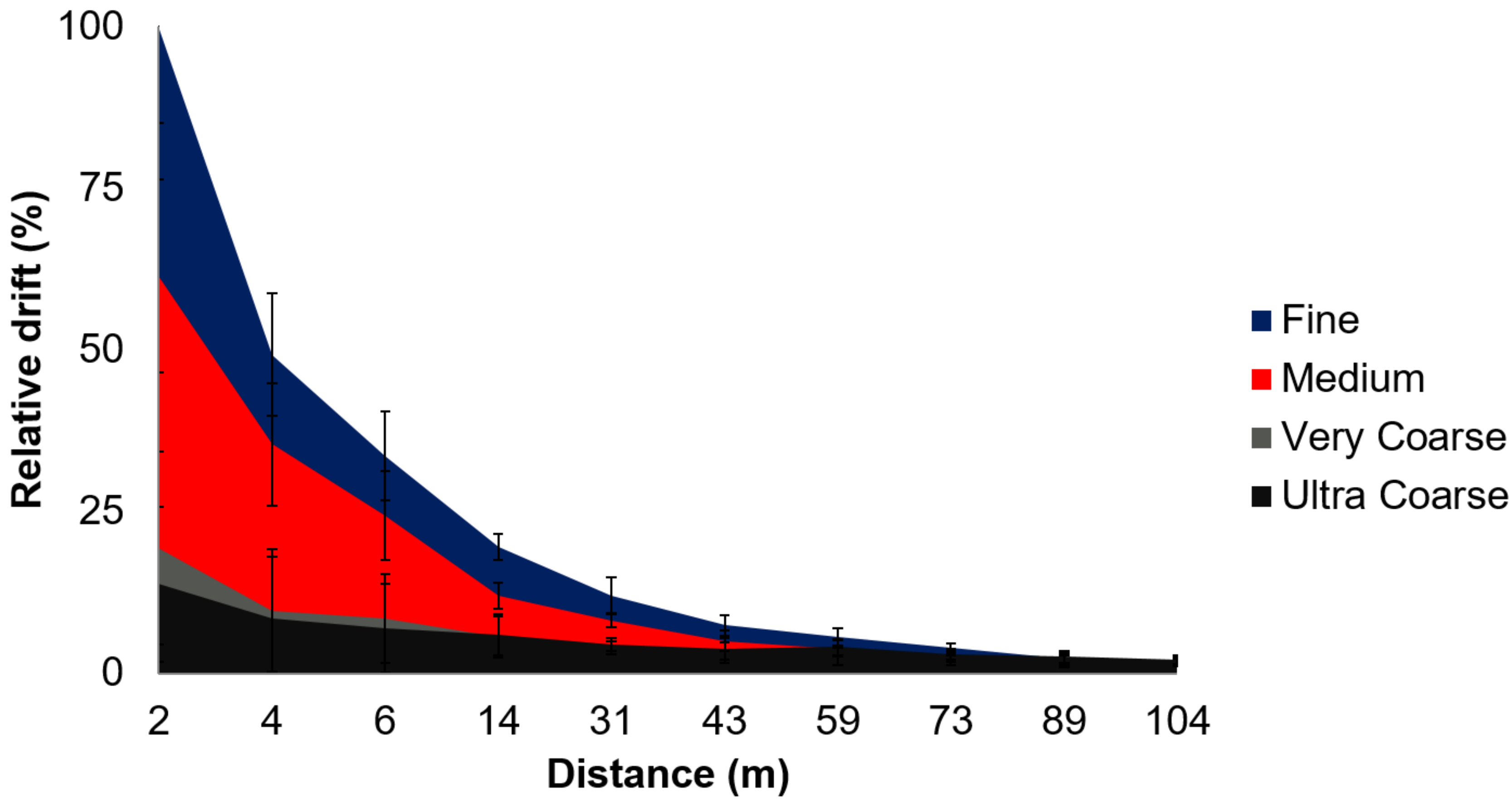

Figure 2.6 Comparison of Fine, Medium, Very Coarse, and Ultra-Coarse droplets with a Redball® open boom sprayer.

Data were subjected to ANOVA to determine interactions between sprayer types at each distance. The percent difference can be seen at each distance. The drift values are relative to the most extreme drift value found in the experiment (Fine spray quality at 2 m).

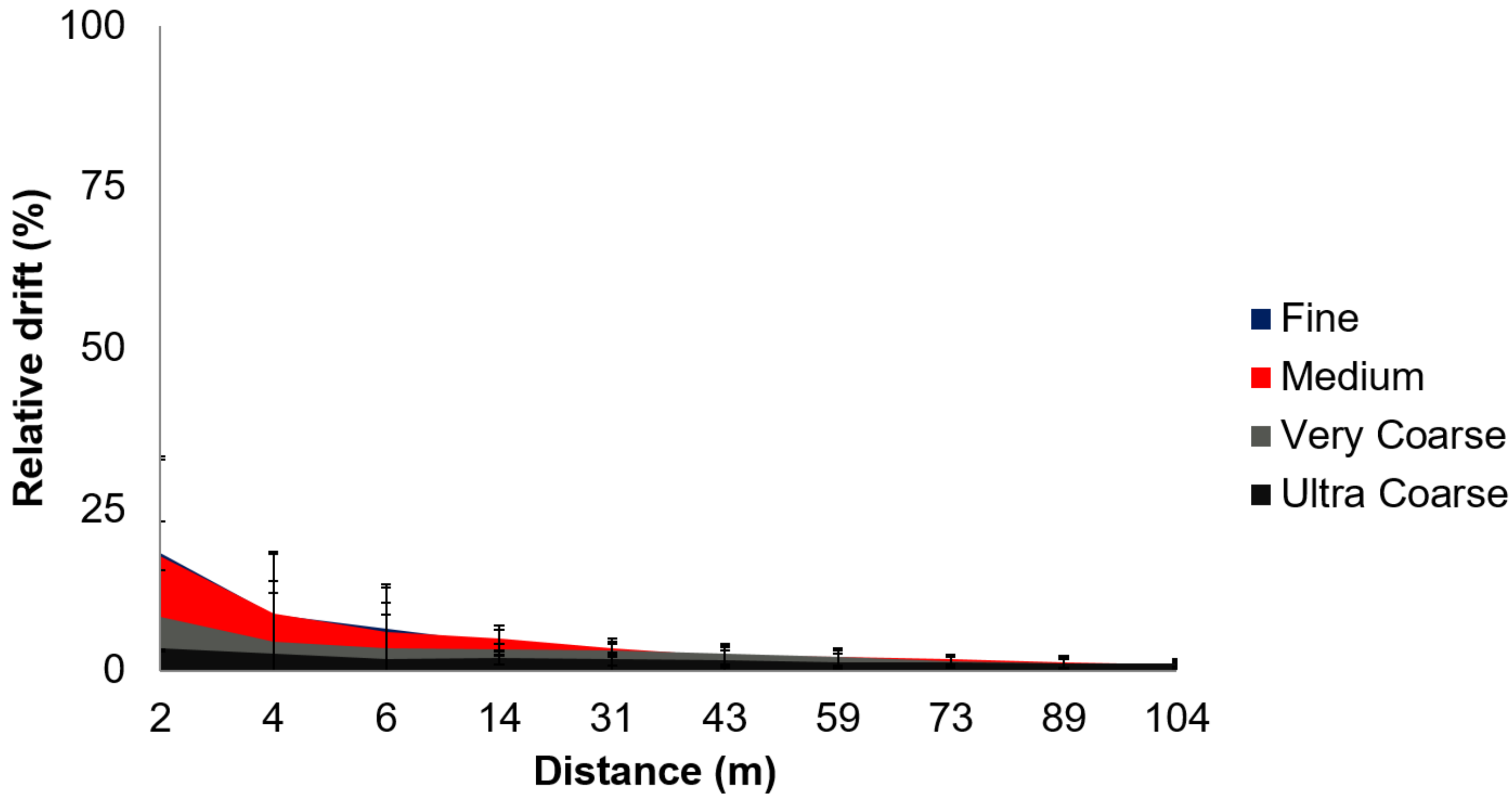

Figure 2.7 Comparison of Fine, Medium, Very Coarse, and Ultra-Coarse droplets with a Redball® hooded boom sprayer.

Data were subjected to ANOVA to determine interactions between sprayer types at each distance. The percent difference can be seen at each distance. The drift values are relative to the most extreme drift value found in the experiment (Fine spray quality at 2 m).

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