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Evaluation of herbicide formulation and spray nozzle selection on physical spray drift

By

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Evaluation of herbicide formulation and spray nozzle selection on physical spray drift

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New transgenic crops are currently being developed which will be tolerant to dicamba and 2,4-D herbicides. This technology could greatly benefit producers who are impacted by weed species that have developed resistance to other herbicides, like glyphosate-resistant Palmer Amaranth. Adoption of this new technology is likely to be rapid and widespread which will lead to an increase in the amount of dicamba and 2,4-D applied each season. It is well-documented that these herbicides are very injurious to soybeans, cotton, tomatoes, and most other broadleaf crops, and their increased use brings along increased chances of physical spray drift onto susceptible crops. Because of these risks, research is being conducted on new herbicide formulation/spray nozzle combinations to determine management options which may minimize physical spray drift.

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CHAPTER I

INTRODUCTION

The implementation of biotech crops in agriculture has greatly impacted the global agricultural world. As of 2013, 175.2 million hectares were planted globally in 27 different countries. This is a 100-fold increase compared to the 1.7 million hectares planted in biotech crops in 1996. Also, the data indicate biotech crop usage has resulted in $116.9 billion in economic gains from 1996 to 2012. It is estimated that 58% of these gains came from reduced production costs and 42% from yield increases (James, 2013). One of the most significant developments is agricultural technology has been the introduction of glyphosate-tolerant crop varieties. Adoption of this technology was rapid because it provided a simple, effective, and environmentally safe weed management strategy resulting in decreased costs generally associated with controlling weed populations (Duke and Powles, 2009). However, in spite of the many benefits of glyphosate tolerant crops, it has also brought about one of the most significant problems facing agriculture today, glyphosate-resistant weeds. Weed species developing herbicide resistance did not begin with the introduction of herbicide-tolerant crops. However, over-reliance on glyphosate as the primary tool for weed control and the lack of incorporating herbicides with other mechanisms of action (MOA) into weed management strategies placed high levels of selection pressure on weed populations. This led to the increase in weed species that were either poorly controlled by glyphosate or completely resistant to the herbicide (Vencil et al., 2012). Some of the most troublesome glyphosate-resistant weeds in the United States are the broadleaf species tall waterhemp (*Amaranthus tuberculatus*), horseweed (*Conyza canadensis*), and Palmer amaranth *(Amaranthus palmeri*). A relatively new addition to most trouble weed species list, Palmer amaranth is now one of the most economically harmful glyphosate-resistant weeds (Beckie, 2006). In order to control many of these resistant weed species, it is prudent to incorporate multiple MOA into a weed management plan. Using multiple herbicide chemistries as tank mix partners can also help reduce the occurrence of resistance development when compared to using the same chemistries in rotation (Powles et al., 1997). A recent study shows the potential for incorporation of auxin herbicides, such as dicamba and 2,4-D, into a producer's herbicide arsenal. One particular study showed increased control of both resistant and non-resistant weed biotypes was achieved when applying dicamba alone and in combination with glyphosate (Johnson et al., 2010). A large number of plant species, both crop and non-crop, are also susceptible to damage from these auxinic herbicides.

In response to the need for new tools to manage herbicide resistance, new crop cultivars have been developed which are tolerant to 2,4-D or dicamba herbicides. The dicamba tolerant technology was first discovered by scientists at the University of Nebraska - Lincoln. They found that a certain soil bacterium *Pseudomonas maltophilia,* contains the enzyme dicamba monooxygenase (DMO) which is capable of mineralizing dicamba into the inactive compound 3,6-dichlorosalicylic acid (DCSA). Scientists were then able to genetically engineer the DMO gene and insert it into a plant allowing it to metabolize dicamba molecules. This provided dicamba tolerance in plant species like tobacco and soybean, which are normally susceptible to dicamba injury (Behrens, et al., 2007). After discovery, Monsanto Co. purchased the rights to use this new technology to develop new crop species tolerant to applications of dicamba. This technology is expected to be released in 2015 in their Roundup Ready Plus Xtend System™. Dow AgroSciences is also developing genetically modified crops capable of metabolizing 2,4-D as part of their new Enlist™ cropping system. By incorporating this new technology, producers will be able to apply herbicides with different MOA's and thereby attack and better manage resistant weed populations. However, because of the sensitivity of many plant species to auxin herbicide chemistry, these technologies also bring their own challenges as well. Issues like off target movement of the herbicides due to physical spray and vapor drift and sprayer hygiene will have to be addressed. Dow, Monsanto, and other chemical companies are also working to produce new herbicide formulations to be released in conjuction with the seed technology in order to help mitigate problems of off-target movement.

The purpose of this research is to better understand factors associated with herbicide drift. Concerns over environmental and human health, as well as the effectiveness of spray applications, have contributed to the need for additional research to be conducted in this area. Spray drift can occur with any pesticide application. The Environmental Protection Agency, EPA, defines drift as "the physical movement of pesticide droplets or particles through the air from the target site to any non-target site". A target site is simply defined as the desired area to be treated, while a non-target site is any area not intended for treatment. This occurs during or soon after application. While theoretically herbicide drift could reduce the effectiveness of the initial application, the greatest concern is potential harm to sensitive species neighboring areas as well as potential environmental contamination. Drift has long been a part of agricultural spray applications, and it is becoming even more of a concern as technology continues to advance. Increases in the number of acres planted in herbicide tolerant crops also bring increased likelihoods of incidences involving herbicide drift. As a result of drift, both money and time could be lost. Producers could suffer yield loss due to drift injury, and if the impact is too severe, they would be forced to replant and follow label replanting interval restrictions. There is also the risk of drawn-out, expensive lawsuits. One specific incident in Arkansas occurring in 2006 took over three years to be resolved and resulted in millions of dollars being lost (Schierholz, 2010; Universal vs. AAC). Because of the inherent risks involved, it is essential to fully understand why and how drift occurs in order to effectively combat it.

Research shows three main factors influence herbicide drift. These are the size of the spray droplet, application height, and the environmental conditions under which application occurs. Droplet size is important because small droplets of spray remain in air for longer periods of time than large droplets, making them more susceptible to off-target movement. Droplets are found to be subject to drift if they have a diameter of 100-200 micrometers (Guler, et al., 2007, Wolf, et al., 1993). Increased spray pressure and speeds can cause a reduction in spray droplet size (Hewitt, et al., 2009). Droplets that are smaller in size also fall at a slower rate, exposing them to more wind and evaporation before contact with the target. This can cause a further reduction in droplet size, making them even more susceptible to off target movement. Droplet size is a factor when determining which type of herbicide to spray. Contact herbicides generally are more effective with a larger coverage area of smaller droplets, while systemic herbicides can be just as effective with fewer, larger droplets. The viscosity of the pesticide being used can also affect the size of droplets produced. Thicker formulations generally result in larger droplets (Fishel and Ferrell, 2010).

The height of the boom above the target can also be an important factor of herbicide drift because it directly impacts the amount of time the pesticide will be exposed to the environment. Applications with ground equipment can be done with the boom height one to two feet over the top of a crop, and this height can be lowered with the use of spray tips with a wider spray discharge angle. However, these wider orifices produce smaller spray droplets, which are more susceptible to drift. This makes it necessary to find the right balance between nozzle selection and boom height when applications are being made. Shielded booms used to apply herbicides can reduce the amount of drift from the sprayer by 65% to 85% when compared to the same spray tips without a shield (Wolf, et al., 1993). The height of the spray boom is a bigger concern in aerial applications, when the sprayer is generally eight feet or higher above the canopy (Fishel and Ferrell, 2010). A past study performed by the Spray Drift Task Force compared the drift potential of aerial applications made at three different heights. They found the potential for herbicide drift up to 198 m increased as height increased. The highest spray release height, 9.0 m, had the greatest potential for drift beyond this distance. The remaining heights tested, 2.5 m and 5.0 m respectively, showed no difference in the potential for drift beyond 198 m (Hewitt, et. al, 2002).

The final factor, and probably the primary cause, of herbicide drift is environmental conditions at the time of application. Specifically, wind speed and direction primarily control the extent of spray drift. Greater wind speeds result in higher levels of drift (Wolf, et. al, 1993). Typically, the maximum wind speed acceptable for herbicide applications is ten miles per hour. A gentle wind is desirable during application. In stagnant conditions, temperature inversions can form and result in severe cases of off target movement of spray particles. Normally, air temperature decreases with altitude above the earth surface. Temperature inversions occur when this is reversed, and the cooler air is trapped close to the ground. These are common conditions which generally are seen early in the morning. These conditions can cause small droplets to remain suspended in the air until the inversion subsides, which could be after the pesticide has moved a substantial distance away from the target area (Fishel and Ferrell, 2010). Some air movement will prevent an inversion and minimize the likelihood of drift. Since spray droplets are carried by the wind, drift can occur only downwind of the target area. However, the wind can quickly change from blowing in a safe direction to blowing toward sensitive areas without the operator being aware. Low humidity levels can also increase off-target movement of spray particles by reducing droplet size through evaporation (Thistle, 2004). Because herbicide drift is greatly influenced by environmental conditions beyond human control, it is up to the operator to make wise decisions in order to minimize drift. Most herbicide labels state the applicator should be familiar with local weather conditions and potential for off-target herbicide movement.

There are some factors, however, which can be managed in the effort to minimize drift. Many developments, such as spray nozzles, precision applicators, and new herbicide formulations, have been made in order to reduce the amount of drift that occurs. Some of these new technologies are addressed in our current studies. The first would be the type of nozzle used during an application and how it affects herbicide drift and performance. One of the most significant improvements in controlling the size of droplets produced by sprayers is the production of drift reduction nozzles. These are designed to produce larger droplets at similar rates and pressure compared to standard nozzles without changing carrier volume (Ramsdale and Messersmith, 2001). The nozzles to be tested in this study use air induction and pre-orifice designs in order to increase droplet size. These drift reducing nozzles have been shown to have exit orifices up to 2.75 times larger than other tips with the same labeling. This means that an 8002 air induction nozzle produces larger droplets than a standard 8002 nozzle. By operating conventional nozzles at lower pressures, droplet characteristics similar to those of drift reducing nozzles can be achieved when the orifice size is equal (Guler, et al., 2007). Increasing droplet size does cause some concern in the overall performance of the herbicide. Past studies have shown that the percentages of droplets produced by venturi nozzles that are likely to drift are much less than that of standard nozzles. Only 17% of droplets produced by venturi nozzles were likely to drift compared to 65% of those produced by standard nozzles. The distribution of the spray particles produced by these drift reducing nozzles was much more inconsistent, which could reduce the efficacy in controlling weed populations. Spray droplet size was also found to be affected by the type of herbicide used. Droplet sizes for paraquat, glyphosate, and glufosinate were 470 µm, 460 µm, and 400 µm, respectively (Etheridge, et. al, 1999). Studies show that the effects of nozzle types on efficacy are varied in regards to herbicide. In some instances, no differences were found in herbicide efficacy when comparing different products. Weed control using paraquat, glyphosate, and glufosinate has been shown to be similar when comparing conventional and drift reducing nozzles. Paraquat and glyphosate also showed increased control when applied at 5 GPA versus 20 GPA (Brown, et. al, 2007; Ramsdale and Messersmith, 2001). On the other hand, conventional flat fan nozzles provide better control of some weed species with bromoxynil, dicamba, nicosulfuron, and quizalofop-p-ethyl when compared to air induction nozzles. These results were found to be specific to certain weed species (Brown, et. al, 2007; Sikkema, et. al, 2008).

As previously mentioned, the rapid adoption of new technologies, specifically herbicide tolerant crops, will allow herbicides to be applied over large acreages at a time. In some cases, these applications will occur at times and locations when sensitive crops are being grown in the same area. This will increase the likelihood that herbicide drift incidences onto adjacent, non-tolerant crops may occur. There have been numerous studies to show how simulated drift levels can affect crop growth and yield. One such study examined the effects of simulated drift rates of glyphosate and glufosinate on soybeans and cotton. There were five herbicide treatments ranging from 12.5 to 0.8% of usage rates of 1,120 g ai/ha and 420 g ai/ha for glyphosate and glufosinate, respectively. In general, only the two highest rates showed visual injury and reductions in heights. By the end of the season, both crops had recovered from the injury and yields remained unaffected when compared to the untreated check (Ellis and Griffin, 2002). In one experiment, drift of the herbicide 2,4-D in its ester formulation caused cotton yield reductions ranging from 59% to 100% over a two year period when applied at a range of 1/400 to 1/100 of a normal rate of 561 g ae/ha. Similar results were found in applications made with the 2,4-D amine formulation. While some injury was seen when dicamba was applied to cotton at these rates, no reduction in yield was observed (Marple, et. al, 2007).

In a similar study, cotton yields were reduced by simulated drift rates of 2,4-D and dicamba depending on dosage and application timing. (Everitt and Keeling, 2009).

Recent studies performed at Mississippi State University examined different application rates and timings of 2,4-D and dicamba herbicides applied in soybean. As expected, soybean treated with dicamba exhibited greater visual injury as well as higher reductions in plant heights and yield compared to 2,4-D. Treatments consisted of several different rates of both herbicides, beginning with 0.56 kg ae/ha (1X rate) down to 2.19 x 10^{-3} kg ae/ha (1/256X rate) for the 2,4-D and 5.5 x 10^{-4} kg ae/ha (1/1024X rate) of dicamba. Soybean plants showed over 30% visual injury when treated with dicamba at the 1/256X rate, while 2,4-D at this same amount produced less than 10% visual injury symptoms. Soybean yield, averaged over rates were reduced by 11 and 18% when treated with 2,4-D in the vegetative and reproductive growth stages respectively. Yield reductions were increased in plots treated with dicamba, with losses of 41 and 46% for plots sprayed at the vegetative and reproductive stages of development, respectively. In regards to application timing, soybean yield reductions due to dicamba were found to be the greatest when the herbicide was applied at the late vegetative to early reproductive stages of growth (Blaine, et. al, 2014; Blaine, et. al, 2014). These results support those of Auch and Arnold (1978), who also found significant soybean yield reductions when treated with simulated dicamba drift rates at the early bloom stages compared to early vegetative and late bloom stages.

Damage due to herbicide drift can also have an additive effect on crop injury from labeled in season herbicide applications. Applications of nicosulfuron/rimsulfuron with dicamba/diflufenzopyr made in corn have been shown to result in 5% to 9% visual injury. This is increased to 59% when applications follow simulated glyphosate drift (Brown, et. al, 2009). A similar study was performed in soybeans in which chlorimuron-ethyl, imazethapyr, or bentazon was applied following simulated dicamba/diflufenzopyr drift. When the dicamba and diflufenzopyr were applied alone injury was increased, and both plant heights and yields decreased as drift rates of the herbicides increased. In some locations, soybean injury was increased when these drift rates were followed by applications of the labeled postemergence (POST) herbicides. POST applications did not cause further decreases in plant height. Only plots treated with applications of chlorimuron-ethyl following the simulated drift applications showed yield reductions greater than what was expected (Brown, et. al, 2009).

Because of these risks research is being conducted to determine different management options that may minimize physical spray drift. Current research will examine different nozzle types as well as formulation/spray tip combinations to see which most effectively reduce direct physical herbicide drift.

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CHAPTER II

EVALUATION OF SPRAY NOZZLE SELECTION ON DICAMBA DRIFT EFFECTS WHEN APPLIED UNDER FIELD CONDITIONS

Abstract

New transgenic crops are currently being developed by Monsanto which will be tolerant to applications of dicamba herbicide. This technology could greatly benefit producers who are impacted by weed species that have developed resistance to other herbicides, like glyphosate-resistant Palmer Amaranth. Increased use of dicamba herbicide brings along an increased chance for occurrences of physical spray drift onto susceptible crops. In 2012, an experiment was designed to evaluate off-target deposition of dicamba when applied with these tips under wind speeds of 8 to 16 kilometers per hour (KPH). The experiment was conducted in Brooksville, MS, Jackson, TN, Keiser, AR, and Scott, MS. The two treatments consisted of a comparison of off-target movement of MON 76754 when applied at 1.5 lbs ae/A with 11004 AI and 11004 TTI nozzles calibrated to deliver 140 L/ha. MON 76754 is a premix of 320 g ae dicamba with 160 g ae glyphosate per liter of product. Each treatment was replicated three times. Non-transgenic soybean were utilized as a bio-indicator because of their sensitivity to dicamba. Treatments were applied to soybean at the V5-V6 stage of growth. At 28 DAT, the distances beyond which visual injury dropped below 5% were up to 55 meters and 33 meters for the AI and TTI treatments, respectively. The distance to “no-effect” on plant height was up to 22 meters from the treated area edge for both AI and TTI tips. Soybean yield was reduced out to 11 and 12 meters with the TTI and AI spray tips, respectively. These data indicate that malformation can be observed a considerable distance downwind from an application of dicamba. They also show that plant height may be reduced at moderate distances from the treated area. However, even where visual estimates of injury and plant heights were reduced, yields were not reduced beyond 12 meters from the treated area. Additional data are needed to allow the development of buffer restriction relative to applications around sensitive species.

Nomenclature: Dicamba; glyphosate; soybean, *Glycine max* L Merr.

Key Words: Herbicide, segmented regression, visual injury, yield.

Introduction

The introduction of genetically modified crops, particularly those tolerant to glyphosate, revolutionized the agricultural industry. Recent data show 175.2 million hectares of biotech crops were planted in 2013. This is a 100 fold increase compared to the 1.7 million hectares planted in biotech crops in 1996, the introductory year of glyphosate tolerant crops (James, 2013). Since then, Roundup Ready® cropping systems gained momentum throughout the world as a simple, effective, and relatively environmentally-safe weed management tool which also decreased weed control cost (Duke and Powles, 2009). In spite of the benefits gained by employing glyphosate tolerant technology, overuse of this technology has created one of the most significant problems facing agriculture today, the control of glyphosate-resistant weeds. While herbicide resistance did not begin with the introduction herbicide-tolerant crops, the over-reliance on glyphosate technology and the failure to incorporate herbicides with other mechanisms of action (MOA) into weed management strategies placed high levels of glyphosate-specific selection pressure on weed populations. Because of this, the number of weed species that were either poorly controlled by glyphosate or completely resistant to the herbicide increased (Vencil et al., 2012). In the United States, some of the most troublesome broadleaf weed species resistant to glyphosate applications are tall waterhemp (*Amaranthus tuberculatus*), horseweed (*Conyza canadensis*), and Palmer amaranth (*Amaranthus palmeri*). Although it is a relatively new addition to the most troublesome weed species list, Palmer amaranth has rapidly become one of the most economically harmful glyphosate-resistant weeds in many cropping systems (Beckie, 2006). In order to control many of these resistant weed species, herbicides with multiple MOA's must be incorporated into a weed management plan. Using multiple herbicide chemistries as tank mixes can help reduce the development of herbicide resistance when compared to using those chemistries in rotation (Powles et al., 1997). One study shows the potential for the inclusion of auxin herbicides into a producer's herbicide arsenal. Increase in the control weeds both resistant and non-resistant was achieved when applying dicamba alone and in combination with glyphosate (Johnson et al., 2010).

In response to the need for new tools to manage herbicide resistance, new cropping systems are being produced which will include cultivars with tolerance to 2,4-D and dicamba herbicides. In particular, Monsanto is currently producing crops which will be tolerant to applications of both glyphosate and dicamba. By incorporating this new technology, producers could apply numerous MOA's to help control and reduce the impact of resistant weed populations. However, because of the susceptibility of many plant species to injury from dicamba, this technology will bring its own set of challenges.

The potential for damage caused by herbicide movement off target due to physical spray and vapor drift as well as the lack of sprayer hygiene are issues that will have to be addressed. Studies performed at Mississippi State University in 2012 and 2013 examined the effects of different application rates and timings of 2,4-D and dicamba in soybean. More significant visual injury symptoms were observed in soybean plots treated with dicamba as well as significantly higher soybean height and yield reductions compared to plots treated with 2,4-D. Treatments consisted of various rates of both herbicides, beginning with 0.56 kg ae/ha (1X rate) down to 2.19 x 10^{-3} kg ae/ha (1/256X rate) for the 2,4-D and 5.5 x 10^{-14} kg ae/ha (1/1024X rate) of dicamba. Soybean plants showed over 30% visual injury when treated with dicamba at the 1/256X rate, while 2,4-D at this same amount produced less than 10% visual injury symptoms. Soybean yield, averaged over rates were reduced by 11% and 18% when treated with 2,4-D in the vegetative and reproductive growth stages respectively. Yield reductions were more significant in plots treated with dicamba, with losses of 41% and 46% for plots sprayed at the vegetative and reproductive stages of development, respectively. In regards to application timing, soybean yield reductions due to dicamba were found to be the greatest when the herbicide was applied at the late vegetative to early reproductive stages of growth (Blaine et. al, 2014; Blaine et. al, 2014). These results support those found in previous studies showing significant yield reductions in soybeans treated with dicamba during flowering compared to those treated pre-flowering (Auch and Arnold,1978; Wax et al., 1969).

Spray droplet size is also a major factor to consider concerning physical spray drift. (Guler, et al., 2007, Wolf, et al., 1993). Increased spray pressure and speeds can cause a reduction in spray droplet size (Hewitt, et al., 2009). To combat this, spray nozzles which produce coarse to very coarse spray droplets are likely to be required when using these new technologies.

Because of these concerns, a study was conducted in 2012 to evaluate the potential for off-target deposition of dicamba when applied with two spray nozzle types under field conditions. The objective of this experiment was to quantify the effect of spray nozzle selection on dicamba drift when applied through commercial application equipment. In addition we also aimed to estimate the distances to no plant effects on plant height and yield from large scale dicamba spray applications for various locations.

Materials and Methods

Experimental Layout

These experiments were conducted in Brooksville, MS, Scott, MS, Jackson, TN, and Keiser, AR. Non-dicamba tolerant soybean were utilized as a bio-indicator for herbicide drift because of their sensitivity to dicamba. Soybeans were planted between April 12, 2012 and May 29, 2012 at the various locations. Two treatments were used in this study, each being replicated three times giving a total of six treated plots per location. The treated plots were located on the upwind side of the field (Fig. 2.1) and measured 30 meters long. Only one sprayer pass was made during this experiment, so the width of the treated area was dependent upon the width of the spray boom on the sprayer used at each location. The treated area widths were 18 meters for the Brooksville, Scott, and Jackson locations and 8 meters for the Keiser location (Table 2.1). A 30 meter buffer area was left between treated areas to prevent contamination between treatments. Herbicide drift effects were measured in the downwind portion of the field. Untreated check plots were set up on the upwind side of each treated plot. A diagram of this experimental design can be seen in Figure 2.1.

Herbicide Treatment and Application

The two treatments used in this study consisted of the same herbicide mixture applied with different spray nozzle types. The herbicide used in this study was a tank-mix of MON 76754 and Interlock drift retardant®. MON 76754 is an experimental formulation of 320 g ae glyphosate plus 160 g ae dicamba per liter of product. MON76754 was applied at a rate of 3.5 L/ha mixed with Interlock® at 0.29 L/ha. The herbicide was applied with Turbo Teejet® Induction Flat Fan Spray Tips (TTI) and Teejet® Air Induction Flat Spray Tips (AI) with an orifice size of 04. The spray solution was delivered in a volume of 140 L/ha at all locations. Target soybean growth stage for herbicide application was in the late vegetative stages of development. Soybeans were in the V5 stage of growth at the Brooksville and Jackson locations at the time of application. At the Scott location, soybeans were split between V5 and V6 growth stages at application, and soybeans at the Keiser location were at V6 to V7 growth stages. Ground speeds during application were 14.8, 14.8, 14.6 and 12.8 KPH for Brooksville, Scott, Keiser, and Jackson, respectively. Spray boom height was 51 cm above the crop canopy. Target wind speeds for application were between 10 to 16 KPH at an angle perpendicular to the treated area edge. The spray boom was primed at a remote location before approaching the test area. When wind speed and direction reached the specified thresholds, the herbicide application was made to allow the treatment to drift onto the downwind portion of the field.

Data Collection

A weather station[1] was on site for each location to collect data during and after application. Weather stations were set to record on one minute intervals during treatment application and for the subsequent 48 hours. Wind speed ranges as well as average wind speeds are provided in Table 2.2. As previously mentioned, ratings were taken in the downwind portion of the field. Eight rating transects were designated for each treated area, with four adjacent to the downwind edge of the treated area and two on each end. Rating plots measured 7.6 meters in length and four rows wide (Figure 2.2). Ratings were taken on the center two rows of each rating plot. Visual plant injury ratings and plant heights were collected 14 and 28 DAT out to distances from the treated area edge where visual injury was not observed. Rating criteria for soybean with 15% injury were plants that showed an evident cupping effect along leaf margins of the upper expanded leaves, as well as a distorted appearance on the newest axillary buds below the terminal. Little effect on plant heights were seen in these plants. Criteria for plants with 5% visual injury were soybean plants with obvious curling of the tip of the most recently emerged trifoliate. Yield data were collected using a two-row plot combine to assess any potential herbicide yield effects. Yield plots measure 6 meters long and 2 meters wide. Yield was taken at each rating transect at distances of 2, 6, 10, 14, 18, 34, 48, 64, and 80 meters from the treated area edge.

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[1] Watchdog 2700 Weather Station. Spectrum Technologies, Inc. 3600 Thayer Court, Aurora, IL 60504

Statistical Methods

The average of the eight rating plots for a given distance, treatment, and rep are used as the response for analysis for visual injury and plant height. The exception to this was the Keiser location for which, due to larger deviation in wind direction, a cosine distance correction and differing plot selection based on wind direction was used. Visual injury data were analyzed with a linear regression of visual injury using the log of the distance value. This method fits a log linear relationship between percent visual injury and distance. By doing this, the distances for which injury drops below 15% and 5% can be identified. A segmented regression, or piecewise regression technique was used to analyze effects on plant heights and yield due to herbicide drift. This method has been shown to be effective in determining thresholds and edge effects (Toms and Lesperance, 2003). Sometimes called "broken-stick" models, this technique joins two lines at unknown points, or hinge points. The first line, having a positive trend, represents distances which were affected by dicamba drift. This line rises to a second, horizontal line or "plateau", which would represent distances with no treatment effects. The hinge point between the two lines estimates a distance to treatment effects. A traditional analysis of variance (ANOVA) was also performed on yield data in order to determine any differences between soybean yields at given distances from the treated swath edge.

Results and Discussion

Analysis of the visual injury ratings showed that the distances at which percent visual injury fell below 15% using AI tips at 14 DAT were 16, 7, 18, and 9 m for the Brooksville, Scott, Keiser, and Jackson locations, respectively (Table 2.3). These distances were 23, 11, 23, and 11 m for the respective locations using TTI spray tips. At the 28 DAT rating, the distances at which percent visual injury fell below 15% were 18, 3, 55, and 5 m with AI tips and 24, 6, 33, and 9 meters with TTI tips for Brooksville, Scott, Keiser, and Jackson, respectively. The distances at which percent visual injury fell below 5% at 14 DAT were 51, 41, 71, and 21 m for the Brooksville, Scott, Keiser, and Jackson locations, respectively. These distances were 60, 49, 76, and 22 m for the respective locations using TTI spray tips. At the 28 DAT rating, the distances at which percent visual injury fell below 5% were 57, 43, 76, and 26 m with AI tips and 69, 49, 76, and 26 m with TTI tips for Brooksville, Scott, Keiser, and Jackson, respectively. Visual plant injury regression curves for 14 and 28 DAT can be seen in Figures 2.3 and 2.4, respectively, from the Brooksville, MS location. Figures 2.5 and 2.6 show the visual injury regression curves for 14 and 28 DAT, respectively from the Scott, MS location. A summary of the distances to 15% and 5% visual injury for all locations can be seen in Table 2.3.

When looking at the visual injury results, there is no obvious trend present. However, interesting observations can be made when looking at different variables in the data. For instance, the Keiser location had similar ground speeds to both the Brooksville and Scott locations as well as lower average wind speeds, yet it produced the greatest level of drift in regards to visual injury. It can be noted that the soybeans were at a later growth stage (V6-V7) compared to the other locations (V5). As previously mentioned, research conducted at Mississippi State University has shown greater soybean sensitivity to dicamba at late vegetative to early reproductive stages of growth (Blaine, et. al, 2014). This could help explain the greater levels of injury seen at the Keiser location, as the soybeans may have been more susceptible to dicamba damage. If you look at the data from the other test locations, all of which had soybeans in or around the V5 growth stage, a wind speed effect can be seen with greater wind speeds increasing the distances at which dicamba drift effects were observed. The Jackson location produced the lowest distances at which dicamba drift effects were observed. This location had the slowest wind speed. It can also be noted that this location also used the slowest application speed as well, which could have added to the reduced drift effects. Previous research has shown an increase in sprayer speed does result in increased spray drift, while slower application speeds can reduce the level of spray drift (Nuyttens et.al, 2007; van de Zande et. al, 2005). It was also found that the effect of increased sprayer speeds on spray drift were not able to be overcome by using a low-drift type nozzle (van de Zande et. al, 2005).

Reductions in plant heights due to dicamba drift using AI tips were seen out to 55, 12, and 13 m 14 DAT at the Brooksville, Scott, and Jackson locations, respectively (Table 2.4). Reductions in plant height due to dicamba drift using AI tips were not detectable at the Keiser location at 14 DAT. At 14 DAT, distances to no drift effects with TTI nozzles on plant height were 51, 15, 22, and 10 m for the Brooksville, Scott, Keiser, and Jackson locations, respectively. At the 28 DAT rating, the distances to no drift effects on plant height were 22, 14, and 11 m with AI tips and 22, 14, and 6 m with TTI tips for Brooksville, Keiser, and Jackson, respectively. Reductions in plant height were not detectable at the Scott location 28 DAT. Segmented regression analysis of the 14 and 28 DAT rating timings for the Brooksville location are shown in Figures 2.7 and 2.8. Segmented regression analysis of the 14 and 28 DAT rating timings for the Scott location are shown in Figures 2.9 and 2.10 (Table 2.4). Yield reductions due to dicamba drift were not detectable with AI tips at the Brooksville, Scott, and Jackson locations. The distance to no drift effect on soybean yield at the Keiser location was 12 m away from the treated area edge using AI spray tips. Yield reductions due to dicamba drift were not detectable with TTI spray tips at the Brooksville, Keiser, and Jackson locations. The distance to no drift effect on soybean yield at the Scott location was 11 m away from the treated area edge using TTI spray tips. Segmented regression analysis for soybean yield data at the Brooksville and Scott locations are shown in Figures 2.11 and 2.12, respectively. Distances to "no effects" on plant height and yield for all test locations can be seen in Table 2.4.

Conclusions

In conclusion, these data indicate that visual plant injury can be observed a considerable distance downwind from an application of dicamba. They also show that plant height may be reduced at moderate distances from the treated area. However, even where visual estimates of injury and plant heights reductions were observed, yields were not reduced beyond 12 m from the treated area edge. These data suggest a difference in drift potential based on nozzle selection as well. Distances beyond which visual injury dropped below 15% and 5% were numerically less for treatments applied with AI nozzles when compared to TTI nozzles at each experimental location, 14 DAT. Wind speed also seemed to play a role in determining dicamba drift effects on soybean injury and plant heights. Data collected showed a roughly three KPH increase in wind speed between the Brooksville and Jackson locations almost doubled the 28 DAT distance to 5% injury and the distance to "no effects' on plant height with both AI and TTI nozzles. Additional data are needed to allow the development of buffer restriction relative to applications around plant species sensitive to dicamba. This experiment shows the potential for future issues concerning off-target movement of dicamba herbicide. Proper application techniques as well as appropriate decision making are essential in order to minimize the effects of physical spray drift on sensitive plant species.

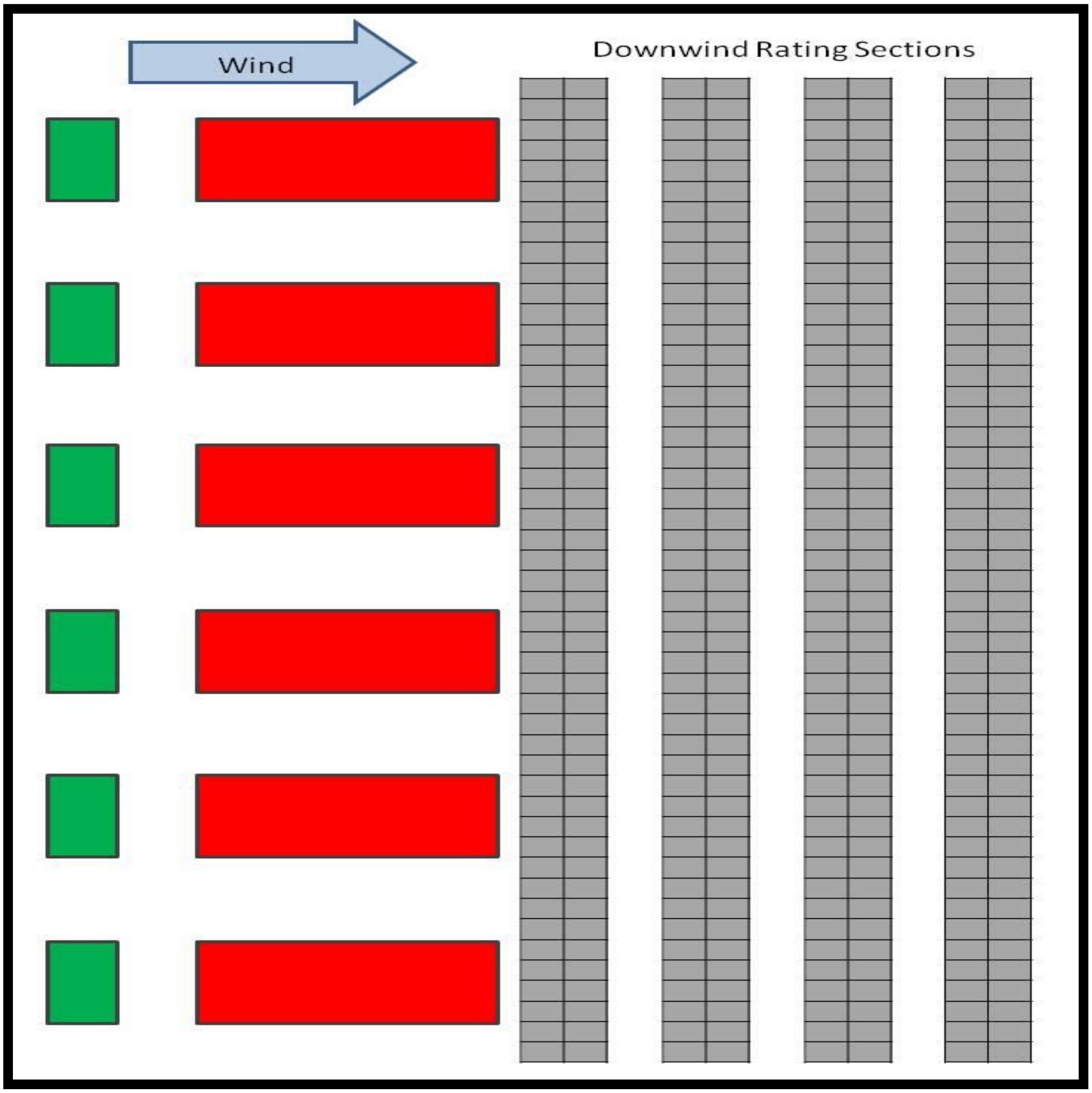

Figure 2.1 2012 Dicamba drift experimental layout for the Brooksville and Scott, MS locations.

Treated areas are designated in red. Sprayer direction moved from the treated area at the bottom of the figure upwards, and wind direction moving from left to right. Check plots are designated in green on the upwind side of treated area. Data were collected downwind of the treated areas. Ratings were taken in four row increments away from the treated area until no visible dicamba injury symptoms were observed.

Table 2.1 Experimental information for 2012 drift trial locations

	Location			
	Brooksville	**Scott**	**Keiser**	**Jackson**
Variety[b]	Asgrow 4907	Asgrow 4703	Asgrow 4303	Asgrow 4632
Planting Date[c]	4/24/12	4/12/12	5/14/12	5/29/12
Row Spacing (cm)[d]	96 single	96 twin	96 single	76 single
Application Date[e]	5/22/12	5/25/12	6/22/12	7/5/12
Growth Stage[f]	V5	V5-V6	V6-V7	V5
Tips[g]	AI/TTI	AI/TTI	AI/TTI	AI/TTI
L/ha[h]	140	140	140	140
Speed (KPH)[i]	14.8	14.8	14.6	12.8
Boom Height (cm)[j]	51	51	51	51
Boom Width (m)[k]	18	18	8.6	18
Plot Length (m)[l]	30	30	30	30

[a] Soil type for drift trial locations
[b] Soybean variety planted at drift trial locations
[c] Soybean planting date for drift trial locations
[d] Soybean row spacing expressed in centimeters
[e] Date of treatment application
[f] Soybean growth stage at the time of application
[g] Spray nozzles used in experiment (AI = Teejet® Air Induction ; TTI = Turbo Teejet® Induction)
[h] Application carrier volume expressed in liters per hectare
[I] Application ground speeds expressed in kilometers per hour
[j] Applicator boom height expressed as centimeters above crop canopy
[k] Applicator boom width expressed as meters.
[l] Treated area length expressed as meters

Table 2.2 Recorded wind speeds for 2012 dicamba drift trial locations

	Location			
Wind Speed[b]	**Brooksville**	**Scott**	**Keiser**	**Jackson**
	------------------------------- (KPH[c])			-------------------------------
Minimum	6.1	3.2	0	4.7
Maximum	13.8	11.3	11.4	11.4
Average	9.9	8.7	8	6.8

[a] Data collected using 2000 Series WatchDog® Weather Station.
[b] Minimum, maximum, and average wind speeds recorded during treatment application.
[c] Wind speeds expressed as kilometers per hour.

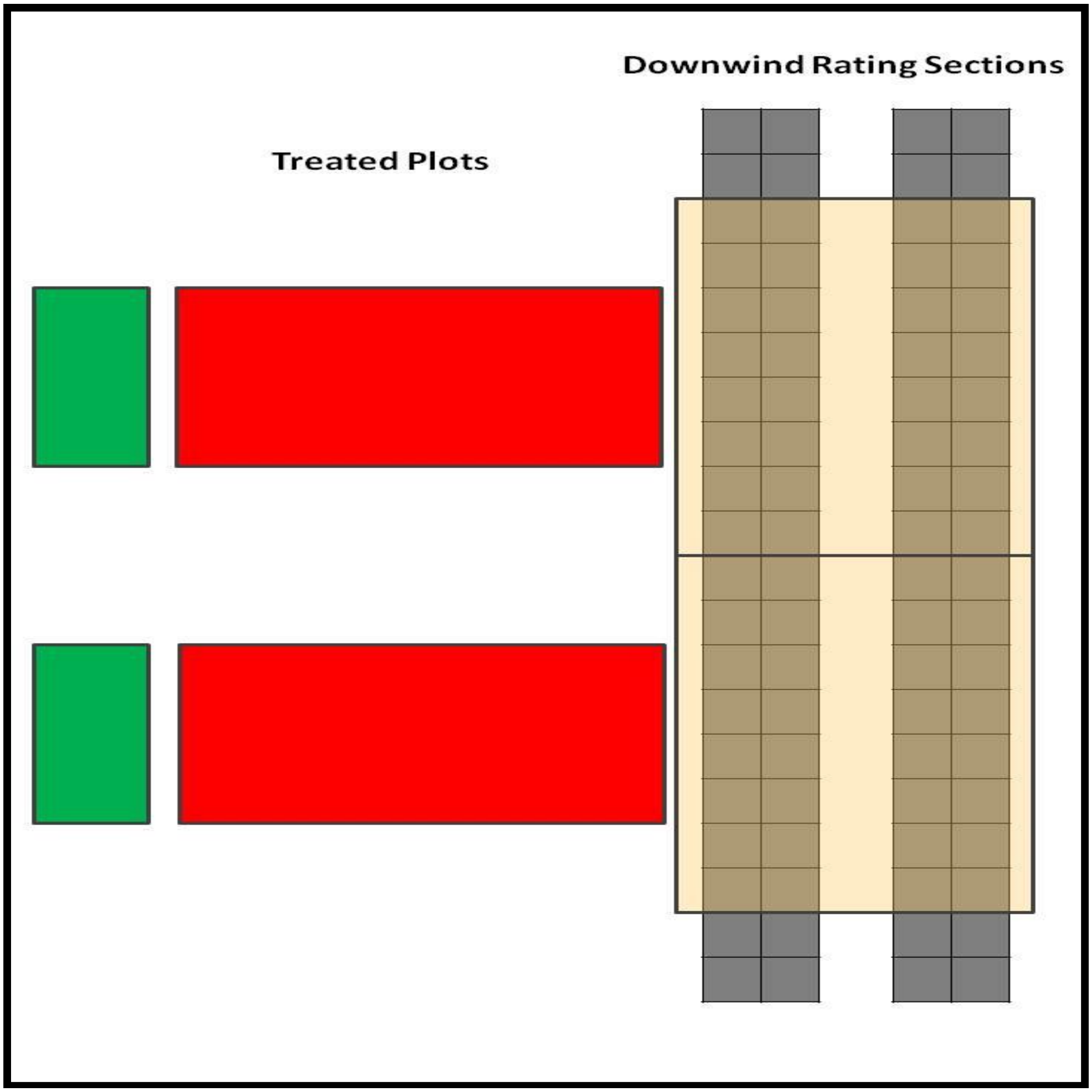

Figure 2.2 Rating transect designations for treated areas.

Wind direction is from left to right. Treated areas are designated in red. Untreated check plots designated in green are located on the upwind side of the treated areas. Eight rating transects were designated to each treated area with four transects located adjacent to treated area edge and two additional transects located on either end.

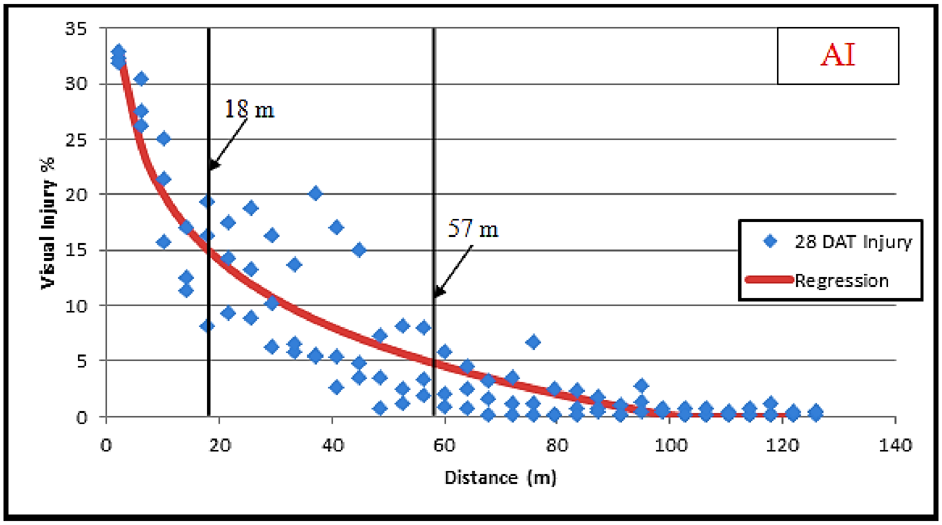

Figure 2.3 28 DAT visual injury regressions for Brooksville, MS.

This graph represents results using Teejet Air Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect averaged over replication at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

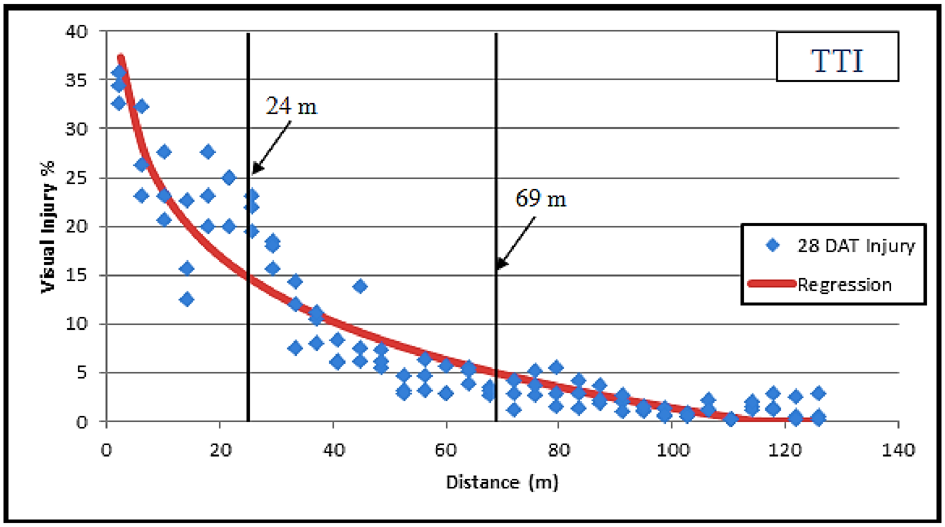

Figure 2.4 28 DAT visual injury regressions for Brooksville, MS.

This graph represents results using Turbo Teejet Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect averaged over replication at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

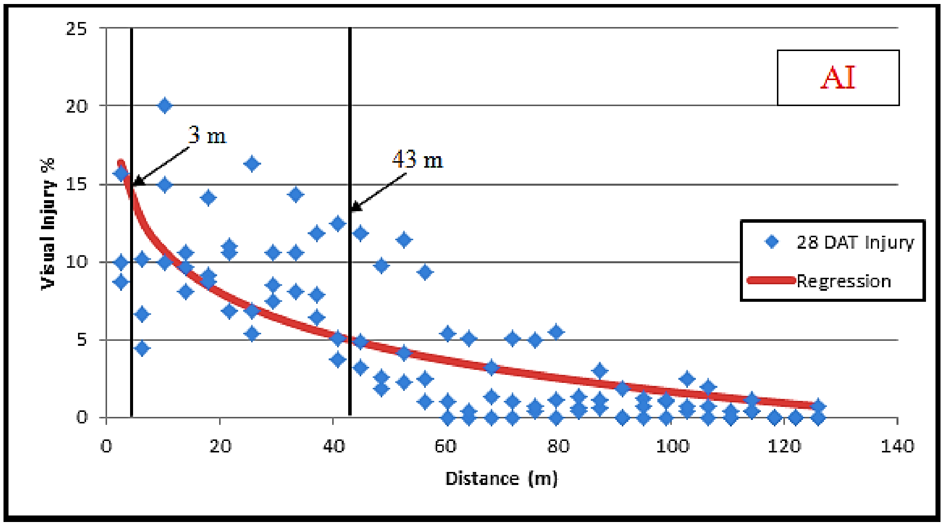

Figure 2.5 28 DAT visual injury regressions for Scott, MS.

This graph represents results using Teejet Air Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect averaged over replication at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

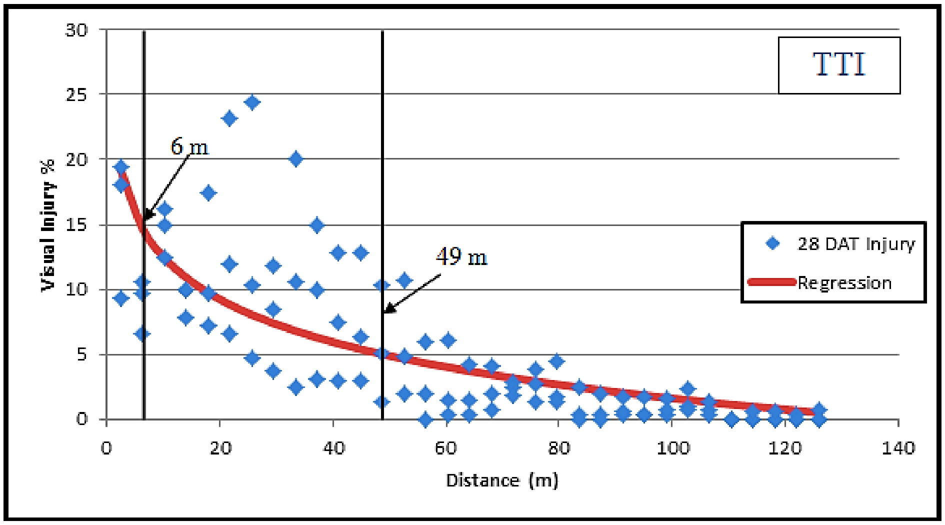

Figure 2.6 28 DAT visual injury regressions for Scott, MS.

This graph represents results using Turbo Teejet Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect averaged over replication at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

Table 2.3 Results summary table of visual injury regressions as a log function of distance.

Location	Nozzle	15 % Visual Injury[a]		5% Visual Injury[b]	
		14 DAT[c]	28 DAT	14 DAT	28 DAT
		------------------------(meters)[d]------------------------			
Brooksville	AI[e]	16	18	51	57
	TTI[f]	23	24	60	69
Scott	AI	7	3	41	43
	TTI	11	6	49	49
Keiser	AI	18	55	71	76
	TTI	23	33	76	76
Jackson	AI	9	5	21	26
	TTI	11	9	22	26

[a] Estimated distance beyond which visual injury levels dropped below 15%

[b] Estimated distance beyond which visual injury levels dropped below 5%

[c] Days after treatment

[d] Distance from treated area edge expressed in meters

[e] Results from areas treated with Teejet® Air Induction spray nozzles

[f] Results from areas treated with Turbo Teejet® Induction spray nozzles

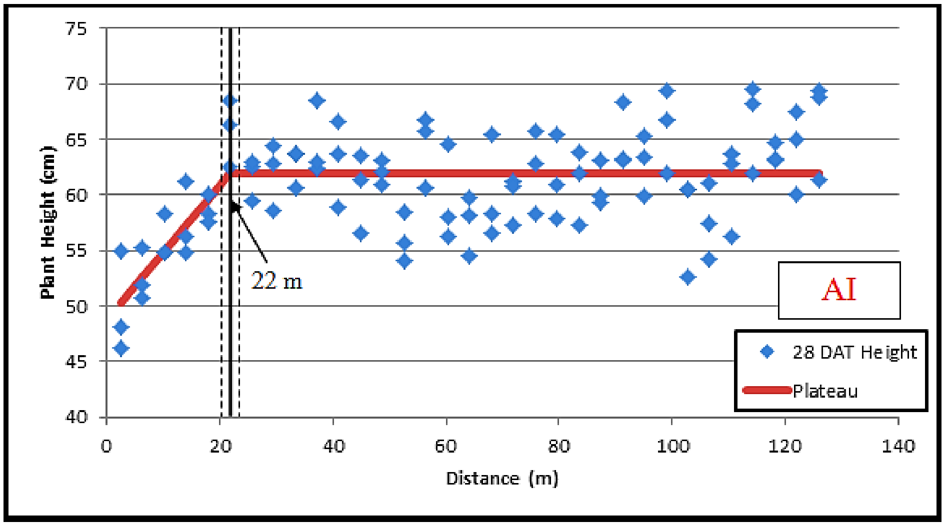

Figure 2.7 28 DAT segmented regression of soybean heights for Brooksville, MS.

This graph represents results using Teejet Air Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean height (expressed in centimeters) measured from each rating transect averaged over replication at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to “no dicamba effect” on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

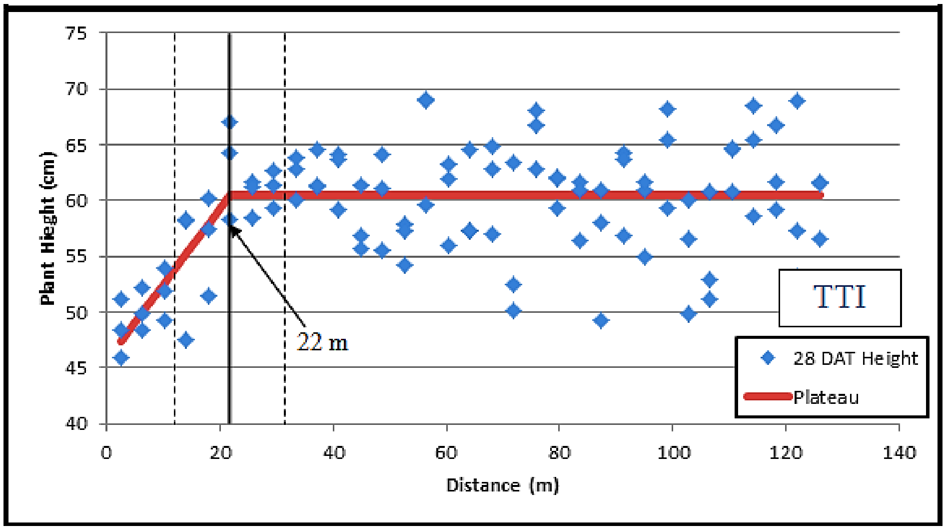

Figure 2.8 28 DAT segmented regression of soybean heights for Brooksville, MS.

This graph represents results using Turbo Teejet Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean height (expressed in centimeters) measured from each rating transect averaged over replication at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to "no dicamba effect" on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

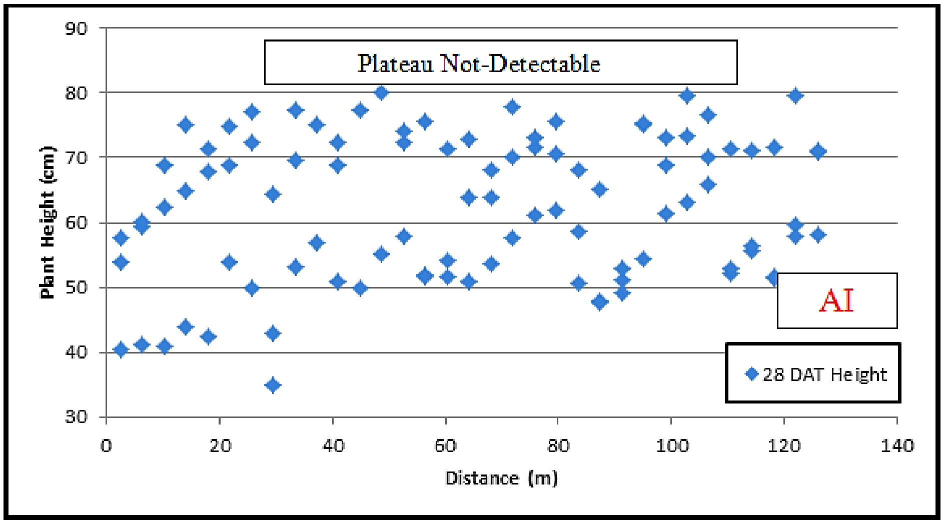

Figure 2.9 28 DAT segmented regression of soybean heights for Scott, MS.

This graph represents results using Teejet Air Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean height (expressed in centimeters) measured from each rating transect averaged over replication at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to "no dicamba effect" on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

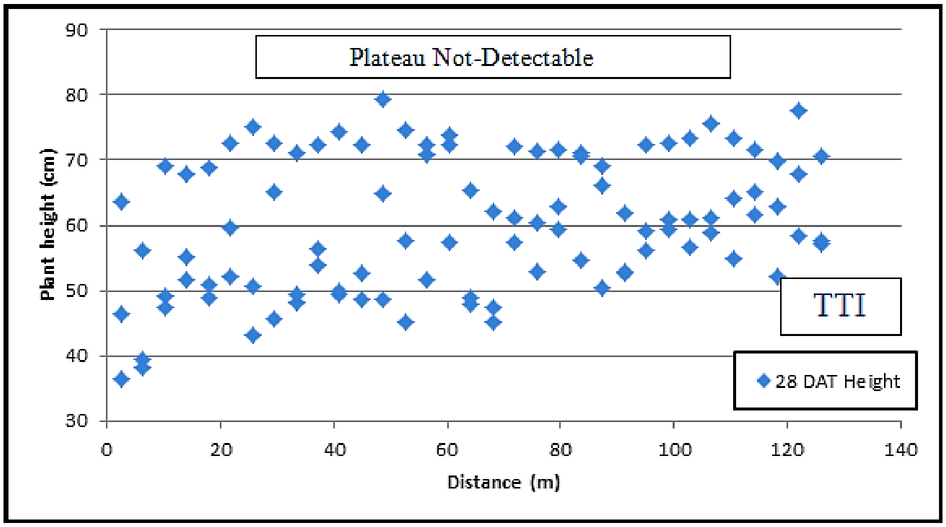

Figure 2.10 28 DAT segmented regression of soybean heights for Scott, MS.

This graph represents results using Turbo Teejet Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean height (expressed in centimeters) measured from each rating transect averaged over replication at a given distance. Dicamba effects on soybean heights were not detectable using the segmented regression analysis for this location for either treatment.

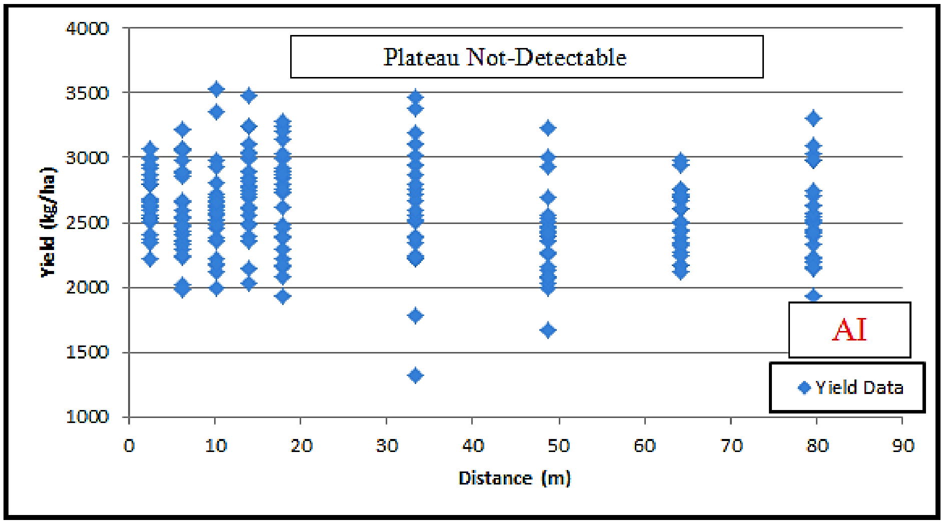

Figure 2.11 Segmented regression analysis of soybean yields for Brooksville, MS.

This graph represents results using Teejet Air Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. Dicamba effects on soybean yields were not detectable using the segmented regression analysis for this location for either treatment.

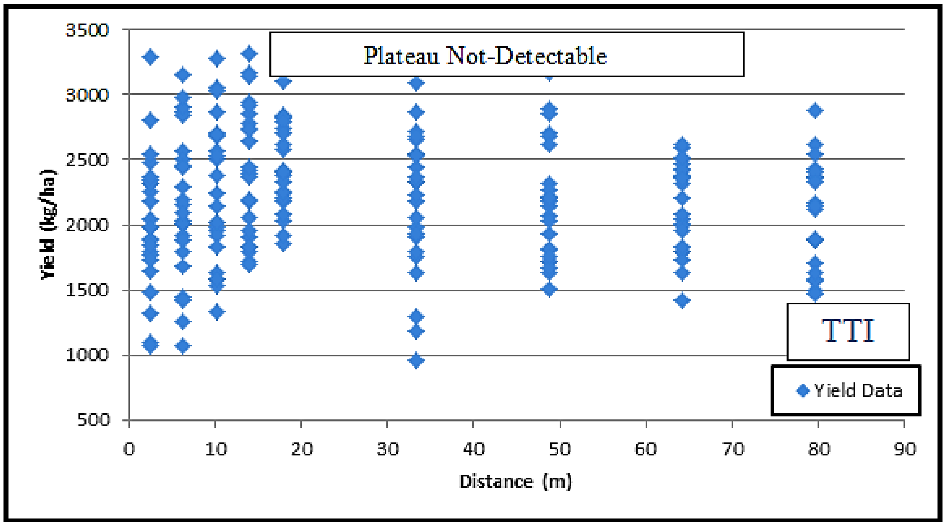

Figure 2.12 Segmented regression analysis of soybean yields for Brooksville, MS.

This graph represents results using Turbo Teejet Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. Dicamba effects on soybean yields were not detectable using the segmented regression analysis for this location for either treatment.

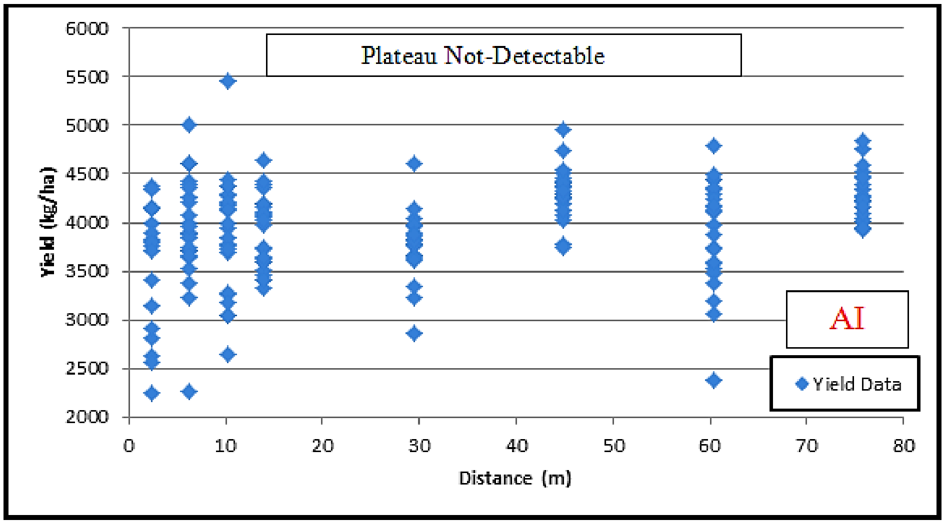

Figure 2.13 Segmented regression analysis of soybean yields for Scott, MS.

This graph represents results using Teejet Air Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. Dicamba effects on soybean yields were not detectable using the segmented regression analysis for this location for either treatment.

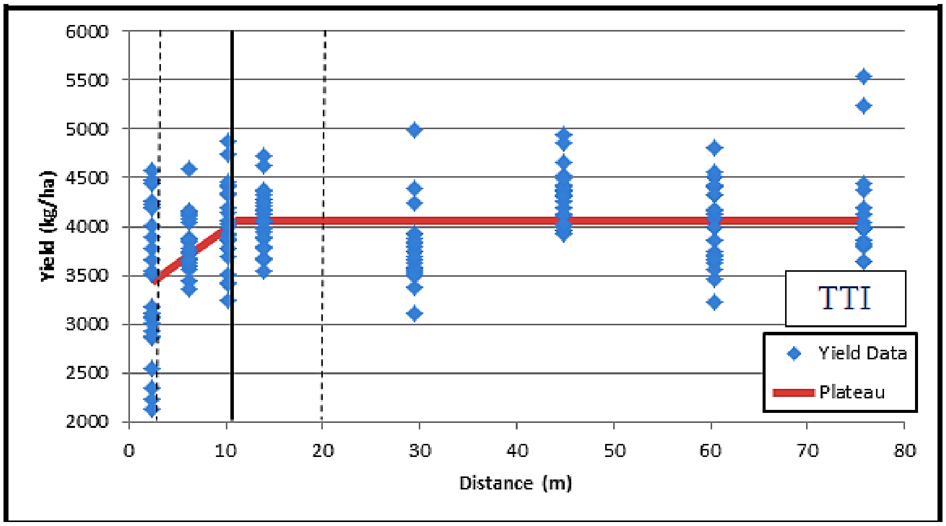

Figure 2.14 Segmented regression analysis of soybean yields for Scott, MS.

This graph represents results using Turbo Teejet Induction nozzles. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. Dicamba effects on soybean yields were not detectable using the segmented regression analysis for this location for either treatment.

Table 2.4 Results summary table of segmented regression analysis on plant height and yield data[a]

Location	Nozzle	Plant Height 14 DAT[b]	Yield 28 DAT	Plateau[c]	ANOVA[d]
		------------------------(meters)[e]--------------------------			
Brooksville	AI[f]	55	22	ND[h]	NSD[i]
	TTI[g]	51	22	ND	~8
Scott	AI	12	ND	ND	~4
	TTI	15	ND	11	~7
Kesier	AI	ND	14	12	~4
	TTI	22	14	ND	NSD
Jackson	AI	13	11	ND	NSD
	TTI	10	6	ND	NSD

[a] Estimated distance from treated area edge to “no dicamba effects” on soybean height and yield.
[b] Days after treatment
[c] Estimated distance to “no dicamba effects” using segmented regression analysis
[d] Estimated distance to “no dicamba effects” using Analysis of Variance method
[e] Distance from treated area edge expressed in meters
[f] Results from areas treated with Teejet® Air Induction spray nozzles
[g] Results from areas treated with Turbo Teejet® Induction spray nozzles
[h] Dicamba drift effects not detectable
[i] No significant difference

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CHAPTER III

EVALUATION OF DICAMBA DRIFT WHEN APPLIED IN SOYBEAN UNDER FIELD CONDITIONS

Abstract

In order to aid in the control of herbicide resistant weed species, new transgenic crops are being developed which are tolerant to applications of dicamba herbicide. The potential for rapid adoption of this technology will lead to an increase in the amount of dicamba herbicide applied to crops each season. It is well-documented that soybeans are very susceptible to injury from dicamba, and the increased use of dicamba herbicide brings along an increased chance for occurrences of physical spray drift onto this and other susceptible plant species. In 2013, an experiment was designed to evaluate the potential for off-target deposition of dicamba when applied under field conditions. The experiment was conducted in Brooksville, MS, Jackson, TN, Keiser, AR, Rohwer, AR, and Scott, MS. Non-transgenic soybean were utilized as a bio-indicator because of their sensitivity to dicamba. The herbicide treatment applied was a combination of MON-1750 (320 g ae glyphosate and 160 g ae dicamba per liter of product) applied at 1.68 kg ae/ha, Dipotassium phosphate at 2% v/v, and Interlock® drift retardant at 0.3 L/ha. The treatment was applied during a cross wind with target speeds between 9.6 and 16 KPH to allow herbicide drift onto the sensitive crop. The soybean growth stage targeted for herbicide application was the early reproductive R1 - R2 growth stage. Applications were made using Turbo Teejet Induction (TTI) nozzles calibrated to deliver 140 L/ha At 28 DAT, the distances beyond which malformation was less than 15% ranged from 15 to 41 meters from the sprayed area edge. Distances beyond which malformation was less than 5% were found to be 25 to 78 meters. Reductions in plant height at 28 DAT were found out to 21 meters from the treated area edge. Soybean yields were reduced out to 19 m.

Nomenclature: Dicamba; glyphosate; soybean, *Glycine max* L Merr.

Key Words: Herbicide, segmented regression, visual injury, yield.

Introduction

The introduction of genetically modified/biotech crop varieties has transformed the agricultural industry. One of the most significant biotechnological developments in agriculture has been the discovery and usage of crops resistant to glyphosate. Recent data show 175.2 million hectares of biotech crops were planted in 2013. This is a 100 fold increase compared to the 1.7 million hectares planted in biotech crops in 1996, the introductory year of glyphosate tolerant crops (James, 2013). The reliance on this technology is evident in its use patterns since it first became available in 1996. This technology saw rapid adoption because it provided a simple, effective, environmentally safe weed management strategy for producers which also resulted in decreases in the costs associated with controlling weed populations (Duke and Powles, 2009). However, in spite of the many benefits of glyphosate tolerant crops, it has also created one of the most problematic issues facing agriculture today, glyphosate-resistant weeds. The development of herbicide resistance in weed species did not begin with the use of herbicide-tolerant crops. However, the over-dependence on the glyphosate technology along with the lack of incorporating herbicides with other mechanisms of action (MOA) into weed management strategies placed high levels of selection pressure on weed populations. This helped lead to an increase in the number of weed species that were either poorly controlled by glyphosate or completely resistant to the herbicide (Vencil et al., 2012). Some of the most troublesome glyphosate-resistant weeds in the United States are tall waterhemp (*Amaranthus tuberculatus*), horseweed (*Conyza canadensis*), and Palmer amaranth (*Amaranthus palmeri*). A relatively new addition to most trouble weed species list, Palmer amaranth is now one of the most economically harmful glyphosate-resistant weeds (Beckie, 2006). To attain acceptable control of many of these resistant weed species, it is prudent to incorporate multiple MOA into a weed management plan. Using multiple herbicide chemistries as tank mix partners can help reduce the occurrence of resistance development when compared to using the same chemistries in rotation (Powles et al., 1997). Auxin herbicides have shown potential to be very effective when incorporated into a producer's herbicide arsenal. One particular study found increases in the control of both resistant and non-resistant weed biotypes when applying dicamba alone and in combination with glyphosate (Johnson et al., 2010).

To aid producers in stemming herbicide resistance, new cropping systems are currently being developed which will include crops tolerant to 2,4-D and dicamba. Monsanto is currently producing crops which will be tolerant to applications of both glyphosate and dicamba. By incorporating tolerance to multiple MOA's, producers will be able to incorporate a variety of herbicides and control and potentially manage resistant weed populations. However, because a wide variety of broadleaf plant species are highly sensitive to dicamba, and dicamba has a relatively low vapor pressure, this technology will also bring its own challenges as well. The likelihood for dicamba spray solutions to move off target makes it necessary for issues such as physical spray and vapor drift and sprayer hygiene to be addressed. Recent studies performed at Mississippi State University examined different application rates and timings of 2,4-D and dicamba herbicides applied in soybean. Treatments consisted of several different rates of both herbicides, beginning with 0.56 kg ae/ha (1X rate) down to 2.19 x 10^{-3} kg ae/ha (1/256X rate) for the 2,4-D and 5.5 x 10^{-4} kg ae/ha (1/1024X rate) of dicamba. Soybean plants showed greater than 30% visual injury when treated with dicamba at the 1/256X rate, while 2,4-D produced less than 10% visual injury symptoms at equal rates. Soybean yield, averaged over rates were reduced by 11 and 18% when treated with 2,4-D in the vegetative and reproductive growth stages respectively. Yield reductions were significantly greater in plots treated with dicamba, with losses of 41 and 46% for plots sprayed at the vegetative and reproductive stages of development, respectively. In regards to application timing, soybean yield reductions due to dicamba were found to be the greatest when the herbicide was applied at the late vegetative to early reproductive stages of growth (Blaine et. al, 2014; Blaine et. al, 2014). These results support previous research which found significant soybean yield reductions when treated with simulated dicamba drift rates at the early bloom stages compared to early vegetative and late bloom stages (Auch and Arnold, 1978; Wax et al., 1969).

Because of these concerns, a study was conducted in 2013 with the objective to evaluate the potential for off-target movement of dicamba when applied with commercial equipment. In addition we also aimed to estimate the distances to no plant effects on plant height and yield from large scale dicamba spray applications for various locations.

Materials and Methods

Experimental Layout

This experiment was conducted in Brooksville, MS, Scott, MS, Jackson, TN, Keiser, AR, Rohwer, AR, and two Monsanto locations, MON 1 and MON 2. Non-dicamba tolerant soybean were utilized as a bio-indicator for herbicide drift because of their sensitivity to dicamba. Soybeans were planted between May 1, 2013 and June 21, 2013 at the various locations. Soybean row spacing was 76 cm for the Brooksville, Scott, MON 1, and MON 2 locations and 96 cm at Keiser, Rohwer, and Jackson. The treated area was located on the upwind side of the field (Fig. 3.1) and measured 183 meters long at all locations except the MON 1 location, where the treated area measured 166 meters. Only one sprayer pass was made during this experiment, so the width of the treated area was dependent upon the width of the spray boom used to make the application. The treated area widths were 18 meters for the Brooksville, Scott, Rohwer, Jackson, and MON 2 locations, 12 meters for the Keiser location, and 27.4 meters for the MON 1 location (Table 3.1). Rating transects were designated in the downwind portion of the field to estimate dicamba drift effects. Each location had three to five transects oriented perpendicular to the spray direction and data were collected at set distances from the treated area edge. These transects were evenly spaced along the treated area edge at 0, 46, 92, 138, and 184 meters (Fig. 3.1). Transects at 0 and 184 meters were only utilized at the Brooksville, and Scott locations. Untreated check transects were designated 46 meters from the beginning and ending edges of the treated areas. Check plots were also set up on the upwind side of the treated area (Fig. 3.1).

Herbicide Treatment and Application

The herbicide treatment used in this study was a tank-mix of M-1750, dipotassium phosphate, and Interlock drift retardant®. M-1750 is an experimental formulation of 320 g ae glyphosate and 160 g ae dicamba per liter of product. This was applied at a rate of 3.5 L/ha. Dipotassium phosphate was applied at 2% v/v, and Interlock® was applied at 0.29 L/ha. Current label requirements for the chemicals to be used with the new dicamba tolerant crop systems will call for the use of some form of drift retardant to be added in the spray solution. Applications were made using Turbo Teejet® Induction Flat Fan Spray Tips (TTI) with an orifice size of 04 at all experimental locations. Target soybean growth stage for herbicide application was in the R1 to R2 stages of development (Fehr and Caviness, 1977). Weather conditions at the Keiser location delayed application until soybeans had reached the R4 growth stage. The herbicide treatment was applied at 140 L/ha at all locations except the MON 2 location which was applied at 111 L/ha. Ground speeds during application were 14.8, 14.8, 12, 13.7, 9.3, 11.4, and 14.9 KPH for the Brooksville, Scott, Keiser, Rohwer, MON 1, Jackson, and MON 2 locations, respectively. Spray boom height was 51 cm above the crop canopy. Target wind speeds for application were between 10 to 16 KPH at an angle perpendicular to the treated area edge. The spray boom was primed at a location away from the test area. When wind speed and direction reached the specified thresholds, the herbicide application was made to allow the treatment to drift onto the downwind portion of the field.

Data Collection

A weather station[2] was on site for each location to collect data during and after application. Weather stations were set to record on one second intervals during treatment application and on one minute intervals for the subsequent 48 hours. Wind speed ranges as well as average wind speeds are provided in Table 3.2. As previously mentioned, rating transects for data collection were designated in the downwind portion of the experimental area. Data were collected along these transects in four row increments beginning at the rows adjacent to the treated area and continuing out to the 40th row from the treated area edge. Data were also collected in eight row increments out to row 80. From there, data were collected in 20 row increments out to row 180. Ten check plots were also designated in equally spaced intervals along the upwind and downwind untreated transects. Data were collected on the center rows of each experimental unit. Percent visual injury and plant heights were taken from all treated and untreated points 14 and 28 days after treatment (DAT). Rating criteria for soybean with 15% injury were plants that showed an evident cupping effect along leaf margins of the upper expanded leaves, as well as a distorted appearance on the newest axillary buds below the terminal. Little effect on plant heights were seen in these plants. Criteria for plants with 5% visual injury were soybean plants with obvious curling of the tip of the most recently emerged trifoliate. Yield data were also taken on these same areas using a two-row plot combine to assess any potential herbicide yield effects.

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[2] Watchdog 2700 Weather Station. Spectrum Technologies, Inc. 3600 Thayer Court, Aurora, IL 60504

Statistical Methods

Visual injury data were analyzed using the PROC GLM procedure in SAS 9.3 to perform a linear regression of visual injury using the log of the distance from the treated area edge. This method fits a log linear relationship between percent visual injury and distance. This can allow a prediction of physical spray drift injury levels at specific distances away from a herbicide application Using this technique, the estimated distances from the application swath at which visual soybean injury drops below 15% and 5% can be identified. A segmented regression technique was used to analyze effects on soybean heights and yield due to herbicide drift. This analysis was performed with SAS 9.3 using the PROC NLMIXED procedure. This method has been shown to be effective in determining thresholds and edge effects (Toms and Lesperance, 2003). Also called "broken-stick" models, this technique joins two lines at unknown points, or hinge points. The first line, which has an upward sloping positive trend, represents distances at which dicamba drift effects were found. This line rises to a second line having a zero slope, or "plateau", which would represent distances at which no dicamba drift effects were found. The hinge point between the two lines estimates a distance to "no dicamba drift" effects.

Results and Discussion

Visual plant injury regression curves for the Brooksville and Scott locations as well as the regression curves obtained when combining locations can be seen in Figures 3.2, 3.3, and 3.4, respectively. Analysis of the visual injury ratings showed that the distances at which percent visual injury fell below 15% at 14 DAT were 11, 14, 16, 20, 30, and 43 m for the MON 1, MON 2, Scott, Jackson, Rohwer, and Brooksville locations, respectively (Table 3.3). At the 28 DAT rating, the distances at which percent visual inury fell below 15% were 15, 15, 19, 29, 33, 41 m for the MON 1, MON 2, Jackson, Scott, Rohwer, and Brooksville locations, respectively (Table 3.3). The distances at which percent visual injury fell below 5% at 14 DAT were 22, 23, 33, 46, 68, and 90 m for the MON 1, MON 2, Jackson, Scott, Rohwer, and Brooksville locations, respectively (Table 3.3). At 28 DAT, these distances were 25, 27, 29, 61, 63, and 78 m for the MON 2, MON 1, Jackson, Scott, Rohwer, and Brooksville locations, respectively (Table 3.3). Distances beyond which visual injury dropped below 15% and 5% were calculated with all test locations, except Keiser, AR, combined. The overall distance beyond which visual injury dropped below 15% was 24 meters at 14 DAT And 28 m 28 DAT (Table 3.3) The overall distance beyond which visual injury dropped below 5% was 59 m at 14 DAT and 58 m 28 DAT (Table 3.3).

Plant injury due to dicamba drift was not detected at the Keiser, AR location. This location did have the least amount of herbicide applied based on treated area size as well as the lowest wind speeds. However, we believe the lack of response to dicamba drift to be attributed to the growth stage at which the herbicide application was made. As previously mentioned, application at the Keiser location was delayed by weather until the soybeans had reached the R4 growth stage. Prior research conducted at Mississippi State University examined soybean response to dicamba herbicide applied at different growth stages (Blaine et. al, 2014). This experiment identified the R4 growth stage as the point at which plant responses due to the herbicide were not seen. In addition to common dicamba injury symptoms like leaf cupping and plant epinasty a reduction in canopy cover was also seen in areas affected by dicamba drift. This would suggest potential for yield losses not only directly from plant injury but also possible increases in weed pressure due to the lack of a healthy crop canopy.

Segmented regression, or plateau model, analysis on plant height and yield reductions for the Brooksville location can be seen in Figures 3.5 and 3.8. These models can be seen for the Scott location in Figures 3.6 and 3.9. The segmented regression models for plant height and yield data when analyzed over all test locations, except the Keiser, AR location, can be seen in Figures 3.7 and 3.10. Reductions in plant heights due to dicamba drift were observed out to 6, 7, 9, 15, 18, and 26 m at 14 DAT and 7, 8, 12, 21, 14, and 12 m 28 DAT for the Jackson, MON 1, Scott, Brooksville, Rohwer, and IL locations, respectively (Table 3.4). Reductions in plant height due to dicamba drift were not detectable at the Keiser location. This is again attributed to the growth stage at which the application was made. Yield reductions due to dicamba drift were not detectable at the Rohwer, and Keiser locations. No yield data were taken at the MON 1 location. The distances to “no-effects” on soybean yields were 4, 17, 14, and 19 m at the MON 2, Jackson, Scott, and Brooksville locations, respectively (Table 3.4). Plant height and yield data were also analyzed over all test locations, with the exception of the Keiser, AR site, in order to estimate overall distances to “no dicamba effects”. Estimated distances to “no dicamba effects” on soybean height were 13 and 15 m at the 14 and 28 DAT rating interval, respectively. The estimated distance to no yield effects was 20 m from the treated area edge. These data can be seen in Table 3.4.

Conclusions

In conclusion, results show the distance to reduction in plant height were typically found to be numerically less than those observed for 15% and 5% visual injury at both 14 and 28 DAT at the respective locations. Also, distances to yield reductions were either non-detectable or numerically less than those observed for 15% visual injury at 28 DAT. Effects of wind speed on soybean injury and height reduction trends were unclear. However, wind speed did seem to play a role in determining dicamba drift effects on soybean yield. Locations with the highest average wind speeds showed the greatest distances to “no dicamba effects” on soybean yields, while at the locations with the lowest wind speeds, Keiser and Rohwer, AR, reductions in yield due to dicamba drift were not detectable. This experiment shows the potential for future issues concerning the off-target movement of dicamba herbicide. Proper application techniques as well as appropriate decision making are essential to minimize the effects of physical spray drift on sensitive plant species.

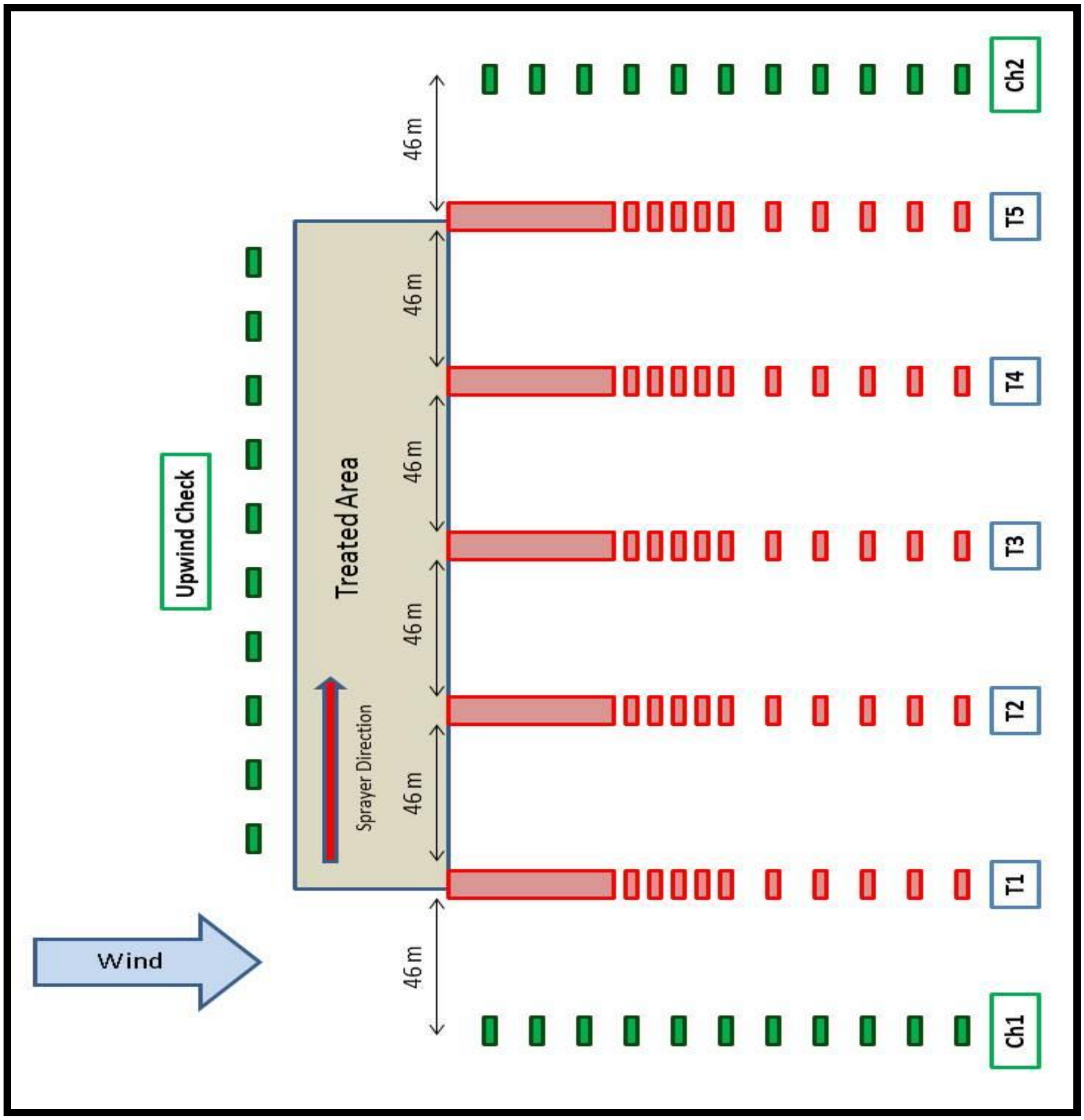

Figure 3.1 2013 Dicamba drift experiment layout.

Treated area is designated in tan. Soybean rows run parallel to treated area. Sprayer direction moves from the bottom edge of the treated area upwards with wind direction moving from left to right. Check plots are designated in green on the upwind side of treated area as well as the downwind portion of the field 46 meters from the beginning and ending treated area edges. Rating transects are designated in red. At distances closest to the treated area edge, data were collected every four rows. Beginning at row 41, data were collected every 8 rows. Beginning at row 81, data were collected every 20 rows.

Table 3.1 Experimental information for 2013 drift trial locations

	Location						
	Brooksville	**Scott**	**Keiser**	**Rohwer**	**Jackson**	**MON 1**	**MON 2**
Variety[c]	Asgrow 4632	Asgrow 4632	Halo494	Asgrow 4632	Asgrow AG4632	Select 3490	Asgrow 2632
Planting Date[d]	5/16/13	5/1/13	6/21/13	5/13/13	6/7/13	6/17/13	6/6/13
Row Spacing (cm)[e]	76	76	96	96	96	76	76
Application Date[f]	6/27/13	6/11/13	8/27/13	6/7/13	7/9/13	6/28/13	7/23/13
Growth Stage[g]	R2	R1-R2	R4	R2	R2	R1-R2	R1-R2
Tips[h]	TTI	TTI	TTI	TTI	TTI	TTI	TTI
L/ha[i]	140	140	140	140	140	140	111.6
Speed (KPH)[j]	14.8	14.8	12.0	13.7	11.4	9.3	14.9
Boom Height (cm)[k]	51	51	51	51	51	51	51
Boom Width (m)[l]	18	18	12	18	18	27.4	18
Plot Length (m)[m]	183	183	183	183	183	166	183

[a] Soil type for drift trial locations
[b] Soybean seeding rate
[c] Soybean variety planted at drift trial locations
[d] Soybean planting date for drift trial locations
[e] Soybean row spacing expressed in centimeters
[f] Date of treatment application
[g] Soybean growth stage at the time of application
[h] Spray nozzles used in experiment (TTI = Turbo Teejet® Induction)
[i] Application carrier volume expressed in liters per hectare
[j] Application ground speeds expressed in kilometers per hour
[k] Applicator boom height expressed as centimeters above crop canopy
[l] Applicator boom width expressed as meters.
[m] Treated area length expressed as meters.

Table 3.2 Recorded wind speeds for 2013 drift trial locations[a]

	Location							
Wind Speed[b]	**Brooksville**	**Scott**	**Keiser**	**Rohwer**	**Jackson**	**MON 1**	**MON 2**	**Overall[c]**
	-------------------(KPH)[c]-------------------							
Minimum	6.4	6.4	4.5	3.0	8.0	12.9	4.8	6.6
Maximum	25.7	14.5	12.0	9.8	14.8	14.4	11.2	14.6
Average	13.4	11.1	7.4	8.0	11.1	13.7	8.9	10.5

[a] Data collected using 2000 Series WatchDog® Weather Station.
[b] Minimum, maximum, and average wind speeds recorded during treatment application.
[c] Recorded wind speeds averaged over all locations.
[d] Wind speeds expressed as kilometers per hour.

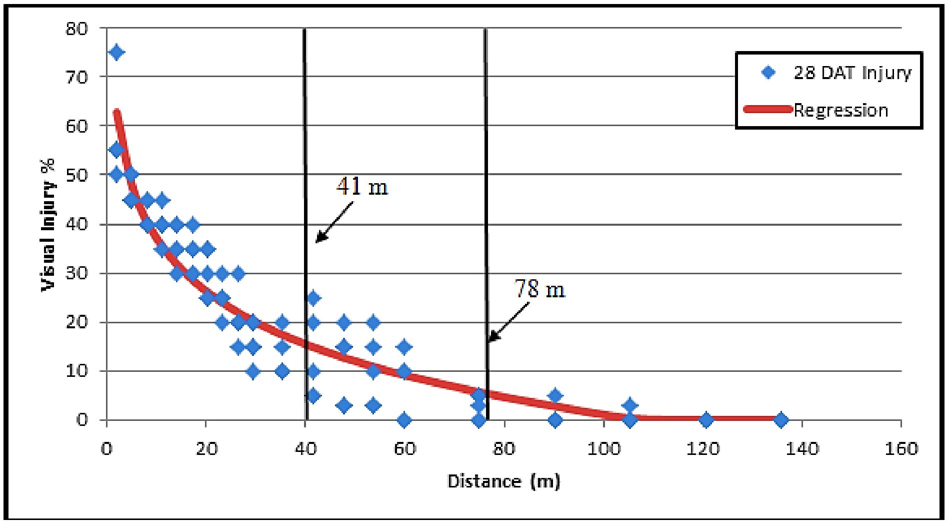

Figure 3.2 28 DAT visual injury regressions for Brooksville, MS.

Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

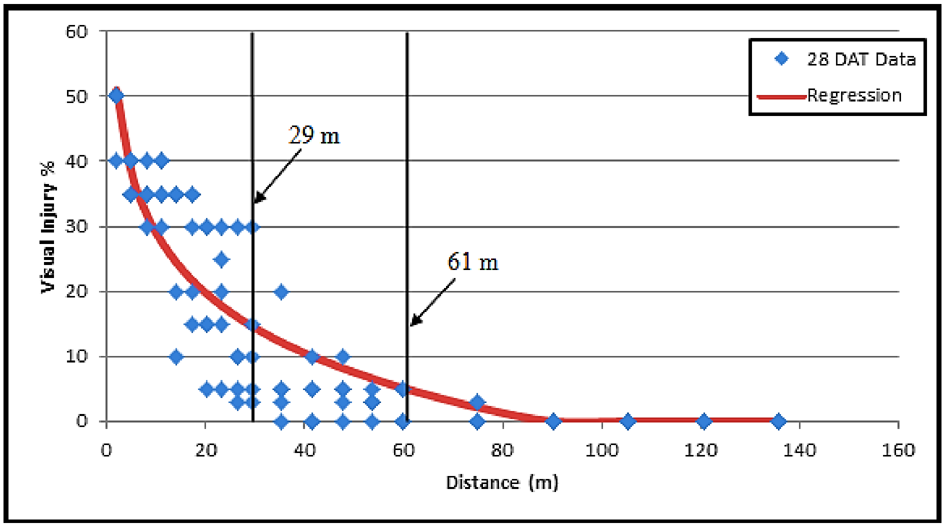

Figure 3.3 28 DAT visual injury regressions for Scott, MS.

Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

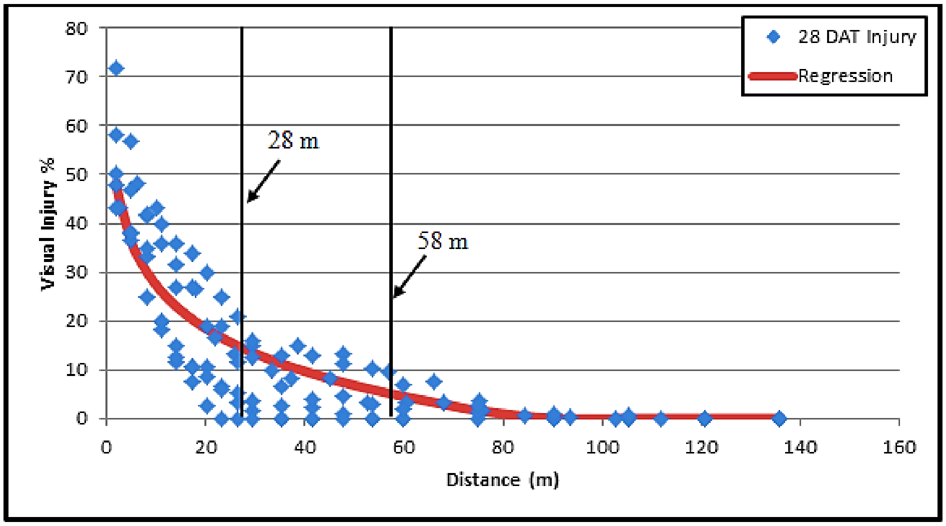

Figure 3.4 28 DAT visual injury regressions over location.

Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury averaged over rating transect at a given distance for each test location. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

Table 3.3 Results summary table of visual injury regressions as a log function of distance

Location	Average Wind Speed[c]	15% Plant Injury[a] 14 DAT[d]	15% Plant Injury[a] 28 DAT	5% Plant Injury[b] 14 DAT	5% Plant Injury[b] 28 DAT
	-KPH-	-----------------------(Meters)[e]-----------------------			
Brooksville	13.4	43	41	90	78
Scott	11.1	16	29	46	61
Keiser	7.4	0	0	0	0
Rohwer	8.0	30	33	68	63
Jackson	11.1	20	19	33	29
MON 1	13.7	11	15	22	27
MON 2[f]	8.9	14	15	23	25
Overall[g]	10.5	24	28	59	58

[a] Estimated distance beyond which visual injury levels dropped below 15%

[b] Estimated distance beyond which visual injury levels dropped below 5%

[c] Average wind speeds recorded in kilometers per hour

[d] Days after treatment

[e] Distance from treated area edge expressed in meters

[f] Smoothing spline used to obtain distance values

[g] Distance values calculated over all test locations combined (excluding Keiser)

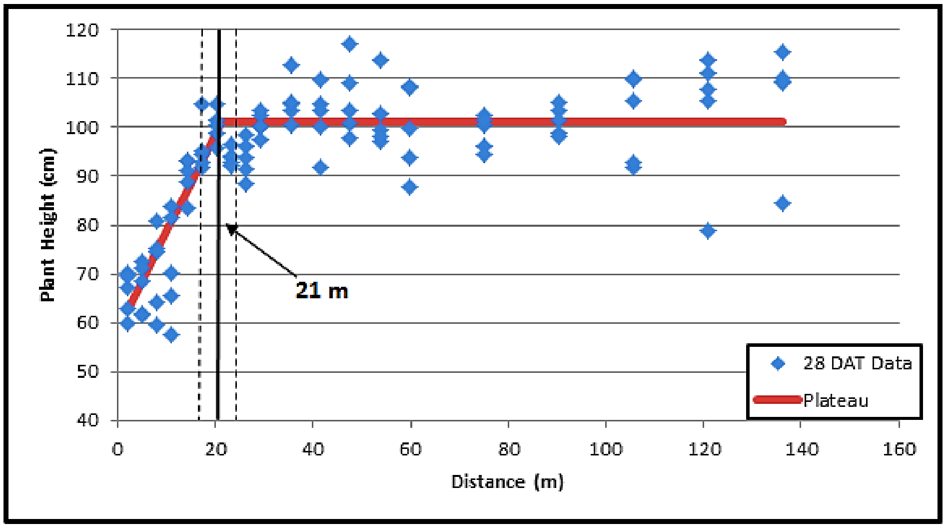

Figure 3.5 28 DAT segmented regression analysis of soybean height data for Brooksville, MS.

Distance represents meters away from the treated area edge. Blue points on graphs represent average soybean height (expressed in centimeters) measured from each rating transect at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to “no dicamba effect” on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

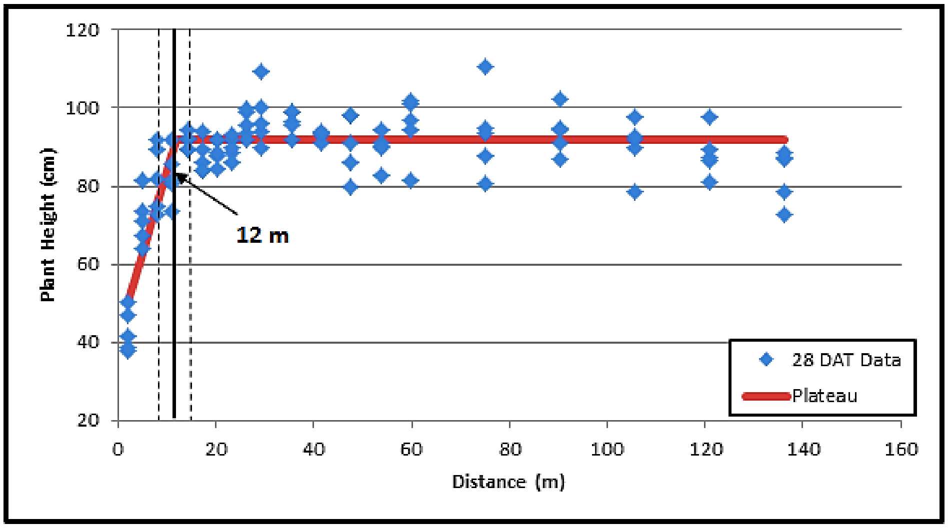

Figure 3.6 28 DAT segmented regression analysis of soybean height data for Scott, MS.

Distance represents meters away from the treated area edge. Blue points on graphs represent average soybean height (expressed in centimeters) measured from each rating transect at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to "no dicamba effect" on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

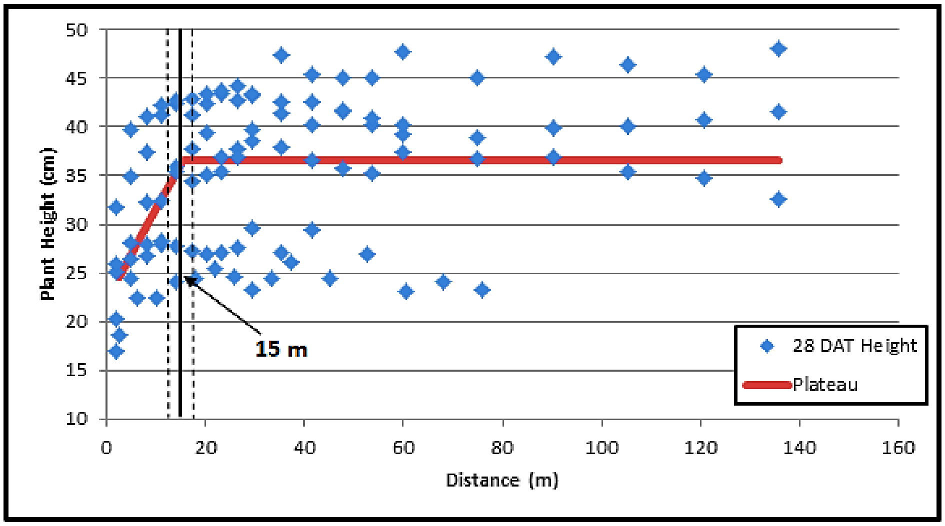

Figure 3.7 28 DAT segmented regression analysis of soybean height data over location.

Distance represents meters away from the treated area edge. Blue points in graph represent soybean height values (expressed in centimeters) averaged over location at a given transect and distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to "no dicamba effect" on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

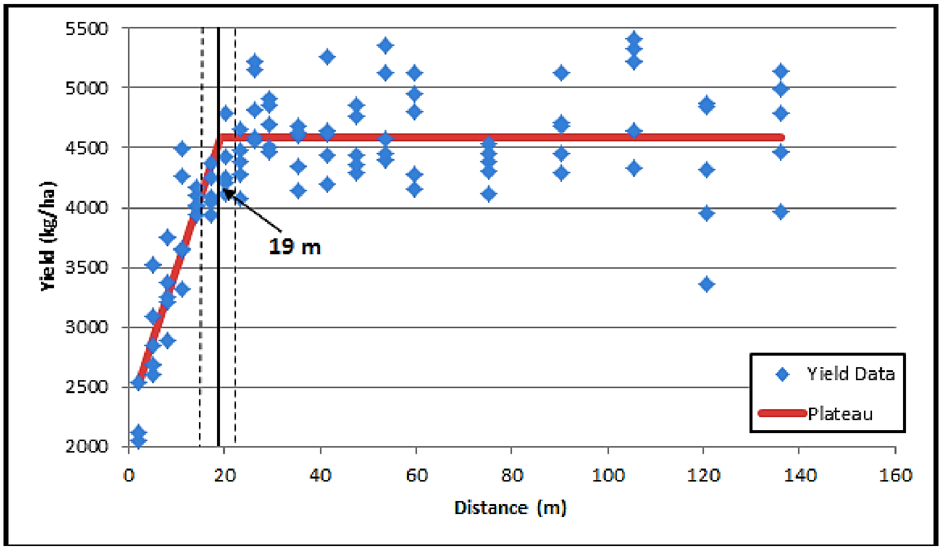

Figure 3.8 Segmented regression analysis of yield data for Brooksville, MS.

Distance is expressed as meters away from the treated area edge. Soybean yield expressed as kilograms per hectare. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. The red line represents the segmented regression analysis of soybean yield. The solid vertical bar indicates the hinge point representing the distance to "no dicamba effect" on soybean yield. Dashed lines represent the confidence interval for the hinge point estimate.

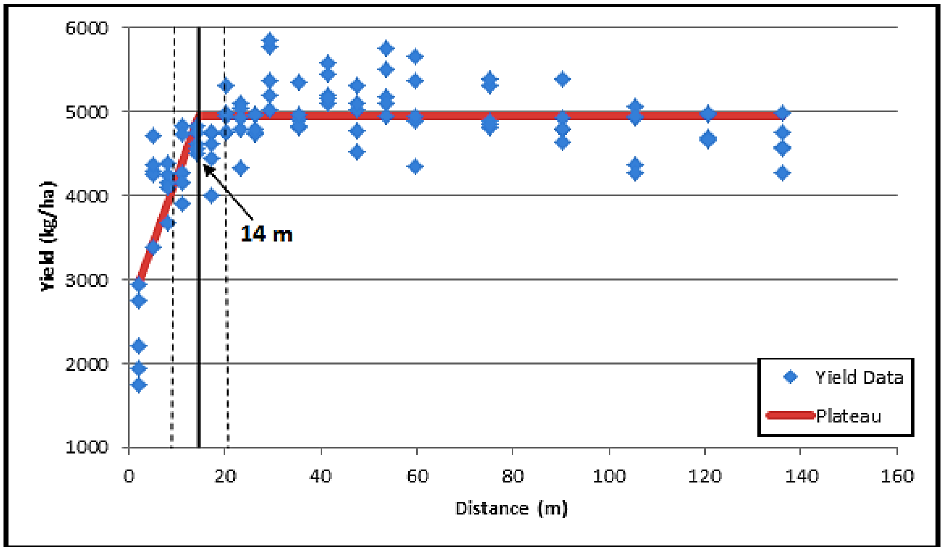

Figure 3.9 Segmented regression analysis of yield data for Scott, MS.

Distance is expressed as meters away from the treated area edge. Soybean yield expressed as kilograms per hectare. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. The red line represents the segmented regression analysis of soybean yield. The solid vertical bar indicates the hinge point representing the distance to "no dicamba effect" on soybean yield. Dashed lines represent the confidence interval for the hinge point estimate.

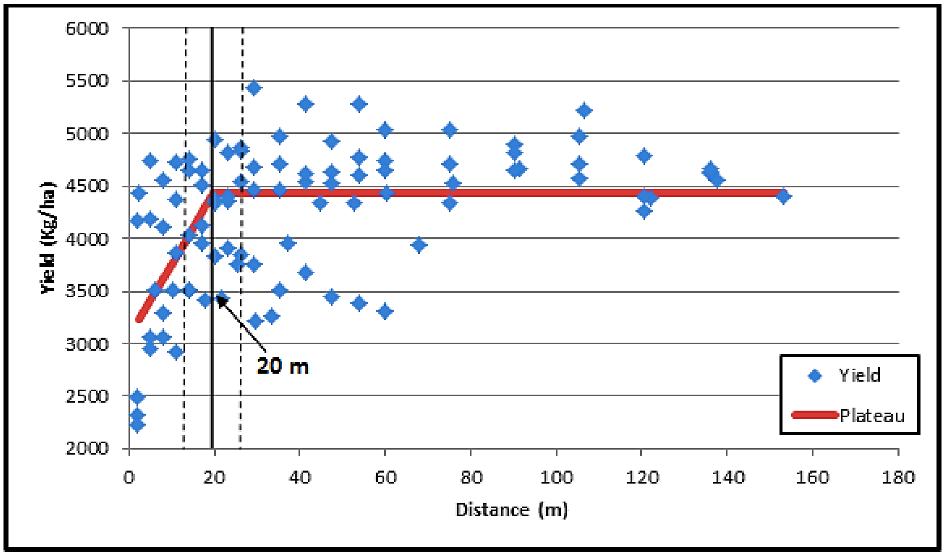

Figure 3.10 Segmented regression analysis of yield data over all test locations (excluding Keiser).

Distance is expressed as meters away from the treated area edge. Soybean yield expressed as kilograms per hectare. Blue points in graph represent soybean yield averaged over all rating transects at a given distance for each location. The red line represents the segmented regression analysis of soybean yield. The solid vertical bar indicates the hinge point representing the distance to "no dicamba effect" on soybean yield. Dashed lines represent the confidence interval for the hinge point estimate.

Table 3.4 Results summary table of segmented regression analysis on plant height and yield data[a]

		Plant Height		Yield
Location	**Average Wind Speed[b]**	**14 DAT[c]**	**28 DAT**	**Plateau**
	-KPH-	---------------------Meters[d]---------------------		
Brooksville	13.4	15	21	19
Scott	11.1	9	12	14
Keiser	7.4	ND[e]	ND	ND
Rohwer	8	18	14	ND
Jackson	11.1	6	7	17
MON 1	13.7	7	8	--
MON 2	8.9	26	12	4
Overall[f]	10.5	13	15	20

[a] Estimated distance from treated area edge to "no dicamba effects" on soybean height and yield.

[b] Average wind speeds recorded in kilometers per hour

[c] Days after treatment

[d] Distance from treated area edge expressed in meters

[e] Dicamba drift effects not detectable

[f] Estimated distance to "no dicamba effects" over all test locations combined (excluding Keiser)

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CHAPTER IV

THE EFFECT OF BEST MANAGEMENT PRACTICES WITH ENGENIA ON DICAMBA DRIFT

Abstract

New transgenic crop species are currently being produced which will be tolerant to applications of dicamba herbicide. This development could greatly enhance agricultural producers ability to control glyphosate resistant weed populations, like glyphosate-resistant Palmer Amaranth. The adoption of this new technology is likely to be rapid and widespread. In 2013, an experiment was designed to determine the effectiveness of Best Management Practices (BMP) in reducing the effects of herbicide drift. The experiment was conducted at the MSU Blackbelt Branch Experiment Station in Brooksville, MS. Non-transgenic soybean were utilized as a bio-indicator because of their sensitivity to dicamba. The "Standard" treatment was a combination of Banvel® herbicide and Roundup Powermax® at 92 g ai/ ha and 184 g ae/ ha, respectively, applied with Turbo Teejet 11004 spray nozzles. The Best Management Practice (BMP) treatment was a combination of Engenia herbicide, Roundup Powermax®, and Interlock® drift retardant applied at 92 g ai/ ha, 184 g ae/ ha, and 42 g ai/ ha, respectively. This treatment was applied using Turbo Teejet Induction 11004 spray nozzles. Treatment was applied during a cross wind with target speeds between 11 and 16 KPH to allows herbicide to drift onto the sensitive crop. At 28 DAT, the distances beyond which malformation was less than 15 % were 34 and 15 meters for the Standard and BMP treatments, respectively. Reductions in plant heights were found at 28 DAT out to distances of 20 and 14 meters for the Standard and BMP treatments, respectively. Natural spatial variability of the field precluded an accurate assessment of treatment effects on soybean yield. These data indicate Best Management Practices can reduce the distance to which soybean injury and plant heights are affected by dicamba herbicide drift when compared to standard application practices.

Nomenclature: Dicamba; glyphosate; soybean, *Glycine max* L Merr.

Key Words: Herbicide, segmented regression, visual injury, yield.

Introduction

The introduction of the Roundup Ready® technology in the late 1990's revolutionized the agricultural industry. Initially launched in 1996, subsequent years saw increased interest in producers using the technology. Adoption of this technology was rapid because it was designed to provide farmers with a simpler, very effective weed management strategy resulting in decreases in the costs generally associated with controlling weed populations (Duke and Powles, 2009). According to 2013 data, $116.9 billion in economic gains were made from 1996 to 2012 with the usage of biotech crops. It is estimated that 58% of these gains came from reductions in crop production costs, and 42% coming from increases in crop yields (James, 2013). However, in spite of the many benefits of glyphosate tolerant crops, it has also brought about one of the greatest problems facing agriculture today, the control of glyphosate-resistant weeds. The development of herbicide resistance in weed species populationse did not begin with the introduction herbicide-tolerant crops. However, due to the over-reliance on the glyphosate technology and the lack of incorporating herbicides with other mechanisms of action (MOA) into weed management plans placed significant amounts of selection pressure on weed populations. This led to the increase in weed species that were either poorly controlled by glyphosate or completely resistant to the herbicide (Vencil et al., 2012). Some examples of these troublesome glyphosate-resistant weed species in the United States are the broadleaf species tall waterhemp, johnsongrass, horseweed, and Palmer amaranth. A relatively new addition to most trouble weed species list, Palmer amaranth is now one of the most economically harmful glyphosate-resistant weeds (Beckie, 2006). In order to control many of these resistant weed species, it is important to incorporate multiple MOA into a weed management plan. Using multiple herbicide chemistries as tank mix partners can also help reduce the occurrence of resistance development when compared to using the same chemistries in rotation (Powles et al., 1997). A recent study shows the potential for the incorporation of auxin herbicides into a producer's herbicide arsenal. Increase in the control of both resistant and non-resistant weed biotypes was achieved when applying dicamba alone and in combination with glyphosate (Johnson et al., 2010).

In response to the need for new tools to manage herbicide resistance, new cropping systems which will include tolerance to 2,4-D and dicamba herbicides are being produced. By incorporating this new technology, producers will be able to incorporate herbicides with numerous MOA's and thereby attack and reduce some of their herbicide resistant weed species problems. However, if the glyphosate-tolerant model is any indication, the auxin-tolerant system is also likely to be widely and rapidly adopted as well. This will bring its own sets of challenges, specifically considering issues like off-target movement of the herbicides due to physical spray and vapor drift as well as sprayer hygiene issues. There are many factors which can influence the off-target movement of herbicides. The size of the spray droplet produced during the application as well as the release height of the droplet can both dramatically affect the physical drift of the herbicide particle (Guler, et al., 2007, Wolf, et al., 1993). These are things that can be directly controlled by the person making the pesticide application. Other factors, like the environmental conditions during which a spray application is made are equally if not more important when hoping to minimize spray drift. In order to reduce the occurrences of physical spray drift, all of these factors must be taken into account before making the herbicide application. Because of this, research is being conducted to determine application techniques most suitable for spray drift reduction. In 2013, an experiment was designed to evaluate the effectiveness of Best Management Practices (BMP) in reducing physical spray drift compared to common application techniques currently in use.

Materials and Methods

Herbicide Treatment and Application

Two treatments were used in this study, a “Standard” treatment and a BMP treatment. The “Standard” treatment consisted of a combination of Banvel® (dimethylamine salt of dicamba) herbicide and Roundup Powermax® (K salt of glyphosate) at rates of 76 g ae/ ha and 184 g ae/ ha, respectively. This treatment was applied with Turbo Teejet® 11004 spray tips. The BMP treatment consisted of Engenia(N,N-Bis-[aminopropyl]methylamine salt of dicamba) herbicide and Roundup Powermax® at 76 g ae/ ha and 184 g ae/ ha, respectively. Interlock® drift retardant was also applied at 0.29 L/ha. This treatment was applied with Turbo Teejet® Induction Flat

Fan Spray Tips (TTI) with an 04 orifice size. Both treatments were applied at a carrier volume of 94 L/ha and a ground speed of 19.3 KPH. A custom built spray boom was attached to John Deere 6700 High Cycle applicator to deliver herbicide treatments. To make the custom boom, a 4.2 meter long, one square inch, hollow metal tube was attached under the central spray boom of the JD 6700. Eight nozzle bodies were placed onto the metal tube equally spaced 48 cm apart. Turbo Teejet® spray nozzles were attached to these nozzle bodies for the Standard treatment. Eight additional nozzle bodies containing TTI spray nozzles were placed next to those facing opposite direction in order to prevent contamination between treatments. A rubber spray hose was used to connect between nozzle bodies. This same hose was used to connect the two spray nozzle types to two 140 liter spray cans which contain the respective herbicide treatments. Compressed air was used to pressurize the spray cans and force herbicide solution out of the spray tips. Target soybean growth stage for herbicide application was in the R1 to R2 stages of development (Fehr and Caviness, 1977). Spray boom height was 60 cm above the crop canopy. Target wind speeds for application were between 9 - 16 KPH.

Experimental Layout

This experiment was conducted at the MSU Black Belt Experiment Station in Brooksville, MS on a Brooksville silty clay soil. Non-dicamba tolerant soybean was utilized as a bio-indicator for herbicide drift because of their sensitivity to dicamba. Soybean variety Pioneer 95Y70, were planted on May 23, 2013 at a rate of 150,000 seed per acre with 96 cm row spacing. The treated areas were located on the upwind side of the field (Fig. 4.1) and measured 90 meters long by 30 meters wide (32 rows). A 60 meter buffer area was left between treated areas to prevent contamination between treatments.

Rating transects were designated in the downwind portion of the field and data were collected at set distances from the treated area edge to estimate treatment effects. These transects were evenly spaced 15 meters apart along the downwind edges of the treated areas. Untreated check plots were set up on the upwind side of each treated area (Fig. 4.1).

Data Collection

A weather station[3] was on site to collect data during and after application. Weather stations were set to record on one second intervals during treatment application and on one minute intervals for the subsequent 48 hours. Wind speeds averaged 7 KPH for both treatments. Wind speeds ranged from 3 to 12 KPH for the standard treatment, and 3. to 10 KPH for the BMP treatment. As previously mentioned, rating transects for data collection were designated in the downwind portion of the experimental area. Data were collected along these transects in four row increments beginning at the rows adjacent to the treated area and continuing out to row 40 from the treated area edge. Data were then collected in eight row increments out to row 80. From there, data were collected in 20 row increments out to row 140. Ten check plots were also designated in equally spaced intervals 5 meters from the upwind side of the treated areas. Data were collected on the center rows of each experimental unit. Percent visual injury and plant heights were taken from all treated and untreated points at 14 and 28 days after treatment

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[3] Wireless Vantage Pro2 Weather Station. Davis Instruments Corp. 3465 Diablo Ave. Hayward, California 94545 USA

(DAT). Yield data were recorded on the field using an AgLeader™ yield monitor to assess any potential herbicide drift affects.

Statistical Methods

In order to identify distances beyond which soybean injury due to dicamba drift dropped below 15 and 5%, visual injury data was analyzed using a linear regression of visual injury and distance. Analysis was performed using the PROC GLM procedure in SAS version 9.3. This particular method fits a log linear relationship between percent visual injury and distance. This gives an estimated value of predicted injury levels at given distances away from the initial spray application edge. A segmented regression, or piecewise regression technique was performed on plant height and yield data in order to determine distances to "no effects" of herbicide drift. This method has previously been shown to be effective in determining thresholds and edge effects (Toms and Lesperance, 2003). This technique joins two lines at unknown points, or hinge points. The first line, having a positive trend, represents distances affected by dicamba drift. This line rises to a second, horizontal line or "plateau", which would reflect distances from the spray edge where no significant dicamba drift effects were observed. The hinge point between the two lines estimates a distance to "no effects" of dicamba drift on soybean heights or yield. Analysis was performed in SAS 9.3 using the PROC NLMIXED procedure.

Results and Discussion

These data indicate distances that plant injury and reductions in plant height occur were lessened with treatments applied by the Best Management Practices compared to the standard herbicide application procedures. Analysis of the visual injury ratings showed that the distance to which percent visual injury fell below 15% for the Standard treatment was 24 m at 14 DAT and 34 m at 28 DAT (Table 4.1). These distances for the BMP treatment were 9 and 15 m at 14 and 28 DAT, respectively (Table 41). The distances at which percent visual injury fell below 5% at 14 DAT were 52 and 28 m for the Standard and BMP treatments, respectively (Table 4.1). At 28 DAT, the distances at which percent visual injury fell below 5% were 66 and 39 m for the Standard and BMP treatments, respectively (Table 4.1). The regression curves, as well as the visual injury ratings for the 14 DAT rating time are shown in Figure 4.2. Visual injury ratings and the regression curves for that data taken at 28 DAT can be seen in Figure 4.3. Reductions in plant heights at 14 DAT were found out to 20 m and 5 m for the Standard and BMP treatments, respectively (Table 4.1). At 28 DAT, reductions in plant heights were seen out to 20 and 14 m for the Standard and BMP treatments, respectively (Table 4.1). Plant height data as well as the segmented regression plateaus for these data can be seen in Figures 4.4 and 4.5. Yield data were inconclusive. The natural spatial variability of the field precluded an accurate assessment of treatment effects on soybean yield.

Conclusions

In conclusion, the BMP treatment reduced the distances to which visual injury fell below 15% and 5% at both 14 and 28 DAT when compared to the Standard treatment. The BMP treatment also showed a reduced distance to “no-effect” on plant heights compared to the standard treatment 14 and 28 DAT. These data indicate Best Management Practices can reduce the distance to which soybean injury and plant heights are affected by dicamba herbicide drift when compared to standard application practices. Application decisions such as spray nozzle selection, carrier volume, spray pressure, application speed, etc., will each influence the potential for herbicides to move off-target and onto susceptible plant species. As always, applicators should be aware of environmental conditions at the time of application as well as high risk zones (i.e. bee hives, residential areas, susceptible crops) near the application area and use that information to make proper spray or no-spray decisions. Further research is recommended to better understand the effects of Best Management Practices in reducing potential dicamba drift injury and height and yield reductions.

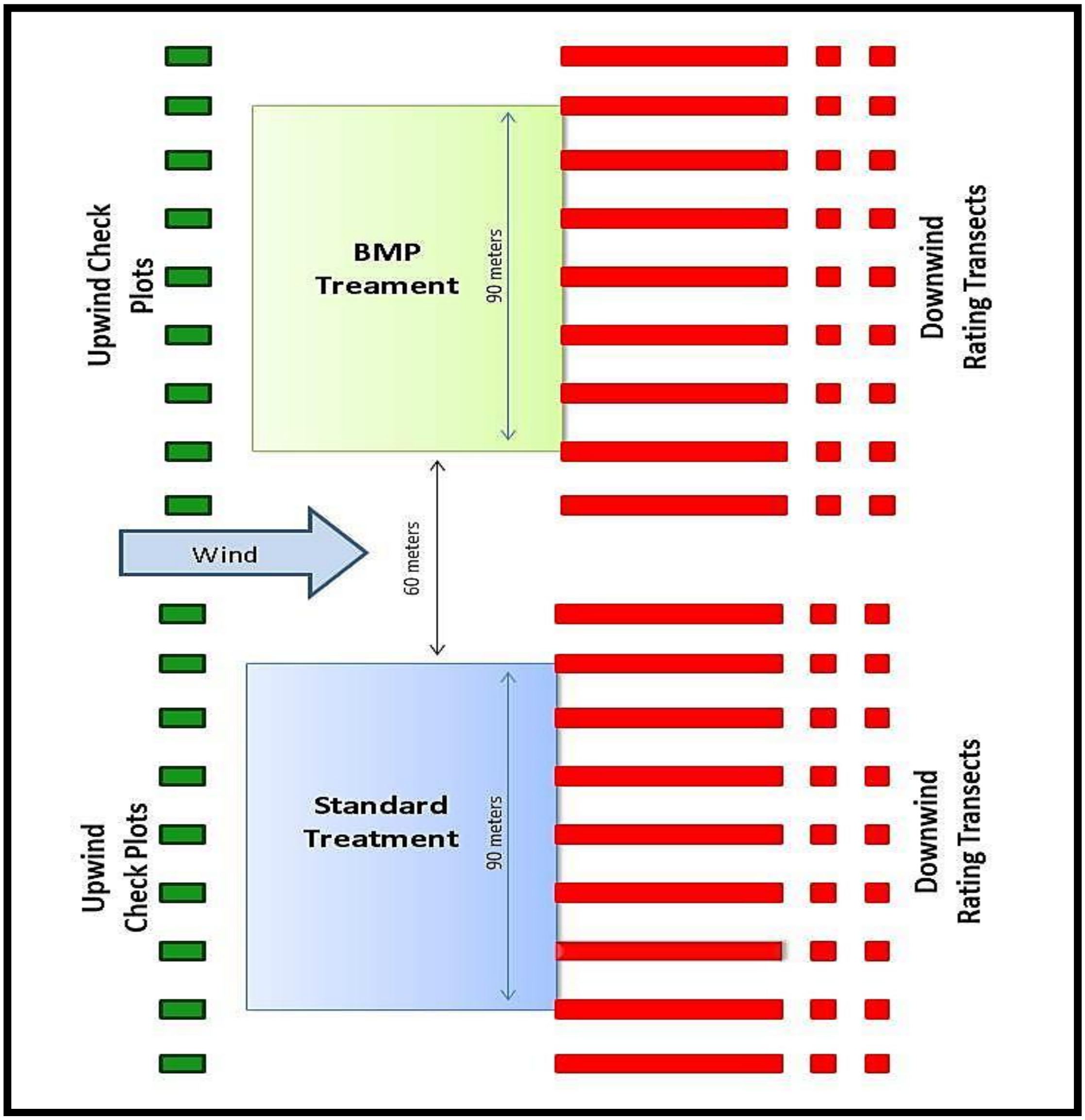

Figure 4.1 2013 BMP Drift trial experimental layout.

The area receiving the BMP treatment is designated in light green. The Standard treatment treated area is designated in blue. Soybean rows run parallel to treated areas. Multiple sprayer passes were made beginning on the most downwind side of the treated areas. Sprayer direction moved from the bottom edge of the treated area upwards with wind direction moving from left to right. Check plots are designated in dark green on the upwind side of treated areas. Rating transects are designated in red. At distances closest to the treated area edge, data were collected every four rows. Beginning at row 41, data were collected every 8 rows. Beginning at row 81, data were collected every 20 rows.

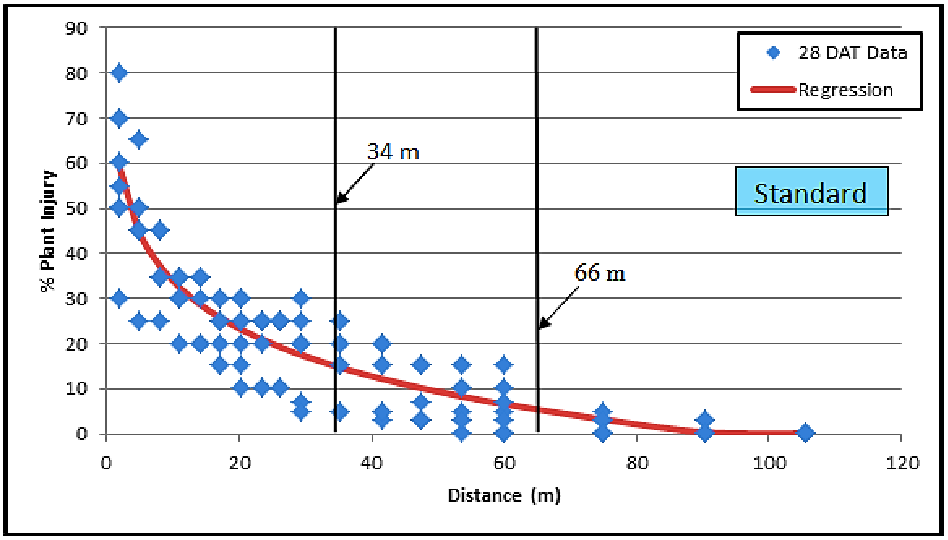

Figure 4.2 28 DAT visual injury regression analysis.

This graph reflects Standard treatment data. Distance is expressed as meters away from treated area edge. Blue points in graphs represent observed visual injury levels at each rating distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

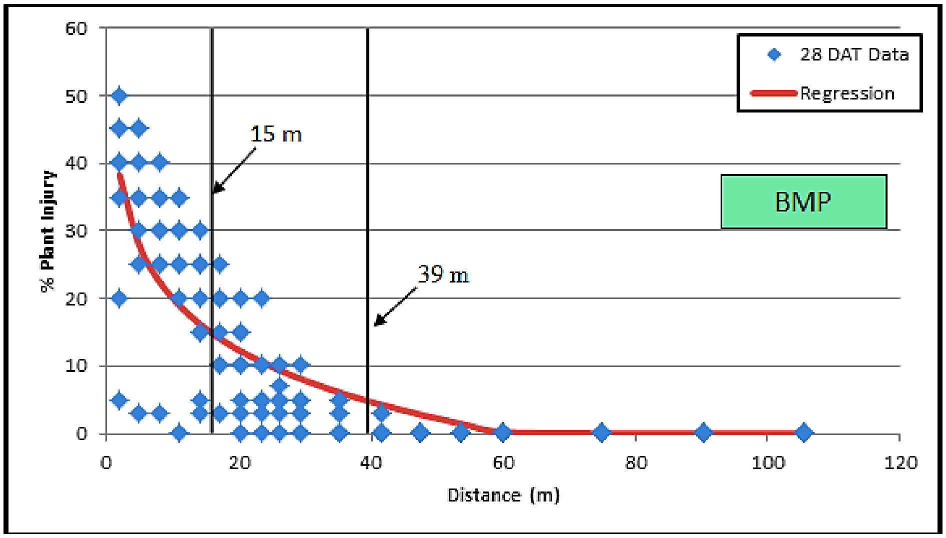

Figure 4.3 28 DAT visual injury regression analysis.

This graph reflects BMP treatment data. Distance is expressed as meters away from treated area edge. Blue points in graphs represent observed visual injury levels at each rating distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. The left vertical bar on each figure shows the estimated distance beyond which visual injury drops below 15%. The right vertical bars indicate estimated distances beyond which visual injury drops below 5%.

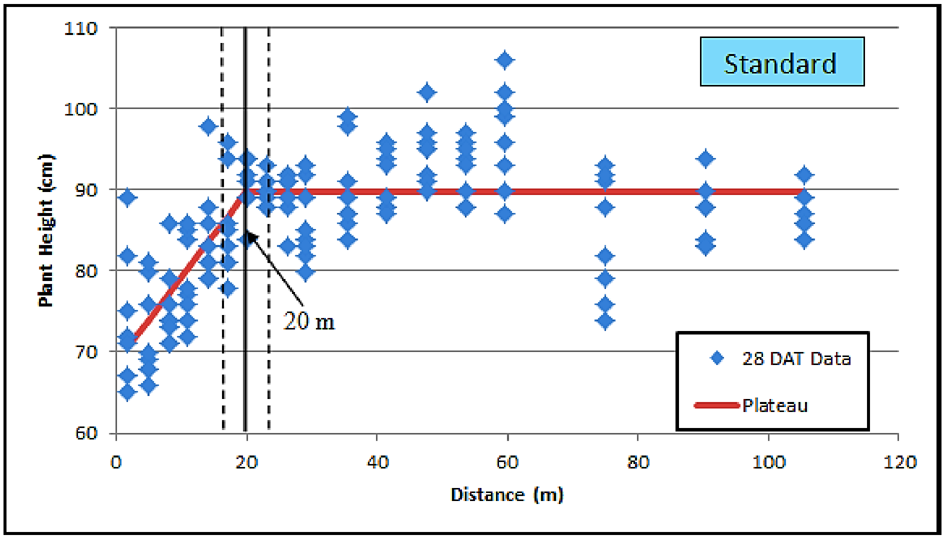

Figure 4.4 28 DAT Segmented regression analysis of plant height data.

This graph reflects Standard treatment data. Distance represents meters away from the treated area edge. Blue points on graphs represent average soybean height (expressed in centimeters) measured from each rating transect at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to “no dicamba effect” on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

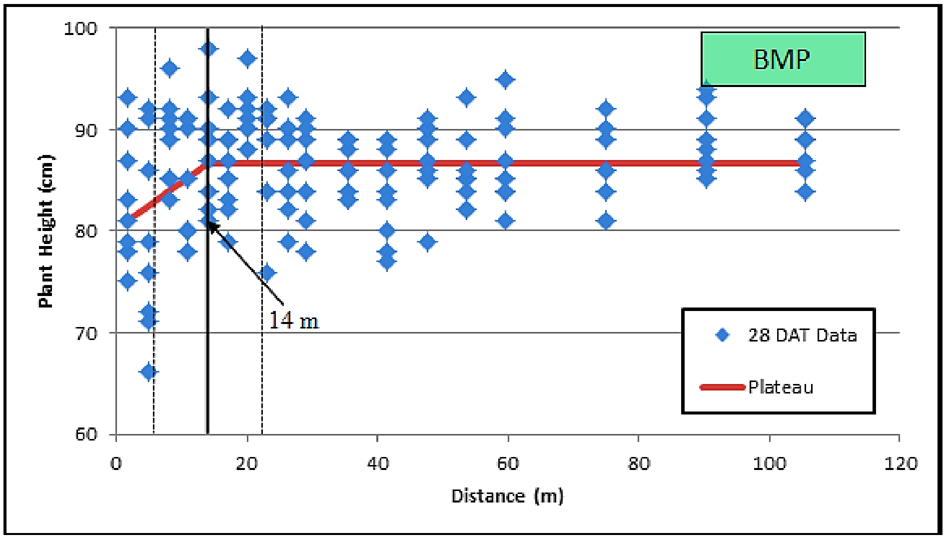

Figure 4.5 28 DAT Segmented regression analysis of plant height data.

The top graph reflects Standard treatment data and bottom graph reflects BMP treatment data. Distance represents meters away from the treated area edge. Blue points on graphs represent average soybean height (expressed in centimeters) measured from each rating transect at a given distance. The red lines represent the segmented regression analysis of soybean height. The solid vertical bars indicate the hinge point representing the distance to “no dicamba effect” on soybean height. Dashed lines represent the confidence interval for the hinge point estimate.

Table 4.1 Results summary of soybean injury and height regression data.

	15% Plant Injury[a]		**5% Plant Injury**[b]		**Plant Height**[c]	
Treatment	**14 DAT**[d]	**28 DAT**	**14 DAT**	**28 DAT**	**14 DAT**	**28 DAT**
	---------------------------------Meters[e]---------------------------------					
Standard[f]	24	34	52	66	20	20
BMP[g]	9	15	28	33	5	14

[a] Estimated distance beyond which visual soybean injury drops below 15%

[b] Estimated distance beyond which visual soybean injury drops below 5%

[c] Segmented regression analysis of soybean height data showing distance to "no treatment effects"

[d] Days after treatment

[e] Distance away from treated area edge expressed in meters

[f] Results using "Standard" treatment

[g] Results using Best Management Practices treatment

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CHAPTER V

EVALUATION OF HERBICIDE FORMULATION AND SPRAY TIP SELECTION ON 2,4-D SPRAY DRIFT IN COTTON

Abstract

In 2012 and 2013, experiments were conducted in order to better understand the off target movement of 2,4-D herbicide when applied under field conditions. The 2012 study was conducted using two 2,4-D formulations and two spray nozzle selections combined into three different treatments. Treatment 1 was a mixture of glyphosate and 2,4-D amine (DMA) at 1,120 and 1,065 g ae/ha, respectively applied with Teejet® XR 11003 spray nozzles. Treatment 2 was the herbicide GF-2726 applied at 2,185 g ae/ha using Teejet® Extended Range (XR) 11003 spray nozzles. Treatment 3 was the GF-2726 herbicide applied at the same rate using Teejet® Air Induction Extended Range Flat Spray Tips (AIXR) 11003 spray nozzles. GF-2726 is a Dow 2,4-D formulation combining of the dimethylamine salt of glyphosate and the choline salt of 2,4-D containing 0.45 lb ae glyphosate /liter and 0.42 lb ae 2,4-D /liter. All treatments included Rhodamine WT spray dye at 0.2% v/v. Treatments were applied at a carrier volume of 94 L/ha and a ground speed of 9.6 KPH using a custom built spray boom. The 2013 trial consisted of one single treatment, GF-2726 applied at 2,185 g ae/ha. Rhodamine WT spray dye was included at 0.2% v/v. Herbicide was applied with AIXR 11004 spray nozzles using a John Deere® 6700 High Cycle applicator with a 18 m spray boom calibrated to deliver 140 L/ha at a ground speed of 14.4 KPH. Treatments were applied to non – 2,4-D tolerant cotton because of its sensitivity to 2,4-D herbicide. For the 2012 experiment, at 28 DAT, the distances to which visual injury fell below 15% were 20, 21, and 31 meters from the treated area edge for the GF-2726 AIXR, DMA XR, and GF-2726 XR treatments, respectively. The distance beyond which injury was less than 5% were 57, 60, and 86 meters for the DMA XR, GF-2726 AIXR, and GF-2726 XR, respectively. The 2013 results estimate distances of 231 and 479 meters required for 2,4-D injury levels to fall below 15% and 5%, respectively. The data indicate the importance of nozzle selection when applying herbicides. They also demonstrate the effect of increased wind speeds and different application techniques on off-target movement.

Nomenclature: 2,4-D; glyphosate; Cotton, *Gossypium hirsutum* L.

Key Words: Herbicide, nozzle, formulation, segmented regression, visual injury, yield.

Introduction

The agricultural industry saw vast changes with the advent of glyphosate tolerant cropping systems. Adoption of this technology was rapid because it was designed to provide a simple, effective weed management strategy which resulted in decreases in the costs generally associated with controlling weed populations (Duke and Powles, 2009). In spite of the many benefits of glyphosate tolerant crops, it also brought about one of the most significant problems facing agriculture today, which is the control of glyphosate-resistant weeds. Weed resistance to herbicides did not begin with the introduction of herbicide-tolerant crops. However, the over-reliance on the glyphosate technology and the lack of incorporating herbicides with other modes of action (MOA) into weed management strategies placed high levels of selection pressure on weed populations. This led to the increase in weed species that were either poorly controlled by glyphosate or completely resistant to the herbicide (Vencil et al., 2012). Some of the most troublesome glyphosate-resistant weed species in the United States are tall waterhemp, johnsongrass, horseweed, and Palmer amaranth. A relatively new addition to most troublesome weed species list, Palmer amaranth is now one of the most economically harmful glyphosate-resistant weeds due in part to its prolific seed production (Beckie, 2006). In order to control many of these resistant weed species, it is prudent to incorporate multiple MOA into a weed management plan. Using multiple herbicide chemistries as tank mix partners can also help reduce the occurrence of resistance development compared to repetitive use of herbicides with same modes of action (Powles et al., 1997). A recent study shows the potential for the incorporation of auxin herbicides into a producer's herbicide arsenal. Increase in the control of both resistant and non-resistant weed biotypes was achieved when applying dicamba alone and in combination with glyphosate (Johnson et al., 2010).

In response to the need for new tools to manage herbicide resistance, Dow AgroSciences has developed genetically engineered crops which will be tolerant to applications of 2,4-D as part of their Enlist™ Weed Control System. Along with tolerance to 2,4-D, Enlist™ cotton and soybean will also have tolerance to glyphosate and glufosinate. Enlist™ corn will have all of these as well as tolerance to aryloxyphenoxypropionates. Dow is developing a new choline formulation of 2,4-D which is designed to reduce off-target movement due to volatility and physical drift (Dow AgroSciences, 2011). By incorporating this new technology, producers will be able to incorporate herbicides with numerous MOA's and thereby attack and better manage resistant weed populations. However, due to many plant species' sensitivity to 2,4-D, issues like physical spray, vapor drift, and sprayer hygiene will have to be addressed. Recent studies performed at Mississippi State University examined different application rates and timing effects of 2,4-D in cotton. Treatments consisted of reduced rates beginning with 0.56 kg ae/ha (1X rate) down to 2.19 x 10^{-3} kg ae/ha (1/256X rate). Results showed an increase in cotton injury and yield reduction to plants treated at the 10 node growth stage compared to those treated at the 16 node stage of maturity. At a rate of 8.8 g ai/ha, complete yield loss was observed for plants treated at 10 nodes while only a 10% loss of yield was seen in 16 node cotton. Significant yield loss was seen for all treatments regardless of visual injury level (Smith et al., 2010). These results support previous research which found 2,4-D in its ester formulation caused cotton yield reductions ranging from 59 to 100% over a two year period when applied at a range of 1/400 to 1/100 of a normal rate of 561 g ae/ha. Similar results were found in applications made with the 2,4-D amine formulation (Marple, et. al, 2007). In a similar study, cotton yields were reduced by sublethal rates of 2,4-D and dicamba depending on the dosage and timing of application. (Everitt and Keeling, 2009). Because of these concerns, experiments were conducted in 2012 and 2013 to evaluate the effects of 2,4-D formulation and spray nozzle selection in reducing the potential for physical spray drift.

Materials and Methods

2012 Herbicide Treatment and Application

Three treatments were used in this study. Treatment 1 was a mixture of the dimethylamine salt of glyphosate and 2,4-D amine (XRM-4436) at 1,120 and 1,065 g ae/ha, respectively, applied with Teejet® XR 11003 spray nozzles. Treatment 2 was the herbicide GF-2726 applied at 2,185 g ae/ha with Teejet® XR 11003 spray nozzles. The third treatment was GF-2726 herbicide applied at 2,185 g ae/ha with Teejet® AIXR 11003 spray nozzles. GF-2726 is a Dow 2,4-D formulation combining of the dimethylamine salt of glyphosate and the choline salt of 2,4-D which contains 204 g ae glyphosate and 190 g ae 2,4-D /liter. All treatments included Rhodamine WT spray dye at 0.2% v/v. Treatments were applied in a carrier volume of 94 L/ha and a ground speed of 9.6 KPH. A custom built spray boom was attached to John Deere 6700 High Cycle applicator to deliver herbicide treatments. To make the custom boom, a one inch square hollow metal tube measuring 4.2 m long was attached under the central spray boom of the JD 6700. Eight nozzle bodies were placed onto the metal tube equally spaced 48 cm apart. Teejet® XR spray nozzles were attached to these nozzle bodies. Rubber spray hose was used to connect between nozzle bodies. The hose split at the center of the tube and was connected to a 140 liter spray can containing the glyphosate + 2,4-D herbicide treatment. To avoid potential contamination between herbicide components of treatments, a separate system of nozzles and hoses were used to deliver the GF-2726 herbicide treatment. Because the herbicide being applied was identical for treatments 2 and 3, the same 140 liter can was used to deliver both treatments, with the appropriate nozzles being attached before applying the respective treatment. This system was operated using a John Deere air compressor with each can being individually regulated to deliver the appropriate amount of herbicide. Treatments were applied July 17, 2012, with the cotton roughly 70 cm tall.

2012 Experimental Layout

This experiment was conducted in Brooksville, MS at the Mississippi State University Black Belt Branch Experiment Station. Cotton was utilized as a bio-indicator for herbicide drift because of its sensitivity to 2,4-D herbicide. Cotton was planted into rows spaced 96 cm apart. The treated areas were located on the upwind side of the field and measured 15 m long by 23 m wide (24 rows). A 30 meter buffer area was left between treated areas to prevent contamination between treatments. Herbicide drift effects were measured in the downwind portion of the field. Untreated check plots were set up on the upwind side of each treated area. A diagram of the field layout can be seen in Figure 5.1.

2013 Herbicide Treatment and Application

The 2013 experiment consisted of only one treatment applied over a significantly larger area compared to 2012. The herbicide treatment used in this study was the numbered compound GF-2726 applied at 2,185 g ae/ha. Included with this herbicide was Rhodamine WT spray dye at 0.2% v/v. Herbicide was applied with Teejet® Air Induction Extended Range Flat Spray Tips (AIXR) with a spray angle of 110 degrees and an orifice size of 04. The treatment was applied when cotton had reached the three to four leaf stage of development. The herbicide treatment was applied using a John Deere® 6700 High Cycle applicator with a 18 m spray boom calibrated to deliver 140 L/ha at a ground speed of 14 KPH. The spray boom was primed at a location away from the test area. Spray boom height was 61 cm above the crop canopy. Target wind speeds for application were 8 to 11 KPH at angles perpendicular to the treated areas. When wind speeds and direction reached specified thresholds, the herbicide application was made to allow the treatment to drift onto the downwind portion of the field. Three sprayer passes were made in order to cover the entire treated area.

2013 Experimental Layout

This experiment was conducted in Brooksville, MS at the Mississippi State University Black Belt Experiment Station. Roundup Ready® cotton were utilized as a bio-indicator for herbicide drift because of their sensitivity to 2,4-D. Phytogen 375 cotton was planted at a rate of 44,324 seed/acre on May 21, 2013 into rows spaced 96 cm apart. The treated area was located on the upwind side of the field (Fig 5.2) and measured 260 m long and 55 m wide. Rating transects were designated in the downwind portion of the field to estimate 2,4-D drift effects. Three transects were evenly spaced along the treated edge 15 m apart at 115, 130, and 145 m. Transects were oriented perpendicular to the spray direction and data were collected at set distances from the treated area edge (Fig. 5.2). Untreated check plots were also set up on the upwind side of the treated area at these same distances for comparison (Fig. 5.2).

2012 Field Trial Data Collection

A weather station[4] was installed adjacent to the field to collect data during and after application. Desired wind speeds for treatment application were between 5 and 16 KPH, with target speeds of 8 to 11 KPH. Actual wind speeds measured from 2 to 12 KPH with average wind speeds of 9 KPH.

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[4] Wireless Vantage Pro2 Weather Station. Davis Instruments Corp. 3465 Diablo Ave. Hayward, California 94545 USA

During application, petri dishes were placed along transects at distances of 0, 2, 3.6, 7.6, 15, 30, and 76 m from the treated area edge to collect herbicide spray drift particles. Petri dishes were also placed in the treated area and upwind check plots to collect herbicide particles. The Petri dishes were placed on platforms set at cotton canopy height. The platforms were constructed of 12 cm by 20 cm plywood pieces attached to fiberglass fence posts. Petri dishes were collected from the field after allowing time for spray particles to settle. Tyvek® suits were worn while petri dishes were collected. Collection started with the petri dish most distant from the treatment swath and continued toward the treatment swath with the petri dish closest to the treated swath collected last in order to prevent contamination. For rating purposes, the downwind portion of the field was gridded into sections of four rows by 7.6 m long (Figure 5.1). Visual injury ratings were measured on the center two rows of each section at 21, 28, and 67 DAT. Yield data were recorded on the field with an AgLeader™ yield monitor to assess any potential herbicide drift affects.

2013 Field Trial Data Collection

A weather station[4] was also on site in 2013 to collect data during and after application. Target wind speeds for application were between 8 to 16 KPH. Actual recorded wind speeds during treatment application ranged from 5 to 24 KPH, with average wind speeds of 12.8 KPH.

As previously mentioned, rating transects for data collection were designated in the downwind portion of the experimental area. During application, petri dishes were placed along these transects at distances of 4, 8, 15, 30, 38, 45, 60, 69, and 76 m from the treated area edge to collect herbicide spray drift particles. Petri dishes were also placed in the treated area (1 per sprayer pass) and upwind check plots to collect herbicide particles. Fifteen minutes were allowed to pass before collecting the petri dishes to allow herbicide particles to settle. Tyvek® suits were worn while collecting petri dishes, and dishes were recovered beginning with the distance furthest from the treated area and working backwards in order to prevent contamination. Injury ratings were collected in the downwind transects at the same points where the petri dishes were located at 14, 28, and 42 DAT. Past 76 m, injury ratings were made in 15 m intervals out to 198 m away from the treated area edge. Injury ratings collected were percent plant injury, percent plant epinasty, and percent epinasty in the uppermost leaf. Nodes above cracked boll data were also collected prior to harvest to determine drift effects on cotton maturity. Yield data were recorded on the field using an AgLeader™ yield monitor to assess any potential herbicide drift affects.

Statistical Methods

Analysis of visual injury data from both the 2012 and 2013 field trials was performed using the PROC GLM procedure in SAS 9.3 to obtain a linear regression of visual injury using the log of the distance value. This method fits a log linear relationship between percent visual injury and distance. By doing this, the distances for which injury drops below 15% and 5% can be identified. A segmented regression, or piecewise regression technique was used for the 2012 field trial data to analyze effects on cotton yield due to herbicide drift. This method has been shown to be effective in determining thresholds and edge effects (Toms and Lesperance, 2003). Sometimes called “broken-stick” models, this technique joins two lines at unknown points, or hinge points. The first line, having a positive trend, represents distances which were affected by dicamba drift.

This line rises to a second, horizontal line or “plateau”, which would represent distances with no treatment effects. The hinge point between the two lines estimates a distance to treatment effects. This analysis was performed in SAS version 9.3 with PROC NLMIXED.

Results and Discussion

2012 Field Trial Results

Analysis of the visual injury ratings showed that the distances to which percent visual injury fell below 15% for the DMA applied with XR nozzles were 19, 21, and 10 m from the treated area edge 21, 28, and 67 DAT, respectively (Table 5.1). Distances beyond which injury dropped below 5% for this treatment were 56, 57, and 45 m at 21, 28, and 67 DAT, respectively (Table 5.1). Distances to which percent visual injury fell below 15% for the GF-2726 applied with XR tips were 30, 31, and 12 m from the treated area edge at 21, 28, and 67 DAT, respectively (Table 5.1). Distances beyond which injury dropped below 5% for this treatment were 80, 86, 55 m at 21, 28, and 67 DAT, respectively (Table 5.1). Distances to which percent visual injury fell below 15% for the GF-2726 applied with AIXR tips were 21, 20, and 8 m at 21, 20, and 67 DAT, respectively (Table 5.1). Distances beyond which injury dropped below 5% for this treatment were 60, 60, and 41 m away from the treated area at 21, 28, and 67 DAT, respectively (Table 5.1). Visual injury regression curves for 21, 28, and 67 DAT can be seen in Figures 5.3, 5.4, and 5.5, respectively. Distances to “no effects” on cotton yields were 11, 19, and 22 m from the treated area edge for the GF-2726 AIXR, DMA XR, and GF-2726 XR treatments, respectively (Table 5.1). The plateaus for yield data can be seen in Figure 5.6.

2013 Field Trial Results

Analysis of visual injury ratings shows a substantial amount of off-target herbicide movement. Estimated distances beyond which plant injury drops below 15% were found 112, 231, and 109 m away from the treated area edge at 14, 28, and 42 DAT, respectively (Figure 5.7). The estimated distances from the treated area at which plant injury dropped below 5% were 252, 479, and 198 m 14, 28, and 42 DAT, respectively (Figure 5.7). These data show the greatest amount of plant injury at 28 DAT. While injury was still present at all rating distances 42 DAT, the severity was reduced, showing the propensity for cotton plants to overcome some drift damage applied earlier in the growth process. Yield data were inconclusive due to a mechanical failure of the cotton yield monitor. The natural spatial variability of the field precluded an accurate assessment of treatment effects on cotton yield.

Conclusions

In conclusion, these results document the importance of spray nozzle selection on off-target 2,4-D movement. Results of the 2012 study show the presence of 2,4-D injury does not automatically translate into yield loss. Both studies showed the highest levels of 2,4-D injury was observed at 28 DAT, with less injury the later rating dates. Due to the lack of yield data in 2013, 2,4-D drift effects on yield trends cannot be compared. However, in 2012, using the low-drift 2,4-D formulation in conjunction with spray nozzles designed to provide coarser droplets did reduce the distance herbicide drift affected cotton yields. Data collected in 2013 showed off-target herbicide movement occurred great distances from the treated area. This trial illustrates the increased potential for issues of herbicide movement off target with the release and subsequent adoption of new herbicide tolerant cropping system technologies. When using these technologies, proper application techniques as well as wise decision making in regards to applying the herbicide are vital to help reduce the amount of off-target movement onto susceptible plant species.

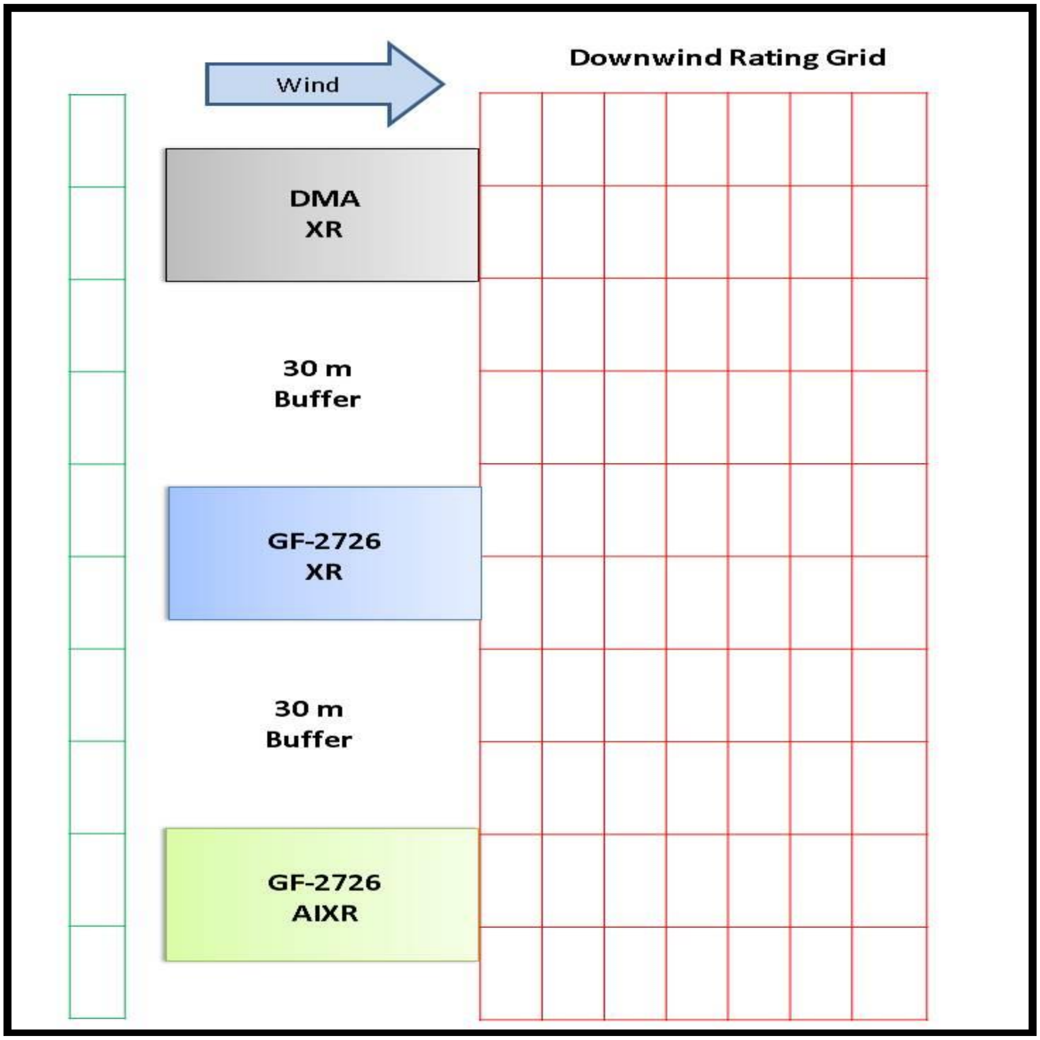

Figure 5.1 2012 2,4-D Drift trial experimental layout.

The treated areas are designated by grey, blue, and light green boxes. Cotton rows run parallel to treated areas. Multiple sprayer passes were made beginning on the most downwind side of the treated areas. Sprayer direction moved up and down through the treated areas with wind direction moving from left to right. Check plots are designated in dark green on the upwind side of treated areas. Data were collected downwind of the treated areas. Ratings were taken in four row increments away from the treated area until no visible dicamba injury symptoms were observed.

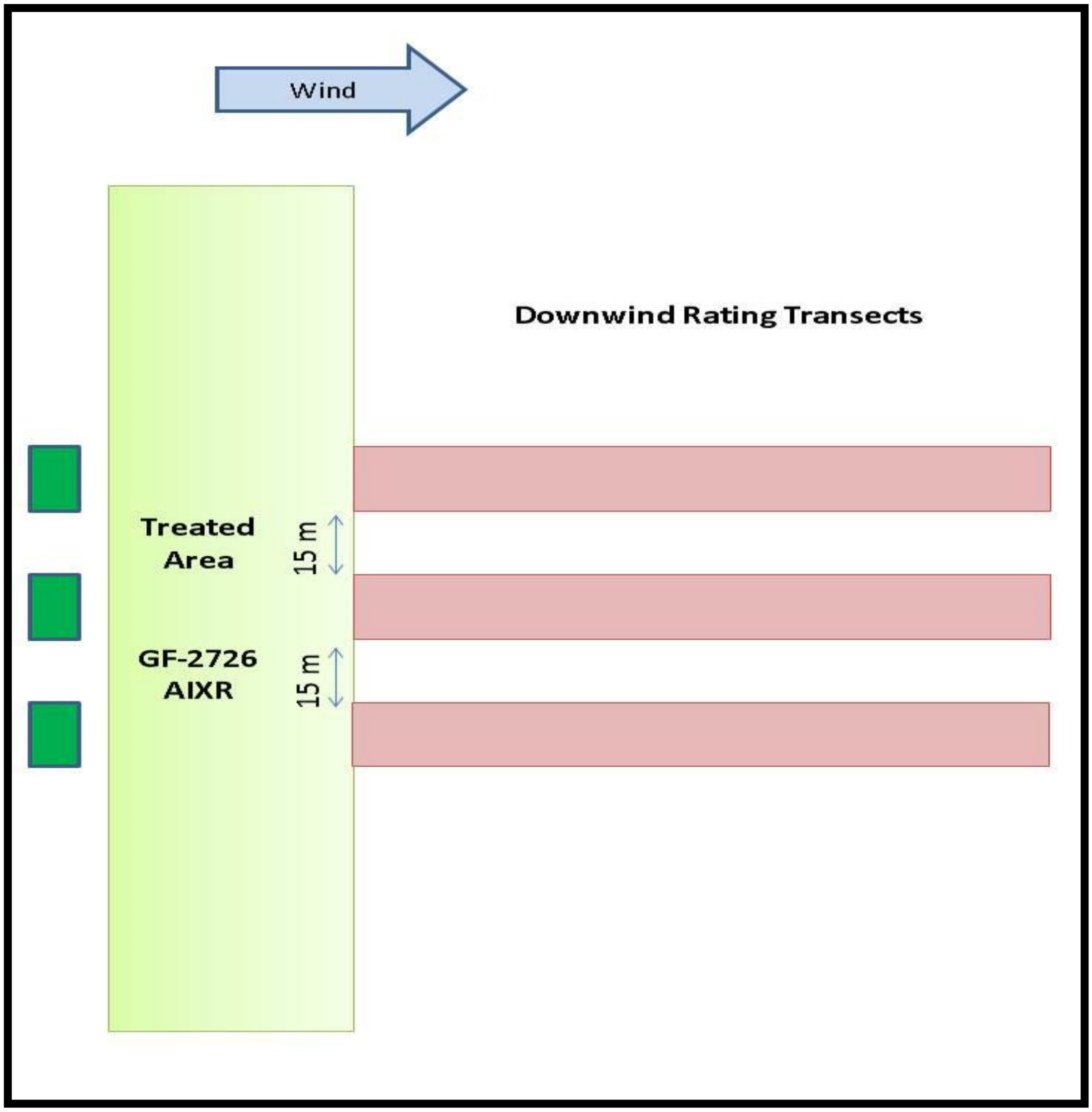

Figure 5.2 2103 2,4-D Drift trial experimental layout.

Treated area is designated in light green. Cotton rows run parallel to treated area. Multiple sprayer passes were made beginning on the most downwind side of the treated areas. Sprayer direction moved up and down through the treated areas with wind direction moving from left to right. Check plots are designated in dark green on the upwind side of treated area. Data were collected along these transects at set distances from the treated area edge at 14, 28, and 42 DAT.

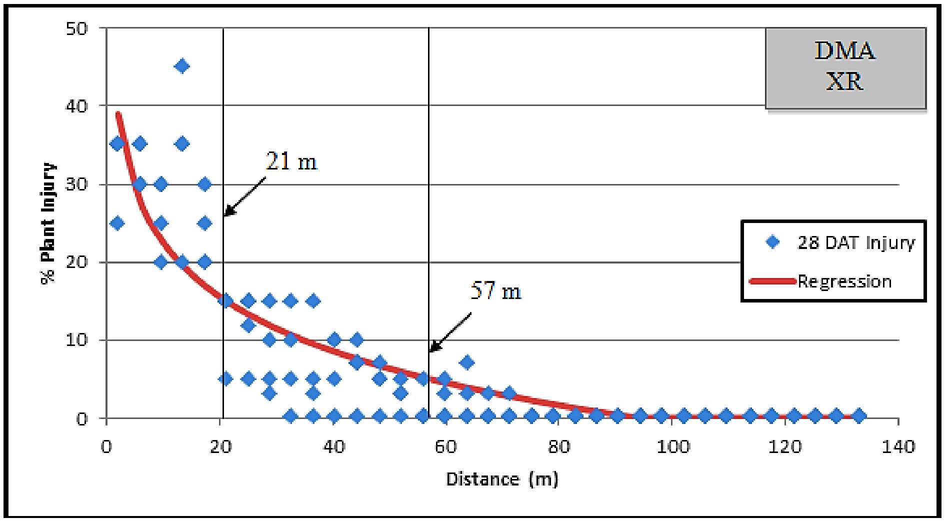

Figure 5.3 2012 Drift trial 28 DAT visual injury regression analysis.

This graph represents data collected for the DMA with XR nozzles treatment. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

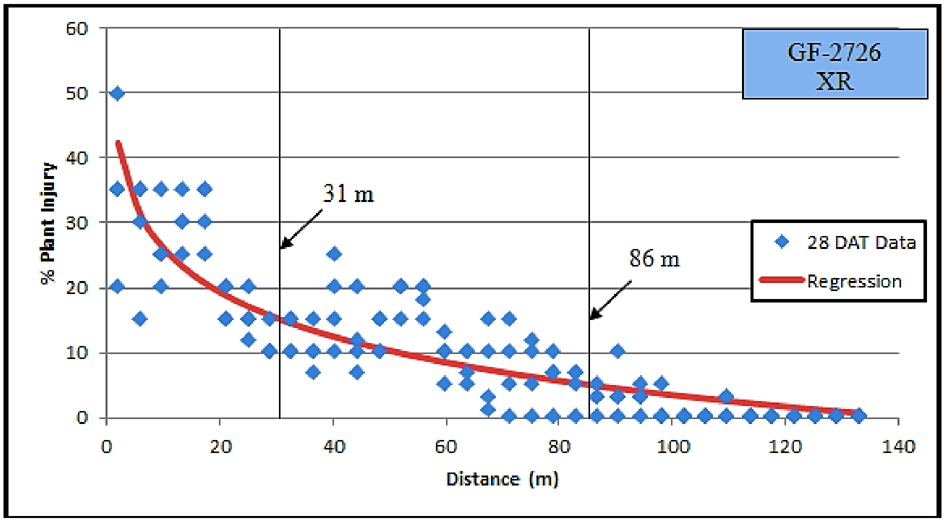

Figure 5.4 2012 Drift trial 28 DAT visual injury regression analysis.

This graph represents data collected for the GF-2726 with XR nozzles treatment. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

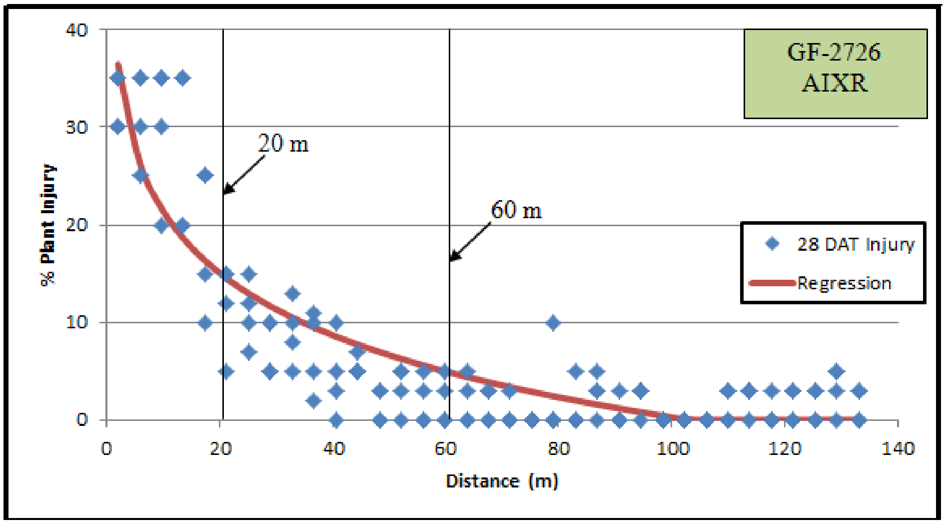

Figure 5.5 2012 Drift trial 28 DAT visual injury regression analysis.

This graph represents data collected for the GF-2726 with AIXR nozzles treatment. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

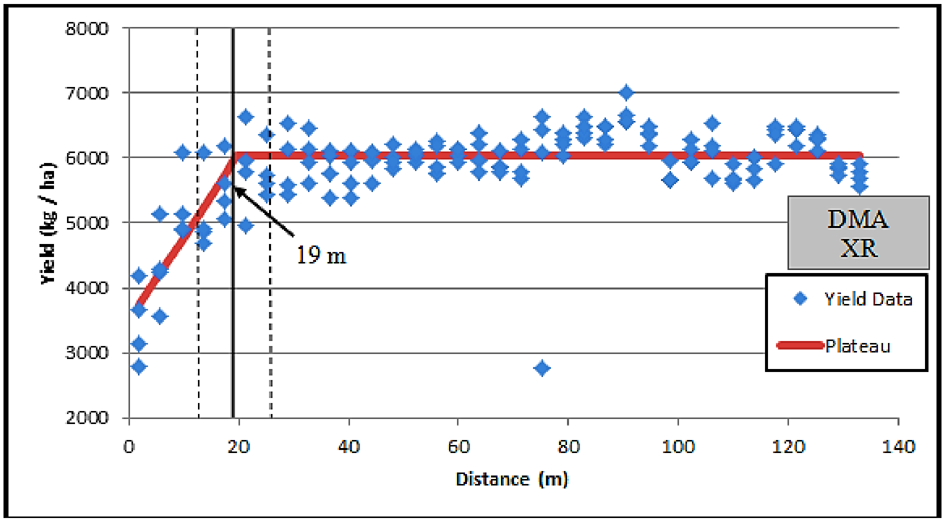

Figure 5.6 Segmented regression analysis of yield data for 2012 drift trial.

This graph represents data collected for the DMA with XR nozzles treatment. Distance is expressed as meters away from the treated area edge. Soybean yield expressed as kilograms per hectare. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. The red line represents the segmented regression analysis of soybean yield. The solid vertical bar indicates the hinge point representing the distance to “no dicamba effect” on soybean yield. Dashed lines represent the confidence interval for the hinge point estimate.

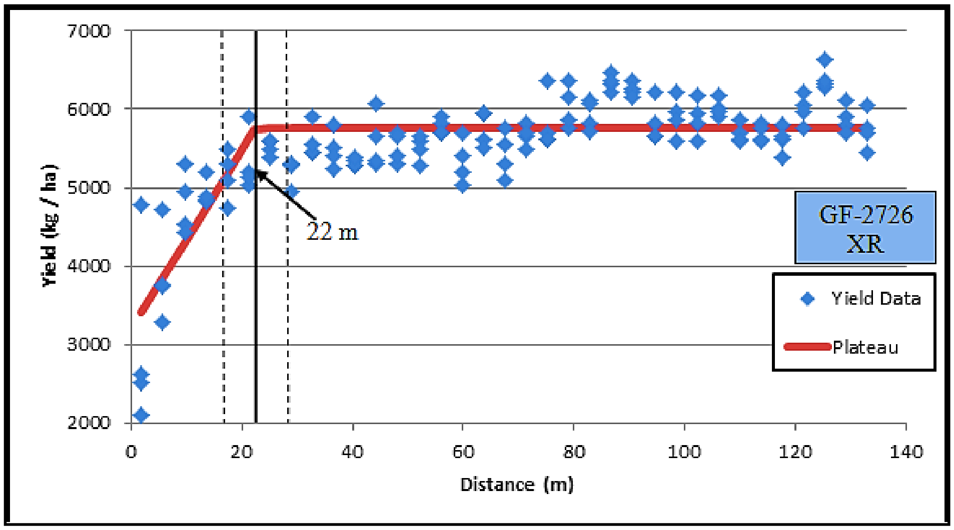

Figure 5.7 Segmented regression analysis of yield data for 2012 drift trial.

This graph represents data collected for the GF-2726 with XR nozzles treatment. Distance is expressed as meters away from the treated area edge. Soybean yield expressed as kilograms per hectare. Blue points on graphs represent soybean yield measured from each rating transect at a given distance. The red line represents the segmented regression analysis of soybean yield. The solid vertical bar indicates the hinge point representing the distance to "no dicamba effect" on soybean yield. Dashed lines represent the confidence interval for the hinge point estimate.

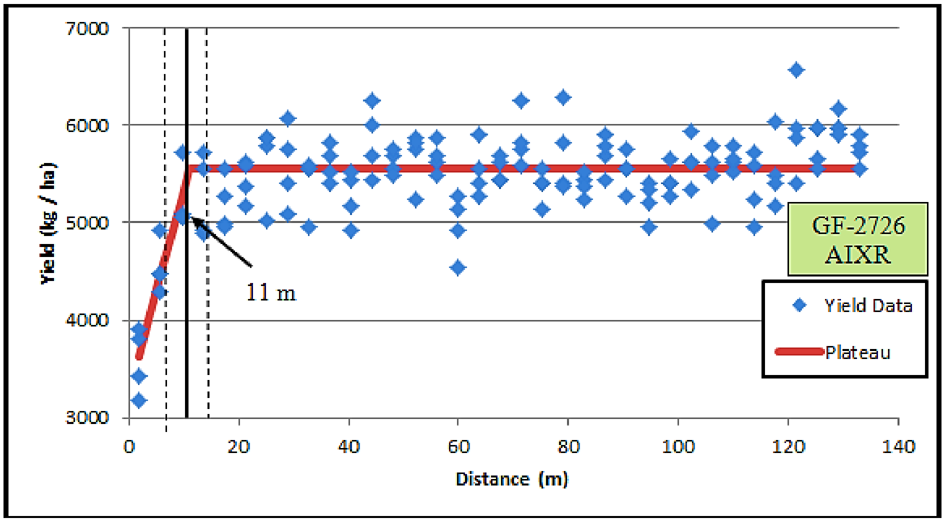

Figure 5.8 Segmented regression analysis of yield data for 2012 drift trial.

This graph represents data collected for the GF-2726 with AIXR nozzles treatment. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

Table 5.1 2012 Drift trial results summary table.

	15% Plant Injury[a]			**5% Plant Injury**[b]			**Yield**[c]
Treatment	**21 DAT**[d]	**28 DAT**	**67 DAT**	**21 DAT**	**28 DAT**	**67 DAT**	**Plateau**
	-----Meters[e]-----						
DMA XR	19	21	10	56	57	45	19
GF-2726 XR	30	31	12	80	86	55	22
GF-2726 AIXR	21	20	8	60	60	41	11

[a] Estimated distance beyond which visual cotton injury drops below 15%
[b] Estimated distance beyond which visual cotton injury drops below 5%
[c] Segmented regression analysis of cotton yield data showing distance to "no treatment effects"
[d] Days after treatment
[e] Distance away from treated area edge expressed in meters
[f] Results using glyphosate + 2,4-D amine applied with Teejet® extended range nozzles
[g] Results using GF-2726 herbicide applied with Teejet® extended range nozzles
[h] Results using GF-2726 herbicide applied with Teejet® air induction extended range nozzles

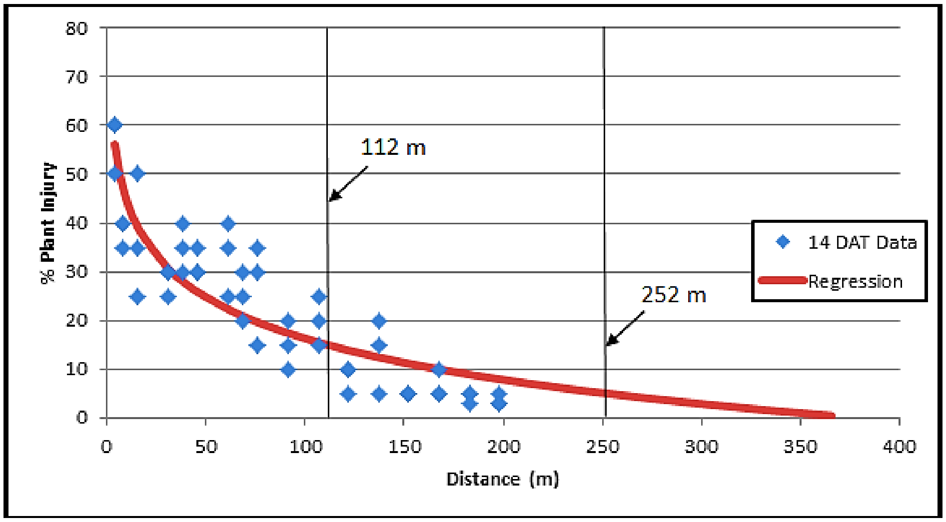

Figure 5.9 2013 Drift trial visual injury regression analysis.

This graph represents data collected 14 DAT. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

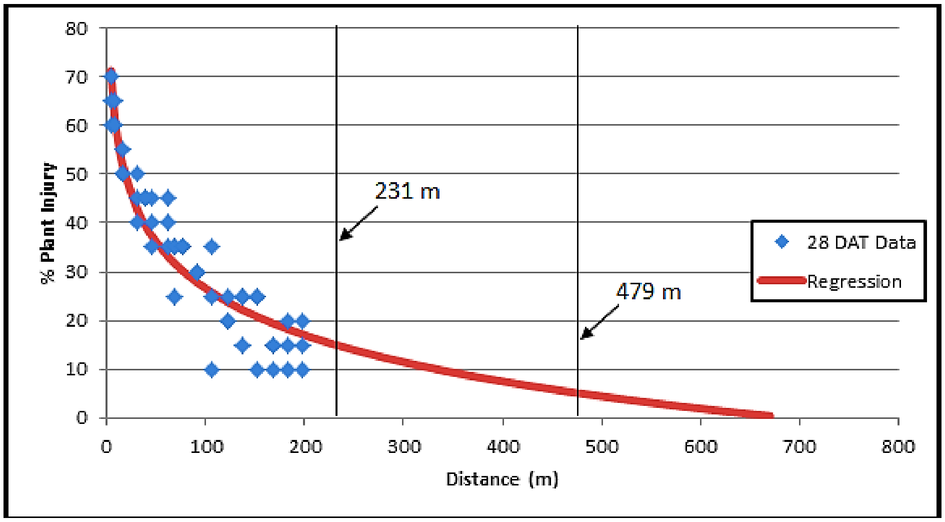

Figure 5.10 2013 Drift trial visual injury regression analysis.

This graph represents data collected 28 DAT. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

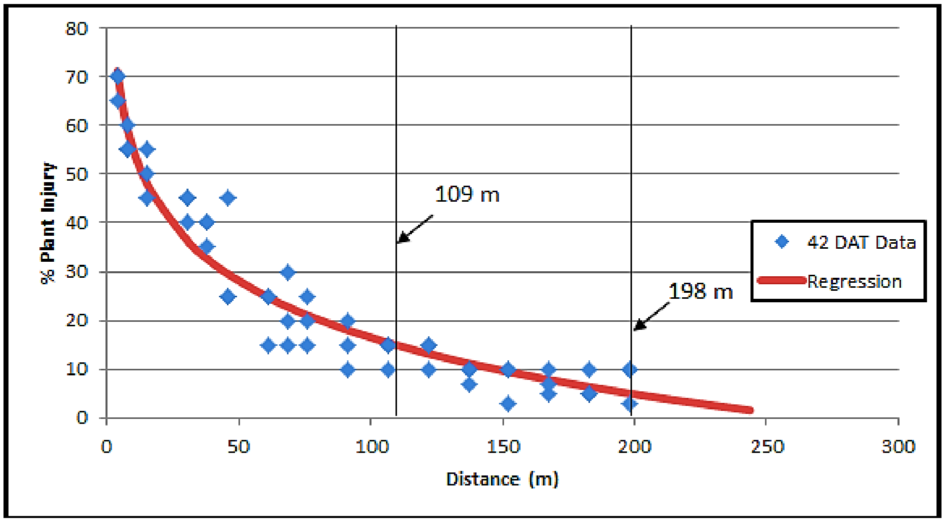

Figure 5.11 2013 Drift trial visual injury regression analysis.

This graph represents shows data collected 42 DAT. Distance is expressed as meters away from the treated area edge. Blue points on graphs represent visual injury observed from each rating transect at a given distance. The red lines represent the regression analysis of visual injury as a function of the log of the distance. Vertical bars on each figure shows the estimated distance beyond which visual injury drops below 15% (left) and 5% (right).

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