ABSTRACT

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Approval is pending for the registration of dicamba tolerant (DT) soybeans [*Glycine ma*x (L.) Merr.]. The use of dicamba on DT soybeans and other DT crops will increase. Risks associated with dicamba applications include off-target movement to sensitive crops. The objective of this study was to evaluate misapplication of dicamba on non-DT soybeans. Greenhouse and field studies examined a rate titration (0.004 to 0.5 lb ai a^{-1}) of dicamba on non-DT soybeans (V3 stage – three trifoliates). Field studies also examined dicamba application to various growth stages (PRE- preemergence to R5- early pod fill) of non-DT soybeans. Results from the greenhouse and field studies showed that as the rate of dicamba increased, the level of injury to vegetative and yield components also increased. Soybean growth stage at time of application influenced the amount of injury. Less injury was observed when dicamba was applied at the PRE growth stage.

EFFECTS OF A SIMULATED DICAMBA MISAPPLCATION ON NON-TOLERANT SOYBEANS (GLYCINE MAX)

By

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Chapter 1. Literature

Dicamba: An Effective Tool

Background

The herbicide dicamba [3,6-dichloro-2-methoxybenzoic acid] became commercially available in 1967 (Anonymous 2006). Dicamba is a selective, synthetic auxin herbicide which mimics an endogenous auxin (indole-3-acetic acid) naturally found in most plants. Dicamba is a systemic herbicide that moves into the plant from the site of contact and initially flows throughout the xylem. After a period of 12 to 24 hours (h) in the plant, dicamba moves in both the xylem and phloem to areas of high metabolic activity (Boerboom 2004). Dicamba's mode of action (MOA) at low concentration works by causing cell elongation, rapid cell division, and increased turgor in the plant. These effects lead to abnormal growth, destruction of the vascular tissue, and eventual plant death. At high concentrations, dicamba causes an inhibition of cell growth and division, also resulting in plant death (Gleason et al. 2011). A lesser MOA is inhibition of nucleic acid metabolism (WSSA 2007). Dicamba is classified as a Group 4 herbicide by the Weed Science Society of America's (WSSA) herbicide classification system (WSSA 2007).

Dicamba is used as a broadleaf herbicide in corn (*Zea mays* L.) for early pre-plant (EPP), preemergence (PRE), and postemergence (POST) applications (Loux et al. 2009). It is one of the most commonly used growth regulator herbicides in the United States (U.S.) in addition to 2, 4-D [(2, 4-dichlorophenoxy) acetic acid] (Young 2006). Dicamba has been recommended for effective broadleaf weed control for over 40 years (Behrens et al. 2007). Dicamba is effective in control of broadleaf weeds, particularly plants that have developed glyphosate [N-(phosphonomethyl)glycine] resistance (Kruger et al. 2010). In addition to corn, dicamba is labeled for use in cotton (*Gossypium hirsutum* L.), fallow croplands, sorghum [*Sorghum bicolor* (L.) Moench], turf, grass hay, soybean [*Glycine max* L. (Merr.)], sugarcane (*Saccharum officinarum* L.) and various other specialty crop applications (Anonymous 2010). In soybean, dicamba is currently limited to an EPP application with a 14 to 28 day (d) waiting period depending upon rate. Additionally, 1 inch (in) of rainfall is needed during the waiting period. It is also labeled for use as a harvest aid in soybean (Anonymous 2010).

Herbicide Resistant Weeds

The first instance of herbicide resistance was reported in 1970 and involved the discovery of triazine resistant common groundsel (*Senecio vulgaris* L.) (Lebaron and Gressel 1982). Since then many other weeds have developed resistance to various herbicides. Currently, there are 449 weed biotypes worldwide with known herbicide resistance (Heap 2015).

With the advent of glyphosate resistant (GR) soybeans in 1996, farmers were able to adopt a weed control program that was easy, economical, and cost effective. In 2000, Monsanto (Monsanto Co., St. Louis, MO) lost patent rights to glyphosate. With the advent of generic glyphosate, a 40% drop in price occurred (Duke and Powels 2009). GR soybeans allow for POST applications of glyphosate, offering farmers broad spectrum weed control and flexible application timing (Green and Owen 2011). Due to its ease of use and economic benefits, GR crops were widely adapted. Additionally, the adoption of no-till farming, where herbicides are used to kill existing vegetation EPP as opposed to tillage, resulted in an increase of glyphosate usage (Dill et al. 2008). GR crops include soybeans, corn, cotton, alfalfa (*Medicago sativa* L.), sugarbeet (*Beta vulgaris* L.), and canola (*Brassica napus* L.) (Duke and Powels (2009).

In 1995, 5.5 million pounds of glyphosate were applied to the total soybean acreage in the U.S. This number increased to 66 million pounds in 2002 (Young 2006). The increase in use coincided with the increase in the number of GR soybean acres. From 2000 to 2011, the number of acres planted with GR soybeans increased 32% in the U.S. (Mithila et al. 2011). With increased reliance on glyphosate for control of all weeds in a crop, the market share for other herbicides was reduced 20 to 25 % (Shaner 2000). Additionally, the number of chemicals needed to be screened in order to find new herbicide products increased from 1000 in 1950 to 500,000 in 2006 (Green 2007). This meant that new herbicide discovery had become more difficult and time consuming since the advent of glyphosate and GR crops. Glyphosate has become the most widely used herbicide in the world. However, it is becoming a herbicide commonly associated with herbicide resistance in weeds (Green 2007).

With reliance on glyphosate as the sole herbicide for weed control in a crop, several weed species with resistance to glyphosate have developed. Herbicide resistance is caused by speeding up basic evolutionary processes. Herbicide resistant biotypes of weeds exist in nature prior to the introduction of a particular herbicide. Once the susceptible biotypes are killed, the resistant biotypes, which survive the herbicide application, increase in population (WSSA 2015). There are two common mechanisms responsible for plant resistance to a herbicide. One involves increased metabolism of the herbicide in the plant, rendering it inactive. The second involves an altered site of action. An altered site of action will not allow the herbicide to bind and therefore it cannot disrupt the normal physiological functions of the plant (Hager and Sprague 2000).

The first instance of glyphosate resistance was documented in 1996 with rigid ryegrass (*Lolium rigidum* Gaudin) in Australia (Powels et al. 1998). As of January 2015, there were 31weed species throughout the world with known resistance to glyphosate (Heap 2015).

Horseweed [*Conyza canadensis* (L.) Cronq.] is a problematic weed for growers in the U.S. Horseweed populations of 100 plants ft^{-2} can reduce soybean yields by 97 %, while lower populations of 1.5 plants ft^{-2} can result in a 69 % reduction in soybean yield (Bruce and Kells 1990). The first confirmation of glyphosate resistant horseweed occurred in Delaware in 2000 (VanGessel 2001). In addition to horseweed, several other important weeds have developed resistance to glyphosate. These species include palmer amaranth (*Amaranthus palmeri* L.) and tall waterhemp (*Amaranthus tuberculatus* L.) (Heap 2015). Previously, glyphosate was one of the most effective herbicides for control of these species POST (Loux et al. 2009).

Increasingly, the development of weeds with resistance to multiple herbicide MOA’s are being reported. The International Survey of Herbicide Resistant Weeds by Heap (2015) lists 38 weeds that are resistant to two or more MOA’s. In the Mid-Atlantic region, horseweed populations can be found with resistance to both glyphosate and sulfonylurea herbicides (Heap 2015). Weeds with resistance to multiple MOA’s present a problem to growers due to the limited, effective options available for control (Trainer et al. 2005; Loux et al. 2009).

With increased incidence of GR weeds and lack of new MOA herbicides, growers are turning to glyphosate alternatives like dicamba and other growth regulating herbicides (Kruger et al. 2010). An example would be GR horseweed. When dicamba was applied to 12 in plants, over 97 % control was observed (Kruger et al. 2010). The herbicide 2, 4-D was also examined in this study, and provided 81 % control of similar size plants. Byker et al. (2013) found that dicamba applied PRE provided 50 to 60 % control of horseweed 8 weeks (wk) after treatment (WAT). When applied POST, 91 to 100 % control of horseweed was observed 8 WAT. Since its discovery, few weeds have been reported with known resistance to dicamba (Sterling and Hall 1997; Mithila et al. 2011).

With the increase of herbicide resistance in weeds, companies have developed crops with resistance to a number of herbicide MOA's including glyphosate and dicamba. Crops have been developed with tolerance to the following: glufosinate [DL-phosphinothricin], sulfonylureas, HPPD [4-Hydroxyphenylpyruvate dioxygenase] inhibitors, imazamox [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid], and 2, 4-D (Peterson and Thompson 2013). These new herbicide resistant crops will allow EPP, PRE, and POST applications of their respective MOA herbicide(s). This is an effort to control herbicide resistant weeds by applying herbicides where they could not previously be used without injuring the crop.

Dicamba Tolerant Crops

The development of GR weeds and lack of new MOA herbicides have driven development of crops with tolerance to other MOA herbicides such as dicamba (Behrens et al. 2007). Soybeans, corn, and cotton are crops that are being genetically engineered for tolerance to both dicamba and glyphosate (Johnson et al. 2012). Widespread use of dicamba will occur with the advent of these new tolerant crops (Behrens et al. 2007).

Monsanto Co. was responsible for development of soybeans with resistance to dicamba (Green 2007). The company identified the soil bacterium, *Pseudomonas maltophilia,* which degrades dicamba to 3,6-dichlorosalicylic acid. This form of dicamba has little to no herbicidal activity (Behrens et al. 2007 and D'Ordine et al. 2009). The degradation is done by an enzyme, dicamba monooxygenase, which carries out an exocyclic monooxygenation reaction. This reaction converts dicamba to its inactive form. This enzyme is uncommon in plants. The gene in *Pseudomonas maltophilia* which is responsible for this conversion was inserted into select soybean cultivars to create dicamba resistance. Dicamba's effectiveness on hard to control annual and perennial broadleaf weeds has made dicamba a leading candidate for breeding herbicide resistance in crops. Resistance to 2, 4-D is also being bred into crops, due to its effectiveness on hard to control broadleaf weeds (Kruger et al. 2010)

Soybeans that have resistance to dicamba will allow for dicamba applications EPP, PRE, and POST (Monsanto 2015). POST applications of dicamba provide better weed control than EPP or PRE applications. Kruger et al. (2010) found that dicamba applied PRE at 0.25 lb active ingredient (ai) a^{-1} provided less than 60% control of smooth pigweed (*Amaranthus retroflexus* L.), giant ragweed (*Ambrosia trifidia* L.), velvetleaf (*Abutilon theophrasti* L.), palmer amaranth, waterhemp (*Amaranthus rudis spp*.), and morningglory (*Ipomoea spp*.) 28 days after application (DAA). When dicamba was applied at the same rate POST (0-3 in. weed height), control was improved to 90% or above for all species 28 DAA.

Dicamba is also effective at controlling GR biotypes of various broadleaf weeds. When applied POST in combination with glyphosate, dicamba improved control of GR palmer amaranth, common waterhemp, horseweed, and giant ragweed (Kruger et al. 2010). In addition to glyphosate, dicamba can be tank-mixed with other herbicides. When applied alone, 2, 4-D provided 68% control, 4 WAT, of benghal dayflower (*Commelina benghalensis* L.), a common weed in cotton production. When 2, 4-D and dicamba were tank-mixed and applied POST, benghal dayflower control increased to 90%. Early POST tank mix applications of dicamba plus glufosinate improved control of GR palmer amaranth (Merchant et al. 2013). POST applications of glufosinate provided 74 % control; whereas a tank-mix of glufosinate plus dicamba provided over 87 % control of GR palmer amaranth 4 WAT.

Dicamba Concerns and Issues

Dicamba's use has increased in part due to its control of GR weeds (Kruger et al. 2010). Problems associated with dicamba's use include volatility, drift, misapplication, and sprayer contamination (Behrens and Lueschen 1979, Sciumbato et al. 2004, Robinson et al. 2013). Soybeans are sensitive to trace amounts of dicamba and can be inadvertently exposed through a nearby application to corn, sorghum, rangeland, or pasture (Robinson et al. 2013). Measures have been taken to limit the risk of dicamba injury to non-target plants. These include spraying restrictions based on air temperature, time of day when sprayed, and wind (Texas Agricultural Code 1984; Ramsdale and Messersmith 2001). Even with these measures in place, dicamba injury to non-target plants may occur. Dicamba injury to soybeans and other non-target, sensitive plants is manifested in the form of leaf cupping and plant malformation of either vegetative or reproductive components (Owen and Hartzler 2002). Yield can be affected based on growth stage at time of exposure, rate of dicamba reaching the plant, and weather conditions (Robinson et al. 2013). Dicamba was shown to cause injury to soybean at concentrations of 0.4 g ai a^{-1} (0.0008 lb ai a^{-1}) (Auch and Arnold 1978). Others have shown that rates of 0.16 g ai a^{-1} (0.0003 lb ai a^{-1}) can result in soybean yield reduction (Weidenhamer et al. 1989).

Growth stage at time of application may influence yield from dicamba drift. Dicamba applied during the vegetative growth stages of soybeans did not affect reproductive components (Auch and Arnold 1978). This was likely due to the detoxification of dicamba prior to the reproductive stage. The only result was injury to the leaves leading to height reduction. Rate is the factor that determines severity of leaf injury (Auch and Arnold 1978). In instances where a high rate (0.56 kg ai ha^{-1}) (1.2 lb ai a^{-1}) was applied to soybeans, complete plant death occurred, and no yield resulted.

Predicting yield of a soybean plant exposed to dicamba can be determined from yield components such as seed count, seed weight, pod number, pods $node^{-1}$, reproductive node number, and total node number (Board and Modali 2005). Pod number, seed number, and reproductive node number were found to be the most important yield components for predicting soybean yield (Kahlon et al. 2011 and Robinson et al. 2013). These are also the yield components of soybean that are most sensitive to dicamba exposure.

Volatility

Crops that are sensitive to dicamba include soybean, tomato (*Solanum lycopersicum* L.), tobacco (*Nicotiana tabacum* L.), peanuts (*Arachis hypogaia* L.), and cotton (Marple et al. 2008). Dicamba injury to soybeans has been a problem since the early 1960's (Wax et al. 1969). Behrens and Lueschen (1979) planted 100 by 100 ft blocks of corn which were treated with dicamba. One h after application, potted soybean plants were placed at multiple distances from the treated corn blocks and left for varying periods of time to measure soybean injury from possible dicamba volatility. Injury levels of 60 to 70 % were observed 1 DAA. This was the highest level of injury observed. Injury levels of 4 to 48 % were observed 3 DAA. Plants that exhibited 60 to 70 % injury 1 DAA were the only ones to have a yield loss. While results of this study showed dicamba volatilization 1 to 3 DAA, dicamba can take up to 14 DAA to volatilize (R.L. Ritter, personal communication 2015).

Several key points about dicamba volatility were observed in the above mentioned study. The dimethylamine salt of dicamba was more volatile than the diglycolamine salt of dicamba. Rainfall after application greatly reduced the amount of injury to soybeans from volatilization. A rainfall amount of 0.04 in applied 3 h after treatment was as effective at reducing volatilization as 0.62 in. It was also shown that temperatures of 77^{o} to 105^{o} F and air speeds less than 5 miles hour^{-1} (mph) were needed for volatilization to occur. Behrens and Lueschens (1979) exposed soybeans to dicamba treated corn in a greenhouse chamber. Under high temperature (77^{o} to 105^{o} F), plants exhibited injury of 32 to 40 %. Low temperature (55^{o} to 75^{o} F) resulted in injury of 3 to 15 %. Wanamarta et al. (1989) also showed that increased temperature allows for greater diffusion of dicamba through the cuticle and membrane of the soybean plant resulting in greater injury. Humidity also plays a role in dicamba volatilization. Dicamba is more likely to volatilize under low humidity (70 to 75 %) than high humidity (85 to 95 %) (Behrens and Lueschen 1979).

Al-Khatib and Peterson (1999) tested volatilization of dicamba, glyphosate, several sulfonylurea herbicides, and glufosinate. Initial dicamba injury was seen 3 h after application. Thirty DAA, plants treated with dicamba still exhibited injury symptoms; whereas injury from all other herbicides had diminished.

The risk for soybean injury from volatilization is also increased due to planting date of the crop. The general range of planting dates for full season soybeans in the Mid-Atlantic region of the U.S. coincides with POST applications of dicamba on corn. This places the soybean plant at a vulnerable growth stage when dicamba applications on corn are occurring (Al-Khatib and Peterson 1999). A wide time range of application and varying environmental conditions necessary for volatilization indicate that planning spray times to avoid off-target movement would be impossible. One way to reduce the potential for volatilization is to reduce the rate of dicamba applied. Rate influences the amount of ai that can volatilize. A rate of 0.5 lb ai a^{-1} of dicamba has half the ai as a 1.0 lb ai a^{-1}, meaning half the amount of ai that can volatilize (Hartzler 2001).

Drift

Soybean and other non-target crops are frequently planted next to corn, sorghum, and rangeland that receive dicamba applications (Regehr et al. 2006). When these areas are treated with dicamba, spray particles may drift with air currents to these sensitive, non-target crops. The use of dicamba as a burndown herbicide in no-till systems for summer crops, such as no-till double crop soybeans, also means that non-target crops may be exposed to drift several times throughout the growing season (Marple et al. 2008). The amount of drift can be attributed to wind speed, application method, and nozzle selection (Everitt et al. 2005; Lanini 2000). An 8004 flat fan nozzle (Spraying Systems Co., Wheaton, IL) held 20 in above the crop, with 40 pounds square inch^{-1} (psi) spray pressure and 8 mph wind can drift 0.5 % of the spray solution 25 ft away from the nozzle; 0.2 %, 100 ft; and 0.125 %, 200 ft (Anonymous 1997). A similar study concluded that up to 16% of the spray solution can drift off target when wind speeds were 18 mph (Maybank et al. 1978).

Drift of dicamba to soybeans has a negative effect on growth. Hartzler (2001) obtained a 67 % yield reduction when dicamba was applied at 0.25 lb ai a^{-1}. Andersen et al. (2004) applied various amounts of dicamba ranging from 1 to 20 % of a 0.56 kg ae ha^{-1} (0.49 lb ai a^{-1}) labeled rate, to soybeans at the three trifoliate (V3) growth stage (Fehr et al. 1971). This resulted in a reduction of soybean yield by 14 to 93 %, compared to the untreated check.

A simulated dicamba drift study conducted by Weidenhamer et al. (1989) showed that soybean can exhibit drift injury symptoms; however, there was no reduction in height, and no corresponding loss in yield. Auch and Arnold (1978) concluded that dicamba drift to soybean during the early flowering (R1) growth stage resulted in greater reduction in yield than drift during any of the vegetative stages (Fehr et al 1971). This is due to the fact that during the R1 growth stage the soybean plant is directing its water and nutrient flow to the reproductive structures (Hartzler 2001). Dicamba drift during the R1 growth stage can lead to bloom necrosis. Where pods form, the resulting seed may be malformed.

Drought stress may influence how long dicamba remains within the plant (Robinson et al. 2013). Under normal growing conditions plants exude auxinic herbicides through their roots (Dexter et al. 1971). Under drought conditions, water retention increases, leading to a decrease in the amount of exudates. This results in a longer period of time for the auxinic herbicide to remain active in the plant.

Injury from dicamba drift can vary depending upon growth stage of soybean and rate utilized. Dicamba applied to soybeans in late vegetative or reproductive stages can result in a high level of yield loss (Auch and Arnold 1978; Wax et al. 1969). Kelley et al. (2005) applied two simulated drift rates (0.56 and 5.6 g ae ha^{-1}) (0.0004 and 0.004 lb ai a^{-1}) of dicamba to soybeans at the V3, seven trifoliates (V7), and full flowering (R2) growth stages (Fehr et al. 1971). Injury ratings were taken 4 to 6 WAT. Severe injury was observed from applications made at the R2 growth stage. Least injury was observed from applications made at the V3 growth stage. The study also concluded that dicamba reduced plant height when applied at the V3 and V7 growth stages. Height was not reduced by applications made at the R2 growth stage. Yield was reduced 6 to 12 %, regardless of growth stage, by the higher rate of dicamba utilized in this study.

Robinson et al. (2013) conducted an experiment where rates (0, 0.06, 0.23, 0.57, 1.1, 2.3, 4.5, 9.1, and 22.7 g ae ha^{-1}) (0, 0.00001, 0.0002, 0.0005, 0.001, 0.002, 0.004, 0.008, 0.02 lb ai a^{-1}) of dicamba were applied to soybeans in various growth stages [two trifoliates (V2), five trifoliates (V5), and R2] (Fehr et al. 1971). Visual ratings were conducted 14 DAA. The effective dose (ED) required to achieve 20 % injury at all growth stages was 0.676 to 0.937 g ae ha^{-1} (0.0004 to 0.0008 lb ai a^{-1}) To achieve 5 % yield loss, an ED of 0.042 to 0.528 g ae ha^{-1} (0.00002 to 0.0005 lb ai a^{-1}) was required regardless of growth stage. An ED of 0.169 to 1.1 g ae ha^{-1} (0.0001 to 0.0008 lb ai a^{-1}) resulted in a 10% yield reduction regardless of growth stage at time of application. When treatments were applied at the V2 growth stage, yield loss occurred when injury was 8 % or higher. Alternatively, when treatments were applied at the V5 and R2 growth stages, yield loss was obtained when injury was 2 % or greater. Less injury resulting in a yield loss with applications made at the V5 and R2 stages can be attributed to soybean plants directing their nutrient flow to the reproductive areas. Dicamba is transported to these areas disrupting normal physiological functions. Dicamba causes necrosis at the reproductive nodes which affects yield through lack of pod formation (Auch and Arnold 1978). Additionally, a reduction in leaf surface area as a result of the dicamba injury, can contribute to yield loss (Robinson et al. 2013).

Marple et al. (2008) tested the effects of dicamba drift on cotton. Highest levels of injury from dicamba occurred when it was applied to the 3 - 4 leaf (lf) growth stage. Dicamba reduced yield at 1/200 g ai a^{-1} (0.00001lb ai a^{-1}) which was the highest rate applied. Everitt and Keeling (2009) also found that cotton was more sensitive at the 3 - 4 lf stage. Dicamba at 0.25 g ai a^{-1} (0.0002 lb ai a^{-1}) was evaluated and resulted in 83%

injury when applied at the 3 - 4 lf stage resulting in a yield loss of 63%. In cotton, late season visual injury estimates from dicamba is a better estimator of yield loss than early season injury estimates (Marple et al. 2008).

Dicamba drift may be minimized by using air induction spray tips and drift control adjuvants (DCA) (Johnson et al. 2006). Air induction spray tips work by reducing the number of fine droplets (<150 µm) in the spray pattern. Fine droplets are high risk to drift due to their small size and ability to move with wind (Yates et al. 1985). Air induction spray tips reduce the number of fine spray droplets by 34% (Ramsdale and Messersmith 2001). When used alone, drift control agents have not been shown to be successful in reducing drift. Bouse et al. (1988) showed that when drift control agents are used in conjunction with air induction spray tips, fine spray particles are better retained in the spray pattern than when DCA's were used with conventional flat fan nozzles. Using air induction spray tips along with a DCA may reduce the amount of spray droplets that can drift off target.

Misapplication and Sprayer Contamination

To avoid dicamba misapplication, care will need to be taken by the applicator locating where dicamba tolerant (DT) crops are planted. When GR soybeans first became commercially available, non-GR soybean fields were mistakenly sprayed (R.L. Ritter, personal communication 2015). This same mistake may occur with DT soybeans (Robinson et al. 2013). In order to reduce the potential for these types of mistakes, an initiative referred to as, "Flag the Technology," is being explored (Scott et al. 2014). Flag the Technology uses a system of color coded flags. Each color corresponds to a particular herbicide tolerance trait. This allows the spray applicator to quickly recognize the trait(s) that crop has.

Misapplication of dicamba can also include planting a sensitive crop too soon after an EPP application or not receiving adequate rainfall between application and planting. An experiment conducted by Thompson et al. (2009) examined an EPP application of dicamba at 0.5 lb ai a^{-1}. Dicamba was applied at 28, 21, 14, 7, and 0 days before planting (DBP) soybean. No injury was observed for the 28 and 21 DBP applications. With the 14 DBP application, 13 to 17 % injury was observed 28 DAA. The 7 and 0 DBP applications resulted in 38 % injury 21 DAA and 73 % injury 14 DAA, respectively. The 0 DBP application was the only timing that resulted in a yield decrease.

Sprayer contamination is one other consideration as to how dicamba can come into contact with non-DT soybeans. Growers often utilize the same sprayer to spray corn and soybeans. Corn is often sprayed with an auxinic herbicide like dicamba (Steckel et al. 2005; Loux et al. 2009). It has been shown that POST herbicides are often sprayed on soybean following the use of an auxinic herbicide in the sprayer. Spray residues can be found anywhere in the spraying system. Certain herbicides and tank-mixed fertilizers are adept at removing auxinic herbicide residue from the spray system (VanGessel 2008; Steckel et al. 2005). The residue flushed from the spray system is a relatively small amount, but it has been shown that 1/10,000 of a 0.25 lb ai a^{-1} rate of dicamba is enough to cause visual injury to soybean (Kelley and Riechers 2003).

Chapter 2. Greenhouse Experiments to Evaluate Soybean Response to a Misapplication of Dicamba

Introduction

Since registration of dicamba with the Environmental Protection Agency (EPA) in 1967 and its subsequent reregistration in 2006, it has become the fourth most commonly applied herbicide in the U.S. (Anonymous 2006). Dicamba is particularly effective on horseweed, a common GR weed, providing 97% control 28 DAA when applied to plants greater than 11.8 inches (Kruger et al. 2010). In 2016, DT soybeans will be available to U.S. farmers. They will be stacked with tolerance to glyphosate (Monsanto Company 2015a). A new prepackaged mix of dicamba plus glyphosate labeled for EPP, PRE, and POST applications on DT soybeans will also be available in 2016 (Monsanto Company 2015b). With the commercial release of DT soybeans, dicamba's use will increase. Misapplication due to sprayer operator error may occur. Mistakes may range from improper cleanout of spray equipment, drift, or accidental dicamba application on non-tolerant soybeans (Steckel et al. 2005).

With the potential increase in use of dicamba and DT soybeans, the goal of this study was to see how non-DT soybeans would respond to various rates of dicamba. Eleven different rates of dicamba were applied to non-DT soybeans at the V3 growth stage. Measurements were obtained on vegetative and reproductive components.

Materials and Methods

Plant Growth and Greenhouse Conditions

Pioneer soybean cultivar ‘93Y91’ with RoundUp Ready II© genetics was utilized. This is an indeterminate soybean cultivar. Seeds were planted 4 seeds pot^{-1} at a depth 1.5 in into a commercial growing medium (Metro-Mix PX1: 30-40% pine bark, 45-60% Canadian sphagnum peat moss, composted peanut hulls, 10-15%, gypsum, nitrogen, dolomitic limestone; Sungro Horticulture, Agawam, MA) in pots measuring 6 in diameter x 7 in height. Pots were placed in a misting room with a 13-hour photoperiod supplemented by high-pressure sodium lamps emitting 325 μmol m^{-2} s^{-1} of photosynthetically active radiation, with day temperatures of 77^{o} F for 12 h and night temperatures of 70^{o} F for 12 h. Overhead misting nozzles supplied irrigation for 1 min every 0.5 h to keep the soil moist. After 1 wk in the misting room, pots were moved to another room which had day temperatures of 85^{o} F for 16 h and night temperatures of 65^{o} F for 8 h. Daylight of 10 h was supplemented by high pressure sodium lamps emitting 325 μmol m^{-2} s^{-1} of photosynthetically active radiation to amount to a total photoperiod of 14 h. Irrigation was supplied by an automated drip tape system that supplied water for 1 h, twice daily. Fertilizer (Plant Marvel 15-5-15, 15% calcium, 2% magnesium; Plant Marvel Laboratories, Inc., Chicago Heights, IL) was added once, 3 wk after germination. Plants remained in the greenhouse until they reached the V3 growth stage (Fehr et al. 1971).

Treatments and Application

A rate titration experiment consisting of eleven treatments plus an untreated check was established in a randomized complete block (RCB) design with four replications. The study was repeated. Treatments are as follows:

Dicamba rate

(lb ai a^{-1})

1. 0.00
2. 1.00
3. 0.5
4. 0.25
5. 0.125
6. 0.0625
7. 0.03125
8. 0.0156
9. 0.0104
10. 0.0078
11. 0.0052
12. 0.0039

Plants were moved outside the greenhouse for application. Applications were made with a handheld CO_2 pressurized backpack sprayer with six TeeJet SS8004 nozzles (Spraying Systems Co., Wheaton, IL) spaced 20 in apart. Applications were applied with a carrying volume of 18 gal a^{-1}, at a pressure of 20 psi, with a travel speed of 3 mph. The boom was held 20 in over the soybean canopy. After application the pots were returned to the greenhouse.

Measurements

Visual ratings were made on a scale of 0 (no phytotoxicity) to 100 (complete plant death). Ratings were made 7, 14, and 28 DAA. After the final evaluation, height measurements were obtained by measuring from the soil surface to where the top leaf folded over. Plants were then cut at the soil surface and fresh weight obtained. After fresh weights were obtained, plants were placed in a forced air dried oven (VWR International, Radnor, PA) at 95^{o} F for 7 d. Plants were then removed and dry weights obtained. Root weight was also obtained 28 DAA. After harvesting above ground plant parts, the root mass was removed from the pots and washed with water. This process was done over a mesh screen to catch any root material. After root fresh weights were obtained, roots were placed in a forced air dried oven at 95^{o} F for 7 d. Roots were removed and dry weights obtained.

Data Analysis

Data collected were subjected to the MIXED procedure of the Statistical Analysis Software 9.2 (SAS Institute, Cary, NC). Fisher's Least Significant Differences (LSD) were calculated using a 0.05 significance level. All data were pooled to see if an interaction existed between them. There was an interaction between plant height and plant weight in the first and second studies, so analyses were performed separately. In the case of root weight, no interaction between studies was observed so data were pooled.

Results and Discussion

Visual Ratings

Visual injury ratings taken 7 DAA indicated differences at the 0.05 level for rates of dicamba 0.03125 lb ai a^{-1} and higher (Table 2.1). Greatest injury was observed with the two higher rates of dicamba (1.0 and 0.5 lb ai a^{-1}). Some differences were observed with the middle rates, while rates from 0.0156 la ai a^{-1} and lower were not different. An increase in injury was observed by the 14 DAA rating. Rates of dicamba from 0.5 lb ai a^{-1} and higher provided 90 to 100 % phytotoxicity. Phytotoxicity varied with rates less than 0.25 lb ai a^{-1}, providing less than 70 % phytotoxicity. Similar results were observed 28 DAA.

Robinson et al. (2013) found similar results when comparing injury of various dicamba rates 14 and 28 DAA. They found that dicamba applied at 2.3 g ae a^{-1} (0.002 lb ai a^{-1}) to the V2 and R5 growth stages resulted in apical meristem death of the plant 14 DAA. As a result, apical dominance was broken and branching at the axillary nodes was observed. Some plant recovery was seen 28 DAA as a result of the branching at the axillary nodes.

Intervals between 7, 14, and 28 DAA ratings in the greenhouse studies allowed additional time for dicamba to remain active in the plant and resulted in further injury. In particular, this was very evident between the 7 and 14 DAA ratings.

Plant Height

Soybean height varied considerably within each study (Table 2.2). There was also a considerable differentiation in soybean plant height between studies. This was due to photoperiod variation, based upon time of year studies were conducted. Due to this variation, data were not pooled. In Study 1, heights did not vary between dicamba rates of 0.0104 lb ai a^{-1} and lower versus the untreated check (Table 2.2) All other rates resulted in plant heights lower than the untreated plants. This was not the case in Study 2 (Table 2.2). All dicamba applications resulted in plants lower in height than the untreated plants. In general, dicamba rates of 0.0625 lb ai a^{-1} or higher resulted in the greatest height reduction for both studies (Table 2.2).

Kelley et al. (2005) examined soybean height reduction from 0.56 and 5.6 g ae ha^{-1} (0.00001 to 0.0005 lb ai a^{-1}) of dicamba applied at the V3, V7, and R2 growth stages. They found that as the rate of dicamba increased, height reduction also increased. In their studies, highest amount of height reduction was observed from applications made at the V3 growth stage. The least amount of height reduction was with dicamba applied at the R2 growth stage. Dicamba, when applied at the R2 growth stage, did not significantly reduce plant height. This reflects results seen in the above mentioned greenhouse studies, with significant height reductions observed when dicamba was applied at the V3 growth stage.

Plant Weight

As the rate of dicamba decreased, the amount of fresh and dry weight increased (Tables 2.3 and 2.4). In the first study, rates of dicamba from 0.25 lb ai a^{-1} and higher provided the least amount of fresh weight; whereas rates from 0.5 lb ai a^{-1} or higher provided the least dry weight (Table 2.3). In the second study, only dicamba at 1.0 lb ai a^{-1} provided least fresh and dry weight (Table 2.4).

Comparisons could not be made between the untreated and treated plants (Tables 2.3 and 2.4). In the first greenhouse study, fresh and dry weights obtained from plants treated with dicamba were at times greater than weights obtained from untreated plants (Table 2.3). This was probably due to volatilization of dicamba in the greenhouse. Untreated plants in the first study exhibited symptoms of dicamba injury. In the second greenhouse study, untreated plants were segregated from the treated plants and exhibited minimal dicamba injury. In the second greenhouse study, plants treated with all rates of dicamba provided less fresh and dry weights than the untreated check (Table 2.4).

These results were similar to those obtained by Grover et al. 1972. They found that when rates of 2, 4-D from 0.05 to 0.25 lb ai a^{-1} were applied to soybeans in vegetative growth stages, significant plant weight reduction occurred. The herbicide 2, 4-D has a MOA much like dicamba, which results in similar injury symptoms to sensitive plants.

Root Weight

Fresh and dry root weights increased as the rates of dicamba decreased (Table 2.5). Rates of dicamba from 0.0052 lb ai a^{-1} or greater resulted in fresh root weights lower than those obtained from untreated plants (Table 2.5). This differed with dry weight. Dicamba rates of 0.0078 lb ai a^{-1} or greater were required to provide dry root weights lower than those obtained from untreated plants (Table 2.5). This high degree of reduction in fresh and dry weight could be due to the plants exuding dicamba through their roots. Watts and Hall (2000) found significant exudates of dicamba in corn plant roots. They showed that dicamba moves readily into the root zone where it can induce injury. The potting medium utilized in these studies was kept sufficiently moist, allowing for good root uptake. Furthermore, the soil surface was also constantly irrigated. Dicamba from the spray applications which landed on the soil could have been washed down and be made available for root uptake.

Table 2.1. Visual estimates of injury with various rates of dicamba applied at the V3 growth stage to non-DT soybeans in the greenhouse[a, b, c].

		Soybean injury[d]	
Dicamba rate	7 DAA	14 DAA	28 DAA
lb ai a^{-1}	-------------------	%	--------------------
1.0	52	100	100
0.5	43	90	90
0.25	30	82	77
0.125	20	68	68
0.0625	15	63	60
0.03125	10	50	48
0.0156	5	25	30
0.0104	3	15	25
0.0078	0	10	15
0.0052	0	10	10
0.0039	0	5	5
$LSD_{(0.05)}$	7	12	11

[a] Abbreviations: V3, three trifoliates; DT, dicamba tolerant; DAA, days after treatment.

[b] Data pooled over two studies.

[c] Data for the untreated control was excluded from the statistical test.

[d] Ratings based on a scale of 0 (no control) to 100 (total plant desiccation).

Table 2.2. Height measurements with various rates of dicamba applied at the V3 growth stage to non-DT soybeans in the greenhouse[a, b].

Dicamba rate	Study 1	Study 2
lb ai a^{-1}	in	in
0.0	9.20	34.87
1.0	5.69	11.54
0.5	5.47	12.08
0.25	5.47	17.65
0.125	6.70	14.43
0.0625	6.45	16.98
0.03125	7.60	17.65
0.0156	7.65	21.87
0.0104	8.73	23.65
0.0078	9.30	23.97
0.0052	9.40	23.64
0.0039	9.08	20.69
$LSD_{(0.05)}$	0.97	4.58

[a] Heights were taken 28 days after application.

[b] Abbreviations: V3, three trifoliates; DT, dicamba tolerant.

Table 2.3. Plant fresh and dry weight of non-DT soybeans treated with various rates of dicamba applied at the V3 growth stage in the first greenhouse study[a, b, c].

Dicamba rate	Fresh weight	Dry weight
lb ai a^{-1}	g $plant^{-1}$	g $plant^{-1}$
0.0	5.55	1.33
1.0	1.21	0.82
0.5	1.94	0.95
0.25	3.34	1.25
0.125	5.77	1.69
0.0625	5.60	1.66
0.03125	5.41	1.58
0.0156	7.20	2.04
0.0104	7.01	2.10
0.0078	8.46	2.39
0.0052	9.42	2.56
0.0039	9.94	2.66
$LSD_{(0.05)}$	1.97	0.54

[a] Weights were taken 28 days after application.

[b] Abbreviations: V3, three trifoliates; DT, dicamba tolerant.

[c] Weights were measured for all plants in a pot then divided by the number of plants pot^{-1} to get the average fresh weight $plant^{-1}$.

Table 2.4.Plant fresh and dry weight of non-DT soybeans treated with various rates of dicamba applied at the V3 growth stage in the second greenhouse study[a, b, c].

Dicamba rate	Fresh weight	Dry weight
lb ai a^{-1}	g $plant^{-1}$	g $plant^{-1}$
0.0	13.78	3.93
1.0	1.96	0.84
0.5	4.70	1.30
0.25	5.82	1.61
0.125	5.82	1.54
0.0625	8.88	2.41
0.03125	9.90	2.47
0.0156	10.87	3.04
0.0104	10.56	2.71
0.0078	11.03	3.04
0.0052	12.70	3.17
0.0039	11.43	3.12
$LSD_{(0.05)}$	1.05	0.44

[a] Weights were taken 28 days after application.

[b] Abbreviations: V3, three trifoliates; DT, dicamba tolerant.

[c] Weights were measured for all plants in a pot then divided by the number of plants pot^{-1} to get the average fresh weight $plant^{-1}$.

Table 2.5. Root fresh and dry weight of non-DT soybeans treated with various rates of dicamba applied at the V3 growth stage in the greenhouse[a, b, c, d].

Dicamba rate	Fresh weight	Dry weight
lb ai a^{-1}	g $plant^{-1}$	g $plant^{-1}$
0.0	46.25	8.95
1.0	1.66	0.56
0.5	4.87	1.42
0.25	12.39	2.29
0.125	32.05	4.56
0.0625	32.41	5.21
0.03125	32.93	5.81
0.0156	33.64	6.13
0.0104	35.40	7.78
0.0078	40.27	7.99
0.0052	43.02	8.46
0.0039	46.56	10.04
$LSD_{(0.05)}$	3.17	0.93

[a] Weights were taken 28 days after application.

[b] Abbreviations: V3, three trifoliates; DT, dicamba tolerant.

[c] Data pooled over two studies.

[d] Weights were measured for all plants in a pot then divided by the number of plants pot^{-1} to get the average root weight $plant^{-1}$.

Chapter 3: Field Experiments to Evaluate the Effect of Dicamba Application Timing and Rates on Soybeans

Introduction

Dicamba is currently labeled for EPP use in non-DT soybeans. When used EPP, a minimum of 1 in of rainfall or overhead irrigation and a waiting interval of 14 d for 8 fluid oz a^{-1}, or 28 d for 16 oz a^{-1}, is required (Anonymous 2010). New technologies are under development that will allow growers to utilize dicamba EPP, PRE, or POST on crops where they previously could not (Byker et al. 2013). These new technologies include soybeans that are genetically modified to resist the herbicide (Monsanto Co. 2015a). One of the problems with this new technology lies in the volatility of dicamba. Many non-target crops are extremely sensitive to low rates of dicamba (Johnson et al. 2012). Dicamba has been shown to reduce soybean yields by 83% when 0.05 lb ai a^{1} was applied to V3 soybeans (Andersen 2004). Off-target injury to non-tolerant soybeans and other crops may occur due to volatility, drift and operator error (Johnson et al. 2012). New technologies to reduce off-target drift include anti-drift nozzles and low volatile formulations (Johnson et al. 2006). Low volatile formulations of dicamba include Ingenia from BASF (BASF Corp., Research Triangle Park, NC) and RoundUp Xtend from Monsanto (Monsanto Co. 2015b; BASF Corp. 2015). These new formulations reduce off-target drift, but cannot prevent misapplication. Rate titration studies and application of dicamba on various soybean growth stages can provide a better understanding about the effects of volatility, drift, and misapplication on the growth and yield of the crop. Measurements of vegetative components of the soybean plant are important. Studies have found that an analysis of yield components (seed number, seed weight, pod number) can provide yield potential (Board and Modali 2005; Robinson et al. 2013).

Materials and Methods

Site

Experiments were conducted in 2013 and 2014 at the Central Maryland Research and Education Center (CMREC) located in Beltsville, MD. The soil type was an Evesboro-Downer loamy-sand. The soil had a CEC of 4.8, pH of 6.3, and 1.3 % organic matter. Rainfall data and date of treatment application can be found in Tables 3.1 and 3.2.

Soybean Cultivar

Pioneer ‘93Y91’ soybean seed [glyphosate tolerant (GT)] were utilized both years. This indeterminate variety is a non-DT soybean commonly grown in the region as part of a double-crop, wheat [*Triticum aestivum* L.]-soybean rotation. The cultivar is considered a RoundUp Ready II© variety. Experiments were planted 17 July 2013 and 9 July 2014 at a rate of 175,000 seed acre^{-1}. All studies were planted no-till, at a depth of 1.5 in with a John Deere 1750 no-till planter (Deere & Company, Moline, IL) with 30 in row spacing.

Treatments and Management

The 2013 field experiment consisted of seven rate titration studies. Seven additional studies were conducted, each consisting of an application of dicamba at 0.5 lb ai a^{-1} over top non-DT soybeans at varying growth stages. For 2014, treatments remained the same except for an additional rate in the titration studies. Each study for the rate titration and growth stage experiments included two treatments: an untreated control and an herbicide treatment. Trials used a randomized complete block design with four replications.

The herbicide treatments for the rate titration studies were as follows:

Dicamba rate
(lb ai a^{-1})

1) 0.5
2) 0.25
3) 0.125
4) 0.0625
5) 0.032
6) 0.016
7) 0.008
8) 0.004 (added for the 2014 experiments)

The 0.004 lb ai a^{-1} rate was the lowest rate utilized in these experiments, but is higher than rates evaluated Robinson et al. (2013) and the highest rate evaluated by Kelley et al. (2005).

Each study for the growth stage experiment had dicamba applied at 0.5 lb ai a^{-1} POST to a specific growth stage.

The growth stages (Fehr et al. 1971) treated were as follows:

1) Preemergence
2) VC - Two leaf stage
3) V3 - Three trifoliates
4) V5 - Five trifoliates
5) V8 - Eight trifoliates
6) R1 - Early flowering
7) R5 – Early pod fill

Plots measured 10 ft wide by 20 ft long. Applications were made using a CO_2 pressurized backpack sprayer with six TeeJet SS8004 nozzles spaced 20 in apart. Applications were made with a carrying volume of 18 gal a^{-1}, at a pressure of 20 psi, with a travel speed of 3 mph. The boom was held 20 in over the soybean canopy. In 2013 and 2014, 1 day after planting (DAP), all experiments received a PRE application of paraquat [N,N′-dimethyl-4,4′-bipyridinium dichloride] at 0.5 lb ai a^{-1} + 8% v/v non-ionic surfactant + cloransulam-methyl [N-(2-carboxymethyl-6-chlorophenyl)-5-ethoxy-7-fluoro-(1,2,4)-triazolo[1,5c]-pyrimidine-2-sulfonamide] at 0.315 lb ai a^{-1} + metolachlor [2-Chloro-N-(2-ethyl-6-methyl-phenyl)-N-(1-methoxypropan-2-yl)acetamide] at 1.33 lb ai a^{-1}. In 2013 and 2014, at 4 weeks after planting (WAP), all experiments received a POST application of glyphosate at 0.84 lb ai a^{-1}.

Experiments were harvested 13 November 2013 and 12 November 2014 using a John Deere combine equipped with a HarvestMaster HM-401 harvest system (Juniper Systems Inc., Logan, UT) to measure grain weight $plot^{-1}$. All four rows of each plot were harvested. Seed moisture was measured using a Dickey-John GAC 2100 moisture sensor

(Churchill Industries, Minneapolis, MN). Yields were calculated to bu a^{-1} and adjusted to 12.5 % moisture. Dates of application, planting, and precipitation are presented in Tables 3.1 and 3.2.

Stand Counts and Height Measurements

At 10 WAP, stand counts were taken for each experiment. Number of plants row^{-1} for the two middle rows were counted. Numbers were combined and averaged to get the average number plants row^{-1}. After stand counts were taken, six plants $plot^{-1}$ from the middle two rows were randomly selected. The height of these plants was obtained by measuring from the soil surface to where the top leaf folded over.

Yield Components

Prior to harvest, six plants $plot^{-1}$ from the middle two rows of every plot were randomly selected. These plants were clipped at the soil surface and stored in a dry room set at 80^{o} F until measurements could be obtained. Yield component measurements included the following:

1) number of pods $plant^{-1}$
2) number of seeds $plant^{-1}$
3) seed weight $plant^{-1}$

After counting the number pods $plant^{-1}$, pods were threshed using a Swanson Plot Thresher (Swanson Machine Co., Champaign, IL). Total number of seed $plant^{-1}$ was counted manually using a 100 seed count plate. The total weight of seed was measured and used to calculate seed weight $plant^{-1}$.

Data Analysis

Data collected were subjected the MIXED procedure of the Statistical Analysis Software (SAS) 9.2 software. Fisher's Least Significant Differences (LSD) were calculated using a 0.05 significance level. Data were pooled over years due to no interaction between them. Completely untreated studies were included in both 2013 and 2014 for comparison purposes. Results from these studies can be found in Table 3.15.

Results and Discussion

Plant Height

Plant heights for untreated plants were greater than those of treated plants for the rate titration and growth stage studies for all dicamba rates (Tables 3.3 and 3.4). Some differences in height occurred among untreated plants for both studies (Tables 3.3 and 3.4). This was largely due to dicamba volatility from nearby treated plants. Within treated plants for the rate titration studies, plant height increased as the rate of dicamba decreased (Table 3.3). Few differences in height existed when plants were treated with dicamba at 0.016 lb ai a^{-1} or lower. Greatest height reduction was observed when dicamba was applied at 0.25 and 0.5 lb ai a^{-1} (Table 3.3).

Within the growth stage studies, no differences in height were observed between plants treated PRE or at the R5 growth stage (Table 3.4). Few differences in height existed with plants treated at the other growth stages, with little to no plant growth with applications made at the V1 through R1 growth stages (Table 3.4).

Reduction in height is a common injury symptom of dicamba on soybean (Behrens and Lusechen 1979; Auch and Arnold 1978; Robinson et al. 2013). Auch and Arnold (1978) found that dicamba reduced soybean height significantly at rates as low as

0.4 g ai a^{-1}(0.0008 lb ai a^{-1}). They showed that dicamba applied at any growth stage would result in a reduction in height. However, it was also shown that dicamba applied at the reproductive growth stages resulted in less reduction in height. Kelley et al. (2005) showed that a dicamba application at V3 would result in greatest height reductions when compared to dicamba applied at reproductive growth stages. Results from the growth stage studies support this, with greater plant height observed when dicamba was applied at the R5 growth stage (Table 3.4).

Stand Count

Few differences existed in stand count for the untreated plants in the rate titration and growth stage studies (Tables 3.5 and 3.6). In the rate titration studies, differences in plant count existed between untreated and treated plants at rates of dicamba higher than 0.016 lb ai a^{-1} (Table 3.5). Least stand count numbers were obtained where dicamba was applied at 0.25 and 0.5 lb ai a^{-1}.

In the growth stage studies, stand counts were lower for plants treated PRE compared to untreated plants (Table 3.6). Little to no plant counts were obtained where plants were treated at the VC through R1 growth stages (Table 3.6). No differences in plant count were obtained between plants treated at the R5 growth stage and the untreated plants. In the 2014 growth stage studies no difference in stand count was observed at the PRE growth stage compared to the untreated check, whereas differences were seen at all other growth stages (Table D.17). This could be a result of rainfall after application. A total of 0.86 in of rain was received within 3 DAA. This rain may have moved the dicamba below the emerging radicle (Table 3.2).

Yield

Soybean yield varied considerably for the untreated plants within the rate titration and growth stage studies (Tables 3.7 and 3.8). This was probably due to volatility from neighboring treated plants affecting overall yield of the untreated plants. For both studies, untreated plants yielded significantly better than treated plants for all dicamba rates and growth stage timings (Tables 3.7 and 3.8).

Little to no yield was obtained where dicamba was applied above 0.032 lb ai a^{-1} in the rate titration studies (Table 3.7). Yield differences did not occur between plants treated with dicamba at 0.032, 0.016, or 0.008 lb ai a^{-1}. Highest soybean yield was obtained where dicamba was applied at 0.004 lb ai a^{-1} (Table 3.7).

No yield was obtained where plants were treated at the VC through R1 growth stages (Table 3.8). While some soybean yield was obtained where plants were sprayed at the R5 growth stage, highest yields were obtained where plants were sprayed PRE (Table 3.8). Similar results were shown by Auch and Arnold (1978). They found that dicamba applied at 0.56 lb ai a^{-1} resulted in yield reduction regardless of soybean growth stage at application. Weidenhamer et al. (1989) found similarly that dicamba rates as low as 0.0125 lb ai a^{-1} resulted in a yield reduction of soybeans regardless of growth stage. Robinson et al. (2013) observed that when dicamba was applied at 0.001 lb ai a^{-1} to soybeans, 20 % yield loss was seen. The titration studies showed similar results with all rates of dicamba significantly decreasing yield of the treated plants when compared to untreated plants (Table 3.7).

Seed Weight

As seen above for the other variables obtained in these studies, seed weight, seed number, and pod number varied considerably among the untreated plants for these studies (Tables 3.9 through 3.14). In general, the highest seed weight, seed number, and pod number were obtained where dicamba was applied PRE in the growth stage studies (Tables 3.10, 3.12, and 3.14). This was probably due to the fact that less volatility occurred with a PRE application since the plants were not out of the ground in comparison to all other applications. Furthermore, rainfall within 3 d of application in 2014 (Table 3.2) washed the herbicide down into the soil profile helping to minimize its volatility later in the season.

For the rate titration studies, higher seed weights were obtained with untreated plants compared to treated plants for most rates of dicamba (Table 3.9). Within treatments, there were no differences in seed weight between plants treated with dicamba at rates greater than 0.004 lb ai a^{-1} (Table 3.9). For the growth stage studies, greatest seed weight was obtained where dicamba was applied PRE (Table 3.10). No differences in seed weight were obtained where plants were treated at any of the other growth stages. Little to no seed were obtained from these treatments (Table 3.10).

Seed Number

More seeds $plant^{-1}$ were obtained from the untreated plants than from the treated plants for all rates of dicamba tested in the rate titration studies (Table 3.11). Within treatments, little to no seed was obtained where dicamba was applied at 0.5, 0.25, or 0.125 lb ai a^{-1}. Differences occurred among the other treatments with the highest seed number obtained where dicamba was applied at 0.004 lb ai a^{-1} (Table 3.11).

Differences also existed in seed number between the untreated plants and the treated plants in the growth stage studies for plants treated at all growth stages (Table 3.12). Highest seed number was obtained where dicamba was applied PRE. Little to no differences in seed number were obtained where dicamba was applied at the other growth stages (Table 3.12). Results from the growth stage studies differed from those found by Auch and Arnold (1978). They observed that dicamba applications made at the V1 and V3 growth stages resulted in less seed loss than applications made at V7. The V1 and V3 growth stage applications did not result in significantly lower seed yield than untreated plants. Robinson et al. (2013) reported greater seed loss when dicamba was applied at R2 than when applied at V2 or V5.

Pod Number

Pod number did not vary for the untreated plants within the rate titration studies (Table 3.13); whereas, they did vary considerably in the growth stage studies (Table 3.14). For the rate titration studies, a decrease in pods was obtained at rates of dicamba above 0.016 lb ai a^{-1} when compared to the untreated plants (Table 3.13). Differences in pod number did not occur with dicamba at 0.016, 0.008, or 0.004 lb ai a^{-1} for treated plants or untreated plants.

For the growth stage studies, highest pod count was obtained when dicamba was applied PRE (Table 3.14). Little to no pods were obtained when plants were treated at the other growth stages (Table 3.14).

Seed weight, seed number, and pod number have been described as the yield components that can influence overall yield (Kelley et al. 2005; Wax et al. 1969). A reduction in these components can lead to a reduction in yield. Robinson et al. (2013)

observed that seed number decreased by 10 % as the rate of dicamba increased from 0.06 to 0.56 g ae ha^{-1} (0.00001 to 0.0005 lb ai a^{-1}). Seed weight has been shown to be sensitive to dicamba, even at low rates. Kelley et al. (2005) reported a reduction in seed weight with dicamba applied at the V3 and V7 growth stages with dicamba at 5.6 g ae ha^{-1} (0.0005 lb ai a^{-1}). They also found that dicamba applied at the V7 growth stage was more injurious to the yield components than dicamba applied at the V3 growth stage. Robinson et al. (2013) found pod number to be reduced by dicamba applied at 0.06 g ae ha^{-1} (0.00001 lb ai a^{-1}). They described a reduction in the number of reproductive nodes which led to reduced pod number.

Table 3.15 is an analysis of a study comparing two treatments that were untreated, for comparison purposes, to the other untreated checks throughout the studies. There were no differences between any of the variables obtained in this study. This was performed to see if volatility was an issue in the other studies. As discussed above, volatility was an issue where dicamba was applied to plants other than a PRE application. A 10 ft buffer was placed between replications and a 20 ft buffer was placed between studies. Within each study, treatments were side by side. Unfortunately, volatility occurred. Optimal conditions for volatility are when temperatures are above 86^{o} F and relative humidity is between 70 and 75 % (Behrens and Lueschen 1979; Wanamarta et al. 1989). Optimal weather conditions required for dicamba volatilization occurred at the time of application in the field studies (Tables A.2 and A.3). Behrens and Lueschen (1979) observed dicamba volatility up to 3 DAA, but dicamba has the potential to volatilize up to 2 WAA (R.L. Ritter, personal communication 2015). The distance that volatiles of dicamba can move has been observed to be up to 1 mile from the application site, but can vary greatly with weather conditions (Scumbiato et al. 2004). They also observed that in order for dicamba volatiles to move greater distances, slow wind speeds at low elevation and a temperature inversion must be present.

Table 3.1. Date of application, planting, and precipitation at the Central Maryland Research and Education Center (CMREC) located in Beltsville, MD, 2013.

	June		**July**	
	Treatment application	**Rainfall**	**Treatment application**	**Rainfall**
Date		(in)		(in)
1				0.12
2		0.41		0.09
3		0.38		0.11
4				
5				
6		0.26		
7		2.01		0.03
8				0.03
9				
10		1.71		0.03
11		0.01		
12				0.56
13		0.43		0.31
14		0.04		0.01
15				
16				
17			Pre[a] + Plant	
18		0.22		
19		0.01		
20				
21				
22				0.05
23		0.11		
24		0.22	VC	
25		0.11		
26		0.27	V1	
27		0.07		
28		0.61		
29		0.01		
30		0.89		
31				0.38

Table 3.1. (Continued)

	August		**September**	
	Treatment application	**Rainfall**	**Treatment application**	**Rainfall**
Date		(in)		(in)
1		0.23		
2				0.12
3		0.09		
4		0.01		
5				
6		0.06		
7	V3	0.07		
8		0.03		
9		0.45		
10				
11				
12				0.36
13		1.03		0.01
14	Rate titrations applied			
15				
16				0.04
17				
18		0.06		
19				
20			R5	0.79
21	R1	0.01		0.06
22		0.01		0.04
23		0.04		
24		0.01		0.01
25				
26				
27				
28		0.17		
29	V8			
30				
31				

[a] Abbreviations: Pre, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; R1, early flowering; V8, eighth trifoliate; R5, early pod fill.

Table 3.2. Date of application, planting, and precipitation at the Central Maryland Research and Education Center (CMREC) located in Beltsville, MD, 2014.

	June		**July**	
	Treatment application	**Rainfall**	**Treatment application**	**Rainfall**
Date		(in)		(in)
1				
2				
3		0.74		
4		0.41		0.54
5		0.17		
6				
7				
8		0.03		
9		0.20	Pre[a] + Plant	0.45
10		0.74		0.33
11		0.11		0.08
12		0.23		
13		0.04		
14				
15				0.14
16				2.14
17				
18				
19		0.22		
20		0.01		
21		0.03	VC	
22		0.01		
23				
24				0.03
25		1.17	V1	
26				
27				
28				0.03
29				
30				
31				

Table 3.2. (Continued)

	August		**September**	
	Treatment application	**Rainfall**	**Treatment application**	**Rainfall**
Date		(in)		(in)
1				0.04
2		0.30		0.18
3		0.05		0.01
4	Rate titrations applied	0.61		
	V3			
5				
6		0.03		0.97
7				
8				0.01
9				
10			R5	
11				
12		1.80		
13				0.12
14				0.01
15				0.01
16				
17				
18				
19				0.01
20	V8	0.10		
21		0.03		0.11
22		0.01		
23		0.39		
24				0.01
25	R1			0.66
26				
27				
28				0.01
29				
30				0.03
31		0.61		

[a] Abbreviations: Pre, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table 3.3. Plant height for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a, b].

Dicamba rate	Untreated plant height	Treated plant height	$LSD_{(0.05)}$
lb ai a^{-1}	In	in	
0.5	27.46	3.21	3.62
0.25	24.56	5.02	4.81
0.125	26.13	9.53	1.76
0.0625	29.40	13.72	3.04
0.032	30.89	16.57	2.45
0.016	28.07	17.11	3.64
0.008	30.97	19.08	2.06
0.004	31.06	20.48	1.66
$LSD_{(0.05)}$	4.59	3.22	

[a] Heights taken 10 weeks after treatment. Data pooled for 2013 and 2014.

[b] Applications made at the V3 (three trifoliate) growth stage.

Table 3.4. Plant height for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Growth stage[b]	Dicamba rate	Untreated plant height	Treated plant height	$LSD_{(0.05)}$
	lb ai a^{-1}	in	in	
PRE	0.5	32.02	25.17	4.13
VC	0.5	26.40	6.59	4.82
V1	0.5	22.97	1.90	6.58
V3	0.5	22.15	0.00[c]	5.64
V8	0.5	25.99	0.00	7.22
R1	0.5	26.43	0.00	8.07
R5	0.5	32.76	27.23	2.66
$LSD_{(0.05)}$		7.48	5.97	

[a] Heights taken 10 weeks after treatment. Data pooled for 2013 and 2014.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table 3.5. Stand count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a, b].

Dicamba rate	Untreated stand count	Treated stand count	$LSD_{(0.05)}$
lb ai a^{-1}	plants 20 ft^{-1} row	plants 20 ft^{-1} row	
0.5	187	2	12
0.25	183	18	10
0.125	183	61	15
0.0625	180	171	8
0.032	197	186	9
0.016	191	184	12
0.008	193	195	10
0.004	182	185	7
$LSD_{(0.05)}$	26	17	

[a] Stand counts taken 10 weeks after treatment. Data pooled for 2013 and 2014.

[b] Applications made at the V3 (three trifoliate) growth stage.

Table 3.6. Stand count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Growth stage[b]	Dicamba rate	Untreated stand count	Treated stand count	$LSD_{(0.05)}$
	lb ai a^{-1}	plants 20 ft^{-1} row	plants 20 ft^{-1} row	
PRE	0.5	192	154	5
VC	0.5	196	1	9
V1	0.5	184	1	9
V3	0.5	166	1	37
V8	0.5	179	0[c]	27
R1	0.5	196	0	4
R5	0.5	196	194	6
$LSD_{(0.05)}$		18	32	

[a] Stand counts taken 10 weeks after treatment. Data pooled for 2013 and 2014.

[b] Abbreviations: PRE, preemergene; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table 3.7. Yield for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a, b].

Dicamba rate	Untreated yield	Treated yield	$LSD_{(0.05)}$
lb ai a^{-1}	bu a^{-1}	bu a^{-1}	
0.5	34.7	0.0	11.7
0.25	37.1	0.0	8.9
0.125	35.5	0.0	17.4
0.0625	38.9	3.1	6.7
0.032	43.6	12.9	11.2
0.016	44.3	19.5	21.9
0.008	44.0	22.7	10.0
0.004	49.8	32.2	7.3
$LSD_{(0.05)}$	7.2	10.6	

[a] Data pooled for 2013 and 2014.

[b] Applications made at the V3 (three trifoliate) growth stage.

Table 3.8. Yield for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Growth stage[b]	Dicamba rate	Untreated yield	Treated yield	$LSD_{(0.05)}$
	lb ai a^{-1}	bu a^{-1}	bu a^{-1}	
PRE	0.5	58.7	33.4	10.6
VC	0.5	25.7	0.0	7.1
V1	0.5	22.3	0.0	7.9
V3	0.5	28.1	0.0	15.4
V8	0.5	25.5	0.0	22.8
R1	0.5	26.2	0.0	20.2
R5	0.5	44.6	14.5	17.5
$LSD_{(0.05)}$		13.9	9.1	

[a] Data pooled for 2013 and 2014.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table 3.9. Seed weight for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a, b].

Dicamba rate	Untreated seed weight	Treated seed weight	$LSD_{(0.05)}$
lb ai a^{-1}	g seed $plant^{-1}$	g seed $plant^{-1}$	
0.5	11.62	0.00	5.84
0.25	10.31	0.08	3.18
0.125	10.09	0.14	4.72
0.0625	9.86	3.18	6.91
0.032	9.04	3.92	4.89
0.016	8.99	5.76	2.02
0.008	7.87	5.53	3.90
0.004	10.47	8.70	1.35
$LSD_{(0.05)}$	1.35	0.54	

[a] Data pooled for 2013 and 2014.

[b] Applications made at the V3 (three trifoliate) growth stage.

Table 3.10. Seed weight for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Growth stage[b]	Dicamba rate	Untreated seed weight	Treated seed weight	$LSD_{(0.05)}$
	lb ai a^{-1}	g seed $plant^{-1}$	g seed $plant^{-1}$	
PRE	0.5	14.66	18.72	3.85
VC	0.5	7.81	0.64	5.21
V1	0.5	6.55	0.36	2.49
V3	0.5	9.26	0.00	1.27
V8	0.5	8.93	0.00	3.18
R1	0.5	6.68	0.00	2.77
R5	0.5	10.32	3.55	4.80
$LSD_{(0.05)}$		3.93	7.28	

[a] Data pooled for 2013 and 2014.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table 3.11. Seed count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a, b].

Dicamba rate	Untreated seed count	Treated seed count	LSD$_{(0.05)}$
lb ai a^{-1}	seeds plant^{-1}	seeds plant^{-1}	
0.5	68.79	0.00	37.82
0.25	54.88	0.84	15.64
0.125	56.43	1.01	20.84
0.0625	60.97	26.42	13.78
0.032	49.58	26.97	17.75
0.016	52.41	35.53	10.41
0.008	54.62	40.05	16.84
0.004	71.00	60.00	5.66
LSD$_{(0.05)}$	19.46	13.83	

[a] Data pooled for 2013 and 2014.

[b] Applications made at the V3 (three trifoliate) growth stage.

Table 3.12. Seed count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Growth stage[b]	Dicamba rate	Untreated seed count	Treated seed count	LSD$_{(0.05)}$
	lb ai a^{-1}	seeds plant^{-1}	seeds plant^{-1}	
PRE	0.5	74.79	92.34	36.27
VC	0.5	48.93	4.75	24.25
V1	0.5	44.30	5.31	16.78
V3	0.5	49.72	0.00	12.43
V8	0.5	51.85	0.00	16.01
R1	0.5	42.44	0.00	20.97
R5	0.5	63.81	2.65	32.18
LSD$_{(0.05)}$		7.56	24.71	

[a] Data pooled for 2013 and 2014.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table 3.13. Pod count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a, b].

Dicamba rate	Untreated pod count	Treated pod count	$LSD_{(0.05)}$
lb ai a^{-1}	pods $plant^{-1}$	pods $plant^{-1}$	
0.5	30.13	0.00	9.47
0.25	24.67	4.44	9.85
0.125	25.94	5.27	11.31
0.0625	28.73	15.65	6.94
0.032	27.50	18.91	7.25
0.016	26.66	23.15	5.21
0.008	23.68	22.62	7.84
0.004	29.00	27.00	2.00
$LSD_{(0.05)}$	8.73	5.28	

[a] Data pooled for 2013 and 2014.

[b] Applications made at the V3 (three trifoliate) growth stage.

Table 3.14. Pod count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Growth stage[b]	Dicamba rate	Untreated pod count	Treated pod count	$LSD_{(0.05)}$
	lb ai a^{-1}	pods $plant^{-1}$	pods $plant^{-1}$	
PRE	0.5	39.12	45.91	1.45
VC	0.5	20.85	6.40	8.42
V1	0.5	19.10	3.28	11.37
V3	0.5	25.73	0.00	4.81
V8	0.5	28.26	0.00	6.29
R1	0.5	21.32	0.00	5.38
R5	0.5	18.46	1.08	1.85
$LSD_{(0.05)}$		7.39	16.84	

[a] Data pooled for 2013 and 2014.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table 3.15. Untreated control measurements at the Central Maryland Research and Education Center (CMREC), Beltsville, MD[a].

Parameter	Measurement	Untreated	Untreated	$LSD_{(0.05)}$
Plant height[b]	in	32.85	33.97	4.68
Stand count[c]	plant 20 ft^{-1} row	196.00	190.00	7.00
Yield	bu a^{-1}	48.20	46.40	3.10
Seed weight	g seed $plant^{-1}$	11.57	10.15	5.84
Seed count	seed $plant^{-1}$	62.91	70.43	10.59
Pod count	pod $plant^{-1}$	29.31	27.82	4.33

[a] Data pooled for 2013 and 2014.

[b] Heights taken 10 weeks after application.

[c] Stand counts taken 10 weeks after application.

Chapter 4. Conclusions

Dicamba has been used for over 40 years in corn, small grains, and other cropping systems (Loux et al. 2009). Dicamba is an effective tool to control non-GR as well as GR broadleaf weeds like horseweed, when applied at 0.5 lb ai a^{-1} (Kruger et al. 2010; Mithila et al. 2011). With the development of DT crops, the use of dicamba may increase (Johnson et al. 2012). Its use is not without concern as many crops are sensitive to trace amounts of dicamba (Marple et al. 2008). Previous research has been conducted to quantify dicamba injury to soybeans. Studies have examined drift, volatility, and misapplication. Auch and Arnold (1978) showed that dicamba can significantly reduce soybean height after exposure to 0.25 lb ai a^{-1} of dicamba. In these greenhouse studies, greatest injury was observed with the two highest rates of dicamba (1.0 and 0.5 lb ai a^{-1}) (Table 2.1). Soybean injury varied with rates less than 0.25 lb ai a^{-1}. Soybean height varied considerably within each study (Table 2.2). In general, dicamba rates of 0.0625 lb ai a^{-1} or higher resulted in the greatest height reduction (Table 2.2). Weidenhamer et al. (1989) showed that a 0.56 g ai a^{-1} (0.001 b ai a^{-1}) rate of dicamba could result in significant reduction in height. In this research (Table 2.2), height reduction in the greenhouse studies was greater than that reported in the field by Robinson et al. (2013).

As the rate of dicamba decreased, the amount of fresh and dry weight increased (Tables 2.3 and 2.4). In one study, rates of dicamba from 0.25 lb ai a^{-1} and higher provided the least amount of fresh weight (Table 2.3). In another study, dicamba at 1.0 lb ai a^{-1} provided the least fresh and dry weight (Table 2.4).

In field studies, plant heights for untreated plants were greater than those of treated plants for the rate titration and growth stage studies for all dicamba rates (Tables 3.3 and 3.4). For the rate titration studies, plant height increased as the rate of dicamba decreased (Table 3.3). Greatest height reduction was observed when dicamba was applied at 0.25 and 0.5 lb ai a^{-1} (Table 3.3). Within the growth stage studies, no differences in height were observed with applications made at the PRE or at the R5 growth stage (Table 3.4). Little to no plant growth was observed with applications made at the V1 through R1 growth stages (Table 3.4). These reductions in height were similar to results reported by Auch and Arnold (1978). They showed that dicamba applied at any growth stage would result in a reduction in height. It was also shown that dicamba applied at the reproductive growth stages resulted in less reduction in height. In these studies, applications made at the R1 growth stage resulted in plant death, while applications made at the R5 growth stage resulted in little to no reduction in height.

In the rate titration studies, differences in plant stand count existed between untreated and treated plants at rates of dicamba higher than 0.016 lb ai a^{-1} (Table 3.5). Least stand count numbers were obtained where dicamba was applied at 0.25 and 0.5 lb ai a^{-1}. In the growth stage studies, stand counts were lower for plants treated PRE compared to the untreated plants (Table 3.6). Little to no plant counts were obtained where plants were treated at the VC through R1 growth stages. No differences in plant count were obtained between plants treated at the R5 growth stage and the untreated plants.

For both studies, untreated plants yielded significantly better than treated plants for all dicamba rates and growth stage timings (Tables 3.7 and 3.8). Little to no yield was obtained where dicamba was applied above 0.032 lb ai a^{-1} in the rate titration studies (Table 3.7).Highest soybean yield was obtained where dicamba was applied at 0.004 lb ai a^{-1}. For the growth stage studies, no yield was obtained where plants were treated at the VC through R1 growth stages (Table 3.8). Some soybean yield was obtained was obtained where plants were treated at the R5 growth stage; whereas, highest yields were obtained where plants were treated PRE (Table 3.8). Similar results were shown by Auch and Arnold (1978). They found that dicamba applied at 0.56 lb ai a^{-1} resulted in yield reduction regardless of growth stage at time of application. Weidenhamer et al. (1989) also found that dicamba rates as low as 0.0125 lb ai a^{-1} resulted in soybean yield reduction regardless of growth stage at time of application.

Seed weight, seed number, and pod number varied considerably among tha untreated plants for these studies (Tables 3.9 through 3.14). For the rate titration studies, higher seed weights were obtained with untreated plants compared to treated plants for most rates of dicamba (Table 3.9). For the growth stage studies, greatest seed weight was obtained where dicamba was applied PRE (Table 3.10). No differences in seed weight were obtained where plants were treated at any of the other growth stages, with little to no seed obtained from these treatments.

More seeds $plant^{-1}$ were obtained from the untreated plants than from the treated plants for all rates of dicamba in the rate titration studies (Table 3.11). Little to no seed was obtained where dicamba was applied 0.5, 0.25, or 0.125 lb ai a^{-1}. The highest seed number was obtained where dicamba was applied at 0.004 lb ai a^{-1} (Table 3.11). Differences in seed number also existed between the untreated and treated plants in the growth stage studies (Table 3.12). Highest seed number was obtained where dicamba was applied PRE. These results differed than those reported by Auch and Arnold (1978). They observed that dicamba applications made at the V1 and V3 growth stages resulted in less seed loss than applications made at V7. In these studies, little to no differences in seed number were obtained when dicamba was applied at most growth stages except the PRE application (Table 3.12).

Pod number varied considerably depending upon study. For the rate titration studies, a decrease in pods was obtained at rates of dicamba above 0.016 lb ai a^{-1} when compared to the untreated plants (Table 3.13). For the growth stage studies, highest pod count was obtained when dicamba was applied PRE (Table 3.14). Little to no pods were obtained when plants were treated at the other growth stages.

Robinson et al. (2013) saw similar effects on yield components with seeds $plant^{-1}$ and pods $plant^{-1}$ being reduced by several dicamba rates and applications made at varying growth stages. Growth stage at application plays an important role in dicamba’s effect on the plant as observed by Weidenhamer et al. (1989), where greatest yield reduction was realized with dicamba applied during the R1 growth stage. The 0.5 lb ai a^{-1} rate used in the growth stage studies resulted in a significant stand count reduction regardless of growth stage. The exception to this was the PRE treatment in 2014 (Table C.17), which may have been affected by rainfall after application.

Additional research examining rate titration studies applied to different growth stages would be beneficial. Studies may also want to consider employing larger buffer areas between studies. This would help to prevent injury to untreated plants from dicamba volatilization. Additionally, buffers between treatments within a study may want to be considered. Injury from dicamba volatilization was observed in these studies and may have affected the results.

In conclusion, with the commercialization of DT crops, dicamba injury to sensitive plants may occur. DT crops present a complex problem in the Mid-Atlantic region. The variety of plants grown in the region includes many that are sensitive to dicamba. Often times these sensitive plants are planted in close to proximity to fields that may receive dicamba applications. Care will have to be taken by applicators when applying dicamba to DT crops, as injury to sensitive plants may occur. However, DT crops may have a fit in the Mid-Atlantic region if precautions are taken with the application of dicamba. Dicamba's utility on GR weeds can make DT crops an effective tool in the management of weeds for Mid-Atlantic growers.

Appendix A

Table A.1. Weather conditions at time of greenhouse application.

Greenhouse Spray Conditions		
	Study 1	**Study 2**
Date	17 April 2014	10 December 2014
Air temp (°F)	57	50
% Humidity	47	56
% Cloud cover	0	75

Table A.2. Weather conditions at time of spray applications at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

CMREC Application Conditions[a]								
2013								
Timing	Rate titration	PRE	VC	V1	V3	V8	R1	R5
Date	14 August	17 July	24 July	26 July	7 August	29 August	21 August	20 September
Air temp (°F)	71	96	88	86	77	84	88	83
% Humidity	61	52	54	54	82	63	60	56
% Cloud cover	0	50	50	50	75	50	50	50
Soil temp (°F at 4 in. soil depth)	80	92	88	94	80	84	84	80

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table A.3. Weather conditions at time of spray applications at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

CMREC Application Conditions[a]								
2014								
Timing	Rate titration	PRE	VC	V1	V3	V8	R1	R5
Date	4 August	9 July	21 July	25 July	4 August	20 August	25 August	10 September
Air temp (^{o}F)	89	95	82	85	89	89	87	86
% Humidity	54	62	75	50	54	57	57	61
% Cloud cover	50	50	0	0	50	50	0	50
Soil temp (^{o}F at 4 in. soil depth)	82	80	78	85	82	80	78	78

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Appendix B

Individual Data Tables for the First and Second Greenhouse Studies

Table B.1. Visual estimates of injury with various rates of dicamba applied at the V3 growth stage to non-DT soybeans in the first greenhouse study[a].

Dicamba rate	Soybean injury[b]		
	7 DAA	14 DAA	28 DAA
lb ai a^{-1}		%	
0.0	0	0	0
1.0	50	100	100
0.5	40	90	90
0.25	30	80	75
0.125	20	65	65
0.0625	15	60	60
0.03125	10	50	50
0.0156	5	25	30
0.0104	0	15	25
0.0078	0	10	15
0.0052	0	10	10
0.0039	0	5	5
$LSD_{(0.05)}$	12	26	21

[a] Abbreviations: V3, three trifoliates; DT, dicamba tolerant; DAA, days after application.

[b] Ratings based on a scale of 0 (no control) to 100 (total plant desiccation).

Table B.2. Visual estimates of injury with various rates of dicamba applied at the V3 growth stage to non-DT soybeans in the second greenhouse study[a].

	Soybean injury[b]		
Dicamba rate	7 DAA	14 DAA	28 DAA
lb ai a^{-1}		%	
0.0	0	0	0
1.0	55	100	100
0.5	45	90	90
0.25	30	85	80
0.125	20	70	70
0.0625	15	65	60
0.03125	10	50	45
0.0156	5	25	30
0.0104	5	15	25
0.0078	0	10	15
0.0052	0	10	10
0.0039	0	5	5
LSD$_{(0.05)}$	9	17	15

[a] Abbreviations: V3, three trifoliates; DT, dicamba tolerant; DAA, days after application.

[b] Ratings based on a scale of 0 (no control) to 100 (total plant desiccation).

Table B.3. Root weight of non-DT soybeans treated with various rates of dicamba applied at the V3 growth stage in the first greenhouse study[a, b, c].

Dicamba rate	Root fresh weight	Root dry weight
lb ai a^{-1}	g plant^{-1}	g plant^{-1}
0.0	37.10	7.38
1.0	1.66	0.29
0.5	5.02	1.20
0.25	12.10	2.25
0.125	28.32	4.40
0.0625	24.56	4.29
0.03125	28.35	4.23
0.0156	27.44	4.26
0.0104	32.58	5.15
0.0078	39.34	6.20
0.0052	42.07	7.30
0.0039	41.40	7.29
LSD$_{(0.05)}$	7.32	1.42

[a] Abbreviations: V3, three trifoliates; DT, dicamba tolerant.

[b] Weights were taken 28 days after application.

[c] Weights were measured for all plants in a pot then divided by the number of plants pot^{-1} to get the average root weight plant^{-1}.

Table B.4. Root weight of non-DT soybeans treated with various rates of dicamba applied at the V3 growth stage in the second greenhouse study[a, b, c].

Dicamba rate	Root fresh weight	Root dry weight
lb ai a^{-1}	g $plant^{-1}$	g $plant^{-1}$
0.0	50.65	9.97
1.0	1.64	0.97
0.5	4.15	1.53
0.25	12.53	2.33
0.125	34.45	4.81
0.0625	37.57	5.71
0.03125	36.26	6.61
0.0156	38.45	7.89
0.0104	38.89	8.88
0.0078	40.49	8.65
0.0052	43.59	10.05
0.0039	49.79	11.04
$LSD_{(0.05)}$	2.00	0.74

[a] Abbreviations: V3, three trifoliates; DT, dicamba tolerant.

[b] Weights were taken 28 days after application.

[c] Weights were measured for all plants in a pot then divided by the number of plants pot^{-1} to get the average root weight $plant^{-1}$.

Appendix C

Data Tables by Year for the 2013 and 2014 Field Studies

Table C.1. Plant height for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013[a].

Dicamba rate[b]	Untreated plant height	Treated plant height	$LSD_{(0.05)}$
lb ai a^{1}	in	In	
0.5	29.08	5.92	5.09
0.25	28.28	10.66	4.86
0.125	28.23	13.29	1.57
0.0625	29.13	15.39	3.39
0.032	31.90	19.11	1.86
0.016	31.59	20.56	1.86
0.008	32.53	21.88	0.60
$LSD_{(0.05)}$	5.82	3.79	

[a] Heights taken 10 weeks after application.

[b] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.2. Plant height for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013[a].

Growth stage[b]	Dicamba rate	Untreated plant height	Treated plant height	$LSD_{(0.05)}$
	lb ai a^{-1}	in	in	
PRE	0.5	32.01	22.83	4.69
VC	0.5	28.04	13.68	6.17
V1	0.5	26.83	3.03	7.87
V3	0.5	20.85	0.00[c]	3.82
V8	0.5	25.46	0.00	10.84
R1	0.5	30.23	0.00	3.28
R5	0.5	33.38	28.13	2.79
$LSD_{(0.05)}$		2.02	6.19	

[a] Heights taken 10 weeks after application.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table C.3. Plant height for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014[a].

Dicamba rate[b]	Untreated plant height	Treated plant height	$LSD_{(0.05)}$
lb ai a^{-1}	in	in	
0.5	22.70	0.00[c]	1.66
0.25	20.51	0.00	4.72
0.125	24.19	4.81	1.97
0.0625	29.53	10.96	2.79
0.032	29.12	13.29	3.98
0.016	26.92	14.37	5.35
0.008	28.17	17.43	2.26
0.004	31.06	20.48	1.66
$LSD_{(0.05)}$	8.23	4.87	

[a] Heights taken 10 weeks after application.

[b] Dicamba applied at the V3 (three trifoliate) growth stage.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table C.4. Plant height for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014[a].

Growth stage[b]	Dicamba rate	Untreated plant height	Treated plant height	$LSD_{(0.05)}$
	lb ai a^{-1}	in	in	
PRE	0.5	32.06	27.12	3.22
VC	0.5	18.22	0.00[c]	1.54
V1	0.5	16.83	0.00	5.67
V3	0.5	24.56	0.00	7.32
V8	0.5	27.12	0.00	3.62
R1	0.5	20.37	0.00	9.15
R5	0.5	32.00	26.37	1.34
$LSD_{(0.05)}$		5.22	10.65	

[a] Heights taken 10 weeks after application.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table C.5. Stand count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013[a].

Dicamba rate[b]	Untreated stand count	Treated stand count	$LSD_{(0.05)}$
lb ai a^{-1}	plants 20 ft^{-1} row	plants 20 ft^{-1} row	
0.5	193	4	13
0.25	185	29	11
0.125	183	89	11
0.0625	178	168	39
0.032	205	184	16
0.016	197	196	27
0.008	187	188	42
$LSD_{(0.05)}$	21	33	

[a] Stand counts taken 10 weeks after application.

[b] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.6. Stand count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013[a].

Growth stage[b]	Dicamba rate	Untreated stand count	Treated stand count	$LSD_{(0.05)}$
	lb ai a^{-1}	plants 20 ft^{-1} row	plants 20 ft^{-1} row	
PRE	0.5	196	94	62
VC	0.5	199	3	15
V1	0.5	177	2	61
V3	0.5	149	1	84
V8	0.5	157	0[c]	81
R1	0.5	198	0	8
R5	0.5	199	199	13
$LSD_{(0.05)}$		9	26	

[a] Stand counts taken 10 weeks after application.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table C.7. Stand count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014[a].

Dicamba rate[b]	Untreated stand count	Treated stand count	$LSD_{0.05}$
lb ai a^{-1}	plants 20 ft^{-1} row	plants 20 ft^{-1} row	
0.5	183	0[c]	11
0.25	173	0	9
0.125	186	40	19
0.0625	182	171	8
0.032	190	185	11
0.016	185	181	13
0.008	185	183	7
0.004	182	185	12
$LSD_{(0.05)}$	23	19	

[a] Stand counts taken 10 weeks after application.

[b] Dicamba applied at the V3 (three trifoliate) growth stage.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table C.8. Stand count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014[a].

Growth stage[b]	Dicamba rate	Untreated stand count	Treated stand count	$LSD_{(0.05)}$
	lb ai a^{-1}	plants 20 ft^{-1} row	plants 20 ft^{-1} row	
PRE	0.5	188	186	10
VC	0.5	188	0[c]	10
V1	0.5	189	0	5
V3	0.5	192	0	10
V8	0.5	185	0	6
R1	0.5	190	0	7
R5	0.5	187	188	8
$LSD_{(0.05)}$		16	31	

[a] Stand counts taken 10 weeks after application.

[b] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

[c] 0 indicates complete plant death and no measurements could be obtained.

Table C.9. Yield for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Dicamba rate[a]	Untreated yield	Treated yield	$LSD_{(0.05)}$
lb ai a^{-1}	bu a^{-1}	bu a^{-1}	
0.5	35.3	0.0	16.7
0.25	37.8	0.0	5.4
0.125	35.6	0.0	6.8
0.0625	33.9	4.6	7.2
0.032	43.1	15.1	9.3
0.016	44.5	24.7	9.9
0.008	48.0	28.4	4.2
$LSD_{(0.05)}$	12.7	6.2	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.10. Yield for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Growth stage[a]	Dicamba rate	Untreated yield	Treated yield	$LSD_{(0.05)}$
	lb ai a^{-1}	bu a^{-1}	bu a^{-1}	
PRE	0.5	47.2	21.8	15.7
VC	0.5	33.7	0.0	31.8
V1	0.5	30.4	0.0	28.0
V3	0.5	19.3	0.0	16.3
V8	0.5	19.9	0.0	24.0
R1	0.5	33.1	0.0	11.3
R5	0.5	43.6	25.4	21.0
$LSD_{(0.05)}$		7.3	5.8	

[a] Abbreviations: Pre, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.11. Yield for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Dicamba rate[a]	Untreated yield	Treated yield	$LSD_{(0.05)}$
lb ai a^{-1}	bu a^{-1}	bu a^{-1}	
0.5	33.4	0.0	7.4
0.25	30.1	0.0	7.0
0.125	39.8	0.0	24.9
0.0625	41.2	2.5	18.5
0.032	42.2	6.3	8.2
0.016	41.0	13.4	17.7
0.008	41.1	18.7	16.3
0.004	49.3	32.1	7.7
$LSD_{(0.05)}$	12.6	10.5	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.12. Yield for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Growth stage[a]	Dicamba rate	Untreated yield	Treated yield	$LSD_{(0.05)}$
	lb ai a^{-1}	bu a^{-1}	bu a^{-1}	
PRE	0.5	60.5	44.3	11.2
VC	0.5	11.1	0.0	8.9
V1	0.5	7 .8	0.0	10.1
V3	0.5	35.5	0.0	19.5
V8	0.5	38.2	0.0	12.8
R1	0.5	12.9	0.0	30.2
R5	0.5	44.0	6.6	17.6
$LSD_{(0.05)}$		9.4	27.5	

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.13. Seed weight for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Dicamba rate[a]	Untreated seed weight	Treated seed weight	$LSD_{(0.05)}$
lb ai a^{-1}	g seed $plant^{-1}$	g seed $plant^{-1}$	
0.5	8.11	0.00	2.46
0.25	7.43	0.13	1.26
0.125	8.55	0.21	1.92
0.0625	7.83	1.05	3.80
0.032	8.51	2.97	1.65
0.016	7.52	4.02	2.69
0.008	9.15	4.75	1.14
$LSD_{(0.05)}$	3.76	1.09	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.14. Seed weight for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Growth stage[a]	Dicamba rate	Untreated seed weight	Treated seed weight	$LSD_{(0.05)}$
	lb ai a^{-1}	g seed $plant^{-1}$	g seed $plant^{-1}$	
PRE	0.5	9.15	11.79	2.37
VC	0.5	7.40	1.11	0.88
V1	0.5	6.30	0.53	2.54
V3	0.5	5.00	0.00	2.49
V8	0.5	6.89	0.00	2.79
R1	0.5	7.84	0.00	2.79
R5	0.5	9.05	4.16	4.01
$LSD_{(0.05)}$		2.61	3.49	

[a]Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.15. Seed weight for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Dicamba rate[a]	Untreated seed weight	Treated seed weight	$LSD_{(0.05)}$
lb ai a^{-1}	g seed $plant^{-1}$	g seed $plant^{-1}$	
0.5	14.49	0.00	7.69
0.25	10.68	0.00	5.62
0.125	10.32	0.00	5.48
0.0625	9.12	5.35	4.40
0.032	8.53	4.48	3.01
0.016	9.44	6.91	5.68
0.008	8.03	6.81	3.39
0.004	10.47	8.70	1.35
$LSD_{(0.05)}$	3.28	2.82	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.16. Seed weight for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Growth stage[a]	Dicamba rate	Untreated seed weight	Treated seed weight	$LSD_{(0.05)}$
	lb ai a^{-1}	g seed $plant^{-1}$	g seed $plant^{-1}$	
PRE	0.5	15.41	19.03	7.24
VC	0.5	8.09	0.00	6.03
V1	0.5	7.21	0.00	1.52
V3	0.5	11.79	0.00	1.31
V8	0.5	10.63	0.00	2.31
R1	0.5	5.64	0.00	5.10
R5	0.5	10.91	1.08	5.35
$LSD_{(0.05)}$		4.09	10.35	

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.17. Seed count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Dicamba rate[a]	Untreated seed count	Treated seed count	$LSD_{(0.05)}$
lb ai a^{-1}	seeds $plant^{-1}$	seeds $plant^{-1}$	
0.5	47.33	0.00	16.93
0.25	42.04	1.12	9.05
0.125	50.96	2.00	15.00
0.0625	46.58	8.29	24.21
0.032	51.47	21.04	13.07
0.016	46.42	27.58	18.70
0.008	57.62	29.62	6.84
$LSD_{(0.05)}$	16.45	8.80	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.18. Seed count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Growth stage[a]	Dicamba rate	Untreated seed count	Treated seed count	$LSD_{(0.05)}$
	lb ai a^{-1}	seeds $plant^{-1}$	seeds $plant^{-1}$	
PRE	0.5	54.54	78.46	14.76
VC	0.5	44.58	9.58	7.29
V1	0.5	38.12	5.17	11.82
V3	0.5	31.57	0.00	16.56
V8	0.5	39.50	0.00	15.51
R1	0.5	45.37	0.00	13.16
R5	0.5	53.58	31.41	24.47
$LSD_{(0.05)}$		12.56	32.67	

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.19. Seed count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Diamba rate[a]	Untreated seed count	Treated seed count	$LSD_{(0.05)}$
lb ai a^{-1}	seeds $plant^{-1}$	seeds $plant^{-1}$	
0.5	84.82	0.00	43.52
0.25	63.45	0.00	30.74
0.125	62.56	0.00	32.34
0.0625	67.91	40.11	29.93
0.032	62.45	32.45	22.12
0.016	62.09	46.18	32.33
0.008	51.30	42.23	20.76
0.004	71.72	60.48	6.47
$LSD_{(0.05)}$	21.68	19.43	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.20. Seed count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Growth stage[a]	Dicamba rate	Untreated seed count	Treated seed count	$LSD_{(0.05)}$
	lb ai a^{-1}	seeds $plant^{-1}$	seeds $plant^{-1}$	
PRE	0.5	91.48	113.43	44.45
VC	0.5	51.34	0.00	37.94
V1	0.5	46.65	0.00	8.94
V3	0.5	76.38	0.00	9.56
V8	0.5	73.58	0.00	15.69
R1	0.5	40.01	0.00	28.23
R5	0.5	71.50	22.98	25.49
$LSD_{(0.05)}$		26.82	37.60	

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.21. Pod count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Dicamba rate[a]	Untreated pod count	Treated pod count	$LSD_{(0.05)}$
lb ai a^{-1}	pods $plant^{-1}$	pods $plant^{-1}$	
0.5	23.37	0.00	8.45
0.25	19.87	7.58	8.67
0.125	25.62	6.99	11.44
0.0625	20.79	9.96	8.03
0.032	22.18	17.79	10.40
0.016	21.75	20.17	5.74
0.008	25.87	17.79	1.89
$LSD_{(0.05)}$	4.72	5.19	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.22. Pod count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2013.

Growth stage[a]	Dicamba rate	Untreated pod count	Treated pod count	$LSD_{(0.05)}$
	lb ai a^{-1}	pods $plant^{-1}$	pods $plant^{-1}$	
PRE	0.5	23.12	40.62	5.18
VC	0.5	19.27	12.87	21.66
V1	0.5	16.42	5.63	13.37
V3	0.5	14.83	0.00	8.38
V8	0.5	16.83	0.00	6.46
R1	0.5	22.66	0.00	4.13
R5	0.5	22.25	24.29	3.22
$LSD_{(0.05)}$		4.43	13.67	

[a]Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.23. Pod count for the rate titration studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Dicamba rate[a]	Untreated pod count	Treated pod count	$LSD_{(0.05)}$
lb ai a^{-1}	pods $plant^{-1}$	pods $plant^{-1}$	
0.5	39.39	0.00	11.28
0.25	28.56	0.00	13.50
0.125	26.10	0.00	11.04
0.0625	29.65	22.23	5.26
0.032	29.19	19.34	9.29
0.016	28.46	24.98	12.10
0.008	26.32	23.75	11.23
0.004	29.68	27.34	2.12
$LSD_{(0.05)}$	12.47	6.98	

[a] Dicamba applied at the V3 (three trifoliate) growth stage.

Table C.24. Pod count for the growth stage studies at the Central Maryland Research and Education Center (CMREC), Beltsville, MD, 2014.

Growth stage[a]	Dicamba rate	Untreated pod count	Treated pod count	$LSD_{(0.05)}$
	lb ai a^{-1}	pods $plant^{-1}$	pods $plant^{-1}$	
PRE	0.5	41.87	47.42	18.42
VC	0.5	21.32	0.00	13.13
V1	0.5	19.29	0.00	5.39
V3	0.5	33.93	0.00	1.25
V8	0.5	32.23	0.00	8.13
R1	0.5	21.78	0.00	9.23
R5	0.5	11.35	1.13	5.48
$LSD_{(0.05)}$		13.15	26.72	

[a] Abbreviations: PRE, preemergence; VC, two leaf stage; V1, first trifoliate; V3, third trifoliate; V8, eighth trifoliate; R1, early flowering; R5, early pod fill.

Table C.25. Untreated control study measurements for 2013 at the Central Maryland Research and Education Center (CMREC), Beltsville, MD.

Parameter	Measurement	Untreated	Untreated	$LSD_{(0.05)}$
Plant height[a]	in	34.73	35.17	1.40
Stand count[b]	plants 20 ft^{-1} row	200.00	198.00	10.66
Yield	bu a^{-1}	50.40	50.70	9.37
Seed weight	g seed $plant^{-1}$	10.91	12.48	2.89
Seed count	seeds $plant^{-1}$	66.41	75.38	23.23
Pod count	pods $plant^{-1}$	28.46	31.62	9.04

[a] Heights taken 10 weeks after application.

[b] Stand counts taken 10 weeks after application.

Table C.26. Untreated control study measurements for 2014 at the Central Maryland Research and Education Center (CMREC)[a].

Parameter	Measurement	Treatment	Treatment	$LSD_{(0.05)}$
		Untreated	Untreated	
Plant height[a]	in	31.19	30.94	3.56
Stand count[b]	plants 20 ft^{-1} row	187.00	184.00	21.00
Yield	bu a^{-1}	46.60	46.30	13.80
Seed weight	g seed $plant^{-1}$	9.62	10.48	5.75
Seed count	seeds $plant^{-1}$	61.50	66.50	11.49
Pod count	pods $plant^{-1}$	28.44	30.39	5.32

[a] Heights taken 10 weeks after application.

[b] Stand counts taken 10 weeks after application.

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