MISSISSIPPI SOYBEAN PROMOTION BOARD
PROJECT NO. 04-2016 (YEAR 3)
2016 FINAL REPORT

Title: Determination of the effects of differing deposition aids on canopy deposition with commonly used pesticides in soybean

PI: Darrin Dodds

EXECUTIVE SUMMARY

The results from these experiments prove that not all pesticide applications can be treated as equal. Furthermore, these data suggest that growers should be mindful of what they are applying before mixing additives to the spray tank to aid with the application.

Based on these findings, guar gum products applied with herbicides can produce a larger droplet and minimize the number of driftable fines produced, thus reducing the potential for off-target movement. However, this came at a cost of decreased canopy penetration of the pesticide.

Polymer deposition aids minimized the level of driftable fines produced and also resulted in greater canopy penetration.

Oil deposition aids tended to reduce the droplet size, which could lead to increased off-target movement.

These data serve as a building block for future research into pesticide pplication technology issues. A grower should attempt to minimize off-target movement while maximizing canopy coverage and penetration. In some instances, using a deposition aid may cause more problems from an off-target movement standpoint because of its resulting in smaller droplet size.

For instance, the oil deposition aids reduced droplet size below that of treatments that did not receive a deposition aid in the insecticide study. Growers are encouraged to consider deposition aids on a case by case basis and not use a one-size-fits-all approach, especially when applying pesticides that are known to cause or result in damage to off-target sites.

Given the propensity of auxin herbicides to cause damage when off-target movement occurs as well as the potential effects of insecticides on non-target species, growers are strongly encouraged to make applications under the best possible environmental conditions. The inclusion of deposition aids will not stop off-target movement when applications are made during poor environmental conditions. Performance of deposition aids appears to be product- and situation-specific, and until each of those situations is clearly identified (pesticide being applied and nearness to sensitive areas), the utility of deposition aids appears to be minimal.

For now, the pesticide label should be the guide to adding any additives or deposition aids to spray mixtures since this will have been tested/verified before placement on the label.

BACKGROUND

Droplet size and velocity distribution are two of the most important factors in accuracy and retention of pesticide applications (Lake and Marchant 1983). The shift to glyphosate-tolerant (GR) crops intensified the need to control off-target movement of glyphosate onto surrounding non-resistant plants (Mueller and Womac 1997; Ramsdale and Messersmith 2001).

Historically, droplet size has been controlled by either increasing or decreasing the application pressure or selecting a larger nozzle orifice size (Spray Drift Task Force 1997). However, off-target movement may be mitigated by increasing the droplet size with a drift control adjuvant in combination with the pesticide (Bode et al., 1976).

Adjuvants can be classified into one of three categories, with some products being labeled as multi-use: (1) the effect they have during the applications process; (2) their function; and (3) the chemical class to which they belong. Multi-use or multi-functionality in adjuvants typically is the result of specific physiochemical properties of the adjuvant (Spanoghe et al. 2006). Utility adjuvants may influence spray formation; this becomes important when applications require an optimum droplet size for activity (Knoche 1994). However, utility adjuvants generally do not affect herbicide efficacy but rather attempt to make the application process more efficient (McMullan 2000).

Adjuvants used to control off-target movement are commonly referred to as drift control agents (DCA). There are several types of DCA's, with the most commonly used being polymer or polymeric products (Jones et al. 2007). A major group of polymeric DCA's are polyacrylamide-based products (McMullan 2000). Among this group of DCA's are polysaccharides, with the most common utilized being guar and xanthan gums (McMullan 2000). Akesson et al. (1994) reported that naturally occurring polysaccharides such as gums, agars, and algin may serve as thickening agents in water-based applications. Guar gum-based polysaccharides can effectively reduce the percentage of the spray droplets ≤ 150 µm (Hazen 1996) due to the altering of the viscoelastic properties of the spray solution (Hewitt 1998). Extensional viscosity can help solutions resist liquid stretching. Shear viscosity is the level of viscosity at a given shear rate. As shear viscosity decreases, spray droplets become coarser (McMullan 2000). Altering both the extensional viscosity and the shear viscosity can produce a coarser droplet with a higher volume median diameter (VMD) therefore, lowering drift potential. (McMullan 2000).

The combination of DCA's with certain formulations of glyphosate may result in decreased efficacy (Anonymous 2005). Jones et al. (2007) reported that the addition of two differing DCA's to glyphosate resulted in 19 and 50% less of the spray volume in droplets <141 µm and in 15 and 59% larger volume median diameter (VMD) of spray droplets, respectively, when compared to glyphosate alone. When application pressure was increased 1.5-fold, the effects were still found to be proportionally similar to that of the original findings (Jones et al. 2007).

Two other subgroups of the polyacrylamides include the nonionic polyacrylamides and the anionic polyacrylamides (McMullen 2000). Anionic polyacrylamides are characterized by a negative net charge and a higher molecular weight. The nonionic subgroup is characterized by a net neutral charge and a lower molecular weight (McMullen 2000). Additional DCA's consist of suspended polyacrylamides in an oil surfactant which forms an emulsion when mixed in a spray solution (Chamberlain and Rose 1998). Invert emulsions consist of water suspended in the oil phase, causing the invert concentrate to encapsulate the pesticide with the droplet also encapsulating water. Invert emulsions increase VMD and also reduce the driftable fraction (Hall et al. 1998).

A deposition aid is defined as "material that improves the ability of pesticide sprays to deposit on targeted surfaces" (ASTM 1995). There are two primary methods to increase pesticide deposition. First, you can increase the level of pesticide deposited directly on the crop, and second you can increase the level of uniformity of the pesticide deposition (McMullen 2000). Farris (1991) reported an increase in the number of droplets observed per cm^2 of the target surface when a deposition aid was added to the spray mix.

Increasing the level of a pesticide making it to the target surface has two primary benefits. Increased levels of a pesticide landing on an intended target could result in increased efficacy, and if a higher level of pesticide is landing on the intended target, there is less pesticide to land on a non-intended target (McMullen 2000). Richards et al., (1998) observed that several deposition aids did not have a significant impact on the VMD or the driftable fraction of a pesticide application.

Numerous cases of legal action involving off-target movement of pesticides are filed with the Mississippi Bureau of Plant Industry each year. Of these, a large majority involve herbicides. With auxin-tolerant crops gaining regulatory approval, off-target movement of auxin herbicides will be deleterious to adjacent crops lacking the appropriate technology.

Insecticide movement is less of a problem due to the lack of visible phytotoxicity and there being no yield loss on adjacent crops. However, worldwide focus has shifted to off-target movement of insecticides and subsequent effects on pollinator species.

Little to no previous research exists regarding the effect of spray additives such as drift retardants on spray droplet size or canopy deposition of insecticides. Given the cost of these products as well as the potential impacts of off-target movement, significant efforts are needed to address the effect of spray additives on spray droplet size and canopy deposition.

MATERIALS AND METHODS

Experiments were conducted in 2014 and 2015 at the R. R. Foil Plant Science Research Center at Starkville, MS and the Black Belt Branch Experiment Station in Brooksville, MS. Soybeans were planted on conventionally-tilled beds spaced 96 cm apart. When soybean plants reached 96 cm in height, applications were made using a Bowman Mudmaster equipped with AIXR 110015 spray nozzles calibrated to deliver 138 L ha^{-1} at 386 kpa. Applications were made 46 cm above the crop canopy at wind speeds less than 8 kph.

Metal stands were constructed and utilized for these experiments. Stands measured 61 cm in height, with each stand made of square tubing serving as the main beam (Figure 1). A card holder was located on each of the four sides of the tubing. Card holders were spaced equidistantly apart on the vertical axis at the top of the canopy; 15 cm downward, 30 cm downward, and 46 cm downward. The holders were positioned in a spiral manner down the main beam in an attempt to mimic the structure of an actual plant. Stands were placed in rows 2 and 3 of the drill in each plot. The stand in row 2 was placed at the front of the plot and the stand in row 3 was placed at the opposite end of the plot. The front stand was placed in the row in a manner to which the bottom most position was perpendicular to the row. The back stand was placed in a manner to which the bottom most position was directly parallel to the crop canopy (Figure 3).

Figure 1. Metal stands used to determine impact of deposition aids on pesticide deposition into the soybean canopy.

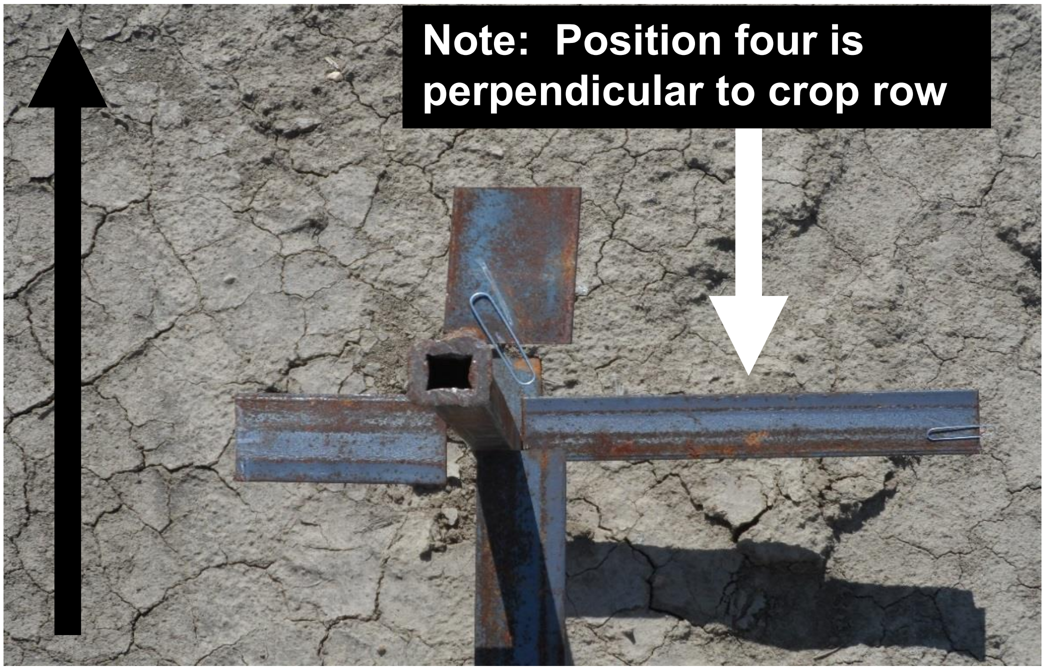

Figure 2. Position of back stand with the black line indicating crop row direction (Stands were placed directly in crop row).

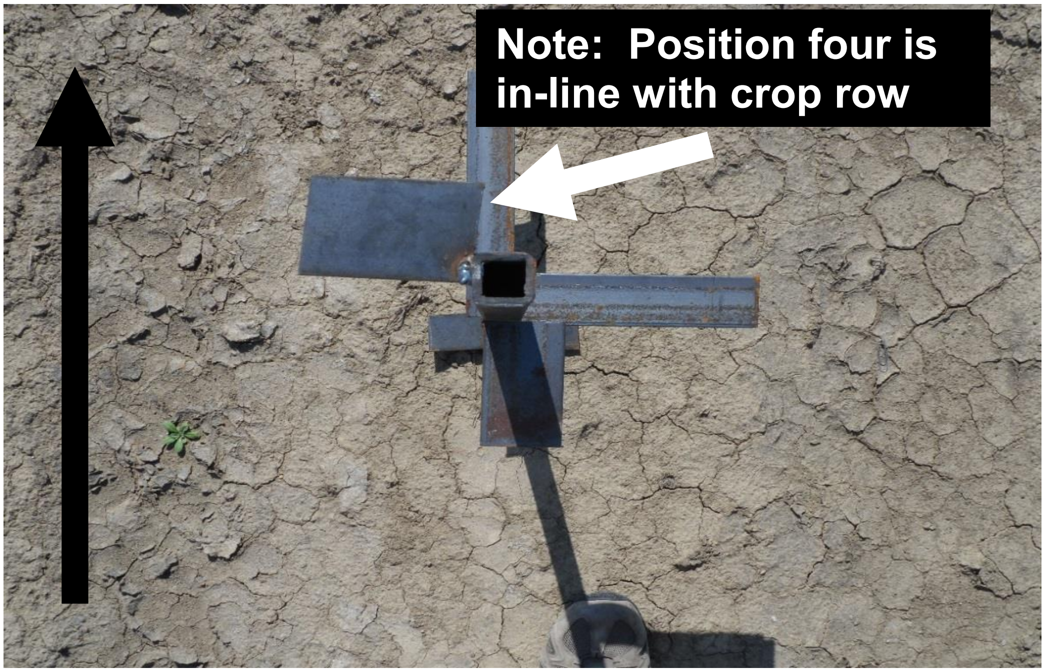

Figure 3. Position of front stand with the black line indicating crop row direction (Stands were placed directly in crop row)

Mylar cards that measured 10 cm by 10 cm in size were utilized in this study. Cards were placed at each position on the stand and held securely using a small paper clip. Cards were never handled with bare skin in order to minimize contamination. A clean pair of latex gloves was used by every individual handling the cards and a fresh pair of latex gloves was used to remove the cards.

Two experiments in soybean were initiated in 2014. Herbicides and deposition aids as well as insecticides and deposition aids were evaluated. Herbicide(s) and herbicide combinations consisted of: glufosinate @ 0.6 kg ai/ha + MON 119096 (dicamba) @ 0.6 kg ae/ha; glufosinate + the premix of glyphosate+ 2, 4-D amine (Enlist Duo) @ 2.33 L/ha; glyphosate @ 1.1 kg ae/ha + fomesafen @ 0.26 kg ai/ha; and glufosinate + fomesafen, and MON 76832 + fomesafen. Each herbicide(s) or herbicide combination was applied alone or in combination with HM 9679A (oil) @ 1% v/v, HM 1428 (polymer) @ 0.5 % v/v, or HM 9733 (guar gum) @ 30 g/38 L of water. A fluorescing red tracer dye was added at 0.2% v/v. Soybean insecticides included acephate @ 0.84 kg ai /ha and lambda – cyhalothrin @ 0.02, and methoxyfenozide @ 0.105 kg ai ha^{-1}. Each insecticide was applied alone or in combination with HM 9679A (oil) @ 1% v/v, HM 1428 (polymer) @ 0.5 % v/v, or HM 9733 (guar gum) @ 30 g/38 L of water.

Prior to pesticide application, mylar cards were placed on all stands. Once the application was made, the spray solution was allowed to dry for 90 seconds after which cards were collected immediately due to high photo degradability of the fluorescing dye. Cards were then placed in a plastic bag and immediately placed in a dark container. At the end of each study, containers were placed in cold storage. Once all cards were collected, they were delivered to the University of Nebraska - West Central Research and Extension Center in North Platte, NE. Cards were analyzed using a fluorimetry analysis. Mylar cards were placed in a bag filled with deionized water and scrubbed from the outside of the bag while wearing latex gloves. After scrubbing, a 1 ml sample was collected and placed in a vile for fluorimetry analysis.

After herbicides, insecticides, and deposition aids were mixed, a 180-ml sample was collected from each treatment and placed in a dark container and kept cool. Samples were delivered to the University of Nebraska - West Central Research and Extension Center in North Platte, NE and droplet size analysis was conducted in a wind tunnel facility equipped with a Sympatc Diffracting Laser system. All pesticides and deposition aids were applied in the wind tunnel through a single nozzle (AIXR 110015) calibrated to deliver 140 L ha^{-1} @ 310 kpa. Droplet size was determined by measuring the level of light that is diffracted by the spray droplet as the spray pattern moves downward across the laser beam.

All experiments were conducted using a factorial arrangement of treatments within a randomized complete block design with factor A being herbicide and Factor B being deposition aid. Statistical analysis was conducted using the PROC MIXED procedure in SAS 9.4. Means were separated using Fisher's Protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Insecticide Field Study

There were no significant interactions between insecticide and deposition aid at position 1 (top of the crop canopy). However, the main factors of insecticide and deposition aid were both observed to have a significant impact on the level of reflectance measured at position 1. Applications containing Intrepid (3338 RFU) and Karate (3163 RFU) had similar deposition levels at position 1 (Figure 4). Both insecticides were deposited at greater levels than that of Orthene (1737 RFU) at position 1 (Figure 4). No differences were present with respect to deposition at position 1 from the polymer deposition aid, the guar gum deposition aid, and when no deposition aid was used in the application. Relative fluorescence unit (RFU) values for these treatments ranged from 2719 - 3422. Inclusion of polymer and guar gum deposition aids resulted in greater deposition values at position 1 than when an oil deposition aid was included in the application (1821 RFU).

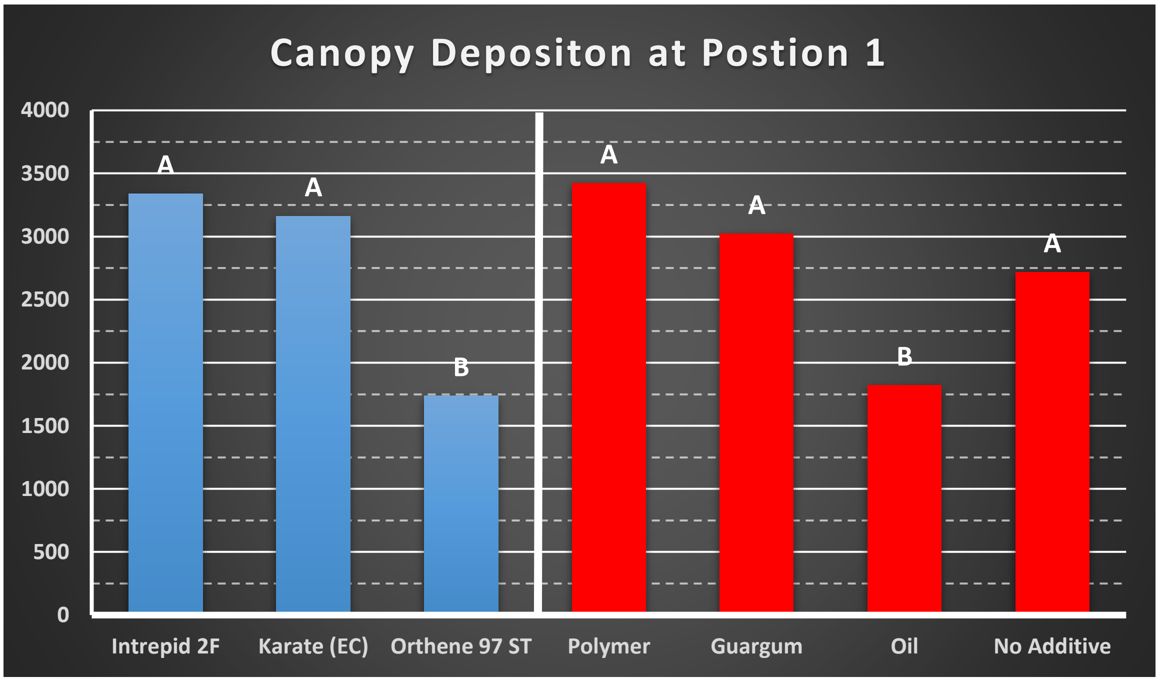

Figure 4. Effect of insecticide and deposition aid on canopy depositiion measured at Positon 1 (top of the crop canopy).

Similar to data from position 1, there were no significant interactions between insecticide and deposition aid at position 2 (15 cm downward into the canopy position 1). However, insecticide had a significant impact on deposition level at position 2. Application of Intrepid and Karate resulted in greater deposition (2156 & 2124 RFU, respectively) compared to Orthene (1154 RFU) (Figure 5). Inclusion of a deposition aid without an insecticide did not have an impact on deposition at position 2, with RFU values ranging from 1506 to 2110.

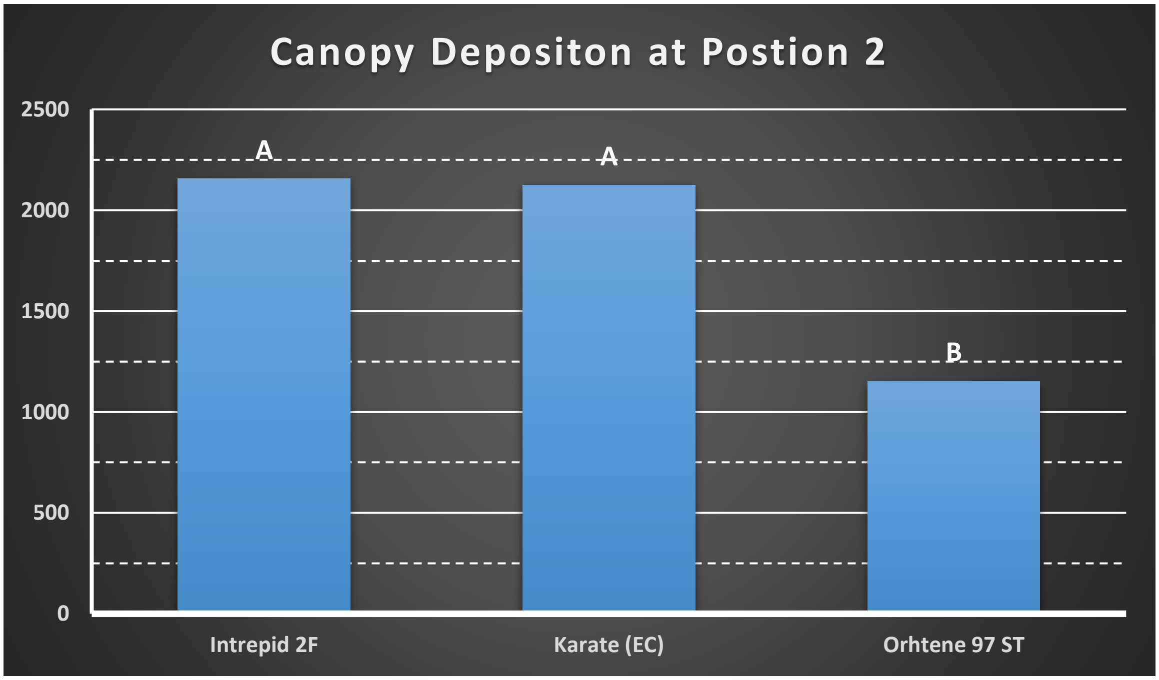

Figure 5. Effect of insecticide on canopy depositiion measured at Positon 2 (15 cm downward into the crop canopy).

Similar to positons 1 and 2, there were no significant interactions between insecticide and deposition aid at position 3 (30 cm downward into the crop canopy). However, neither insecticide nor deposition aid impacted deposition at position 3 (data not shown), with RFU values ranging from 803 to 1520. Droplets traveling to position 3 must cover a greater distance through more dense vegetation prior to landing at this position; thus the lower RFU values.

There was no significant interaction between insecticide and deposition aid at position 4 (45 cm downward into the crop canopy). However, insecticide impacted deposition level at position 4. Similar to positons 1 and 2, Karate and Intrepid were deposited at similar levels (1356 and 1233 RFU, respectively) at position 4 (Figure 6). Inclusion of Orthene resulted in less of the spray solution deposited at position 4 compared to Intrepid and Karate based on the RFU values (Figure 6).

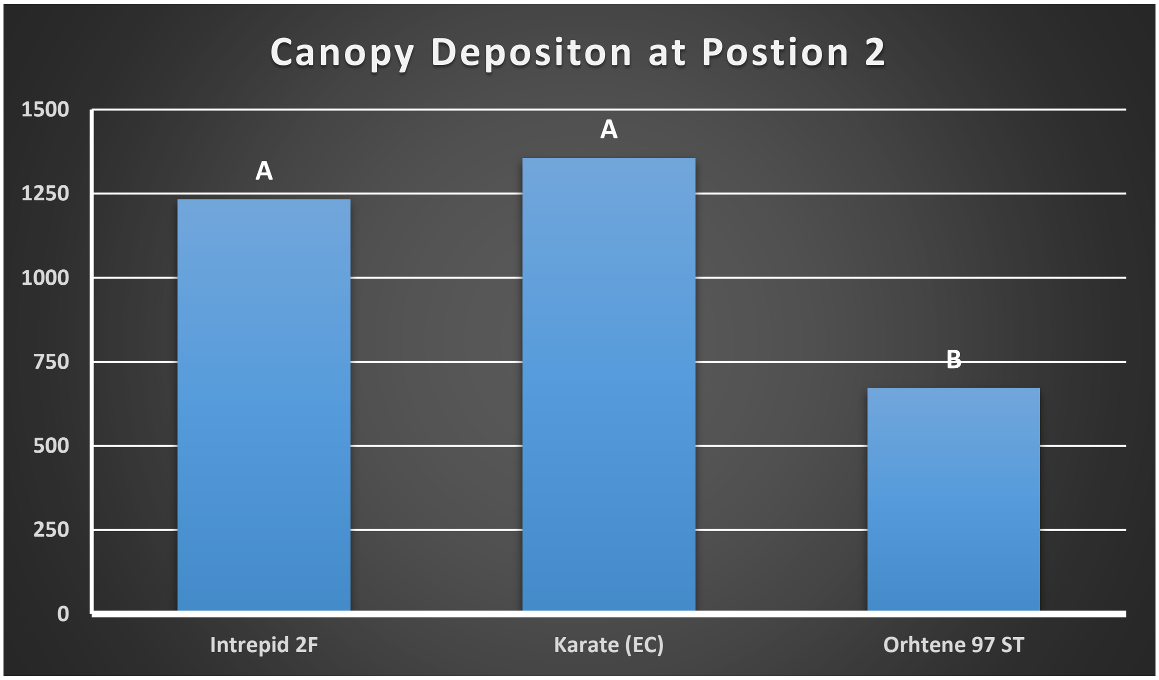

Figure 6 . Effect of insecticide on canopy depositiion measured at Positon 4 (45 cm downward into the crop canopy).

Wind Tunnel Portion of Insecticide Field Study

Insecticide had a significant impact on the volume mean diameter (VMD) of spray droplets. Application of Orthene resulted in significantly greater VMD than applications that included Karate, with droplets from Orthene application having a VMD of 450 µm while droplets from Karate application had a VMD of 427 µm (Figure 7). Although larger droplets were produced when applying Orthene, greater coverage occurred from Karate applications with the 25-µm-smaller droplets (Figures 4-6).

Applications containing the guar gum deposition aid resulted in the largest VMD spray droplets (Figure 7), whereas applications containing the polymer deposition aid produced droplets that were smaller than those from applications containing the guar gum deposition aid. However, droplets produced when the polymer deposition aid was included were significantly larger than those from applications where no deposition aid was included as well as when an oil deposition aid was included. Applications containing the oil deposition aid resulted in spray droplets which were significantly smaller than those from treatments containing both the guar gum and polymer deposition aids as well as when applications were made with no deposition aid (Figure 7).

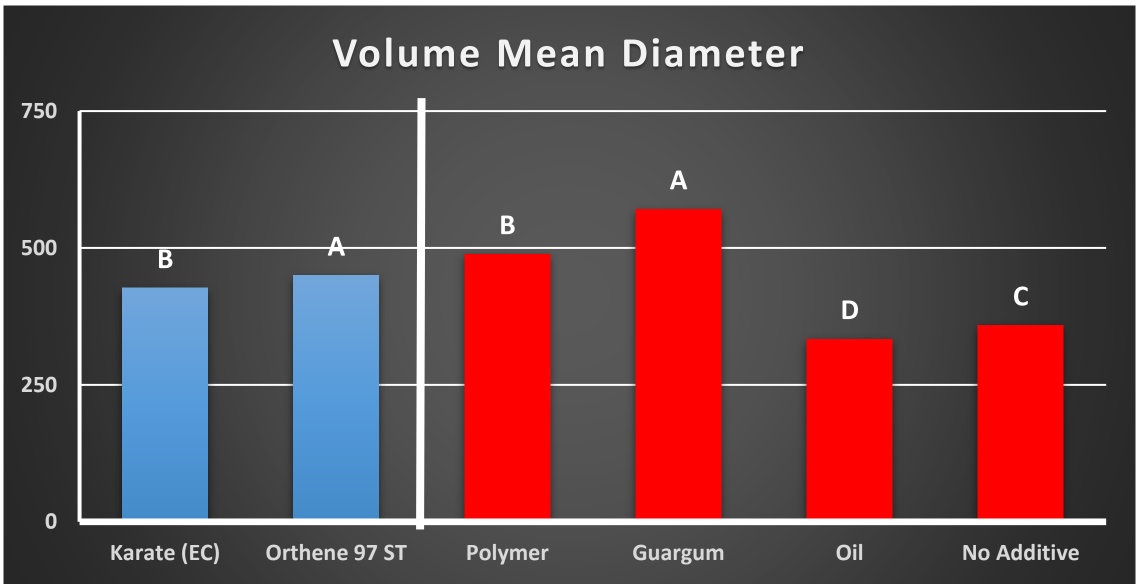

Figure 7. Volume mean diameter (VMD) of droplets as affected by insecticide and deposition aid.

Relative span is determined by finding the difference between the DV10 (10% of total droplets smaller than this value) and the DV90 (90% of droplets smaller than this value) values which ultimately tells how much variation is present among droplet sizes during an application. Both insecticide and deposition aid had a significant impact on relative span of spray droplets during application. Treatments containing Karate had significantly greater relative span when compared to Orthene applications (Figure 8). Additionally, deposition aids that increased droplet size also significantly increased the relative span of spray droplets.

Applications that contained the guar gum deposition aid had a greater relative span of spray droplets when compared to all other treatments (Figure 8). Interestingly, all deposition aids significantly increased relative span of spray droplets compared to applications that did not include a deposition aid in combination with insecticides. These data suggest that the addition of a deposition aid can increase the level of variation produced when an application is made with an insecticide. Similarly, variation can be increased based on the insecticide being utilized to control an insect pest. This could be due to the inert ingredients present in the formulation, or the formulation type.

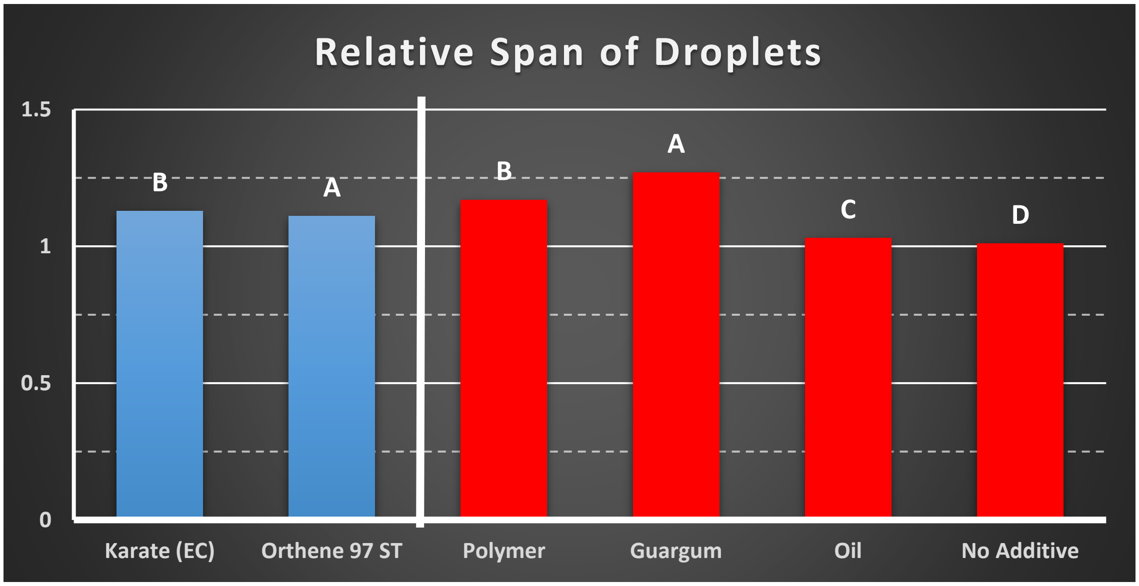

Figure 8. Relative san of droplets as impacted by insecticide and type of deposition aid.

The number of driftable fines produced by a spray was significantly impacted by insecticide and deposition aid. Although a greater relative span of spray droplets was produced by treatments containing Karate, a greater number of driftable fines (droplets <150 µm) was produced when treatments contained Orthene (Figure 9). The greatest level of driftable fines produced when deposition aids were included was with the oil deposition aid combined with an insecticide. Treatments containing the oil deposition aid resulted in more droplets < 150 µm compared to all other treatments (Figure 9). Treatments containing the polymer deposition aid produced fewer driftable fines compared to treatments containing the oil deposition aid or treatments that did not contain a deposition aid. Treatments containing the guar gum deposition aid resulted in fewer driftable fines compared to all other deposition aids.

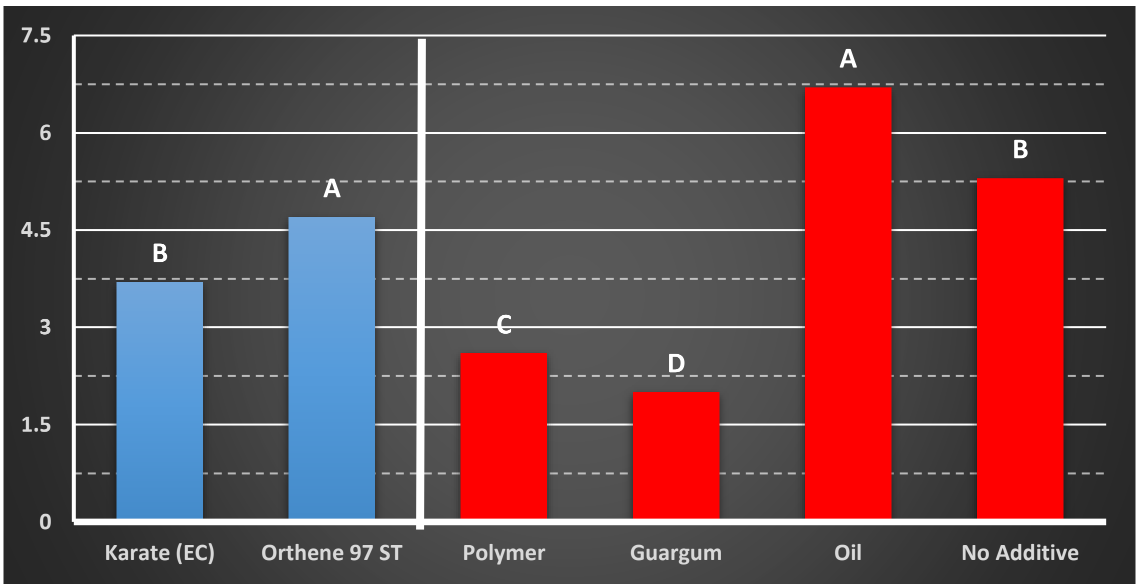

Figure 9. Percent of droplets produced less than 150 microns by insecticide and deposition aid.

Differences observed in the field can be explained by data collected in the wind tunnel. Although droplets containing Karate had a smaller VMD and a greater relative span, fewer droplets smaller than 150 µm were produced. Droplets less than 150 µm have a greater propensity to move off-target. Furthermore, deposition at position 1 can be explained by data collected in the wind tunnel. The greatest spray droplet VMD was produced when the polymer and guar gum deposition aids were added to the insecticide application. Additionally, inclusion of the polymer and guar gum deposition aids resulted in the fewest droplets < 150 µm in size (Figure 9).

The lack of performance with respect to deposition within the crop canopy suggests that guar gum and polymer deposition aids increase the level of deposition the top of the canopy. However, insecticide selection could play a more critical role when targeting pests deeper in the crop canopy. Based on these data, the addition of the oil deposition aid could decrease droplet size and the level of deposition at the top of the crop canopy. Furthermore, the addition of an oil deposition aid performed worse than that of treatments that did not receive a deposition aid with respect to canopy deposition. Growers should only use an oil deposition aid when required by the label. However, with Intrepid, Karate, or Orthene use, a grower could save money by not using an oil deposition aid.

Herbicide Field Study

In the herbicide field study, there were no significant interactions between herbicide and deposition aid at position 1 with respect to deposition. Moreover, there were no significant effects due to herbicide or deposition aid. Relative fluorescence unit values ranged from 1847 - 2768 depending on the treatment (data not shown).

Similar to position 1, there were no significant interactions between herbicide and deposition aid present at position 2 (15 cm downward in the crop canopy). However, herbicide treatment did impact deposition at position 2. Applications containing MON 76832 (Roundup Xtend) + Flexstar were deposited at greater levels at position 2 based on RFU values compared to other herbicide treatments with the exception Liberty + Clarity. Relative fluorescence unit values were 2890 and 2078 for the tank combination of MON 76832 + Flexstar and the tank combination of Liberty + Clarity, respectively. Applications of Liberty + Clarity, Liberty+ Flexstar, Roundup + Flexstar, and Liberty + Enlist Duo were not significantly different from one another with RFU values ranging from 1297 - 2078 (Figure 10).

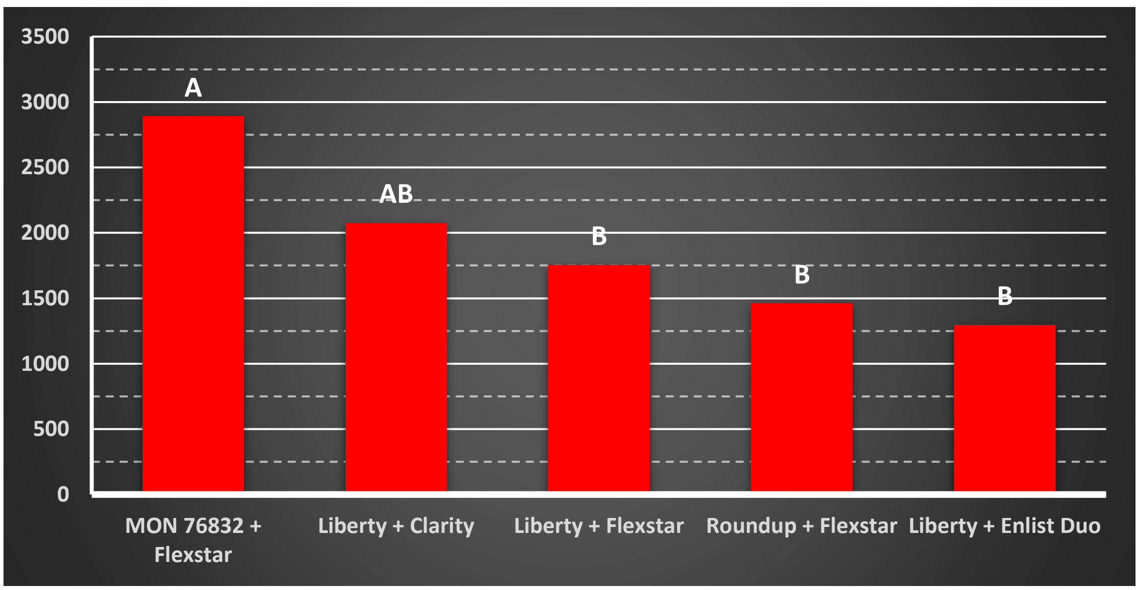

Figure 10. RFU values for herbicide applications position 2 (15 cm below the top of the crop canopy).

There were no significant interactions between the herbicide and deposition aid at position 3 (30 cm downward into the crop canopy). However, deposition aid impacted deposition at position 3. Treatments containing the polymer deposition aid were deposited in greater amounts at this position, except for herbicide combinations that were applied absent a deposition aid (Figure 11).

Relative fluorescence unit values for applications containing the polymer deposition aid and applications made without a deposition aid were 1308 and 1036, respectively. Applications that did not include a deposition aid resulted in similar deposition to those that included an oil deposition aid and guar gum at position 3. Relative fluorescence unit values ranged from 700 - 1036 depending on the treatment (Figure 11).

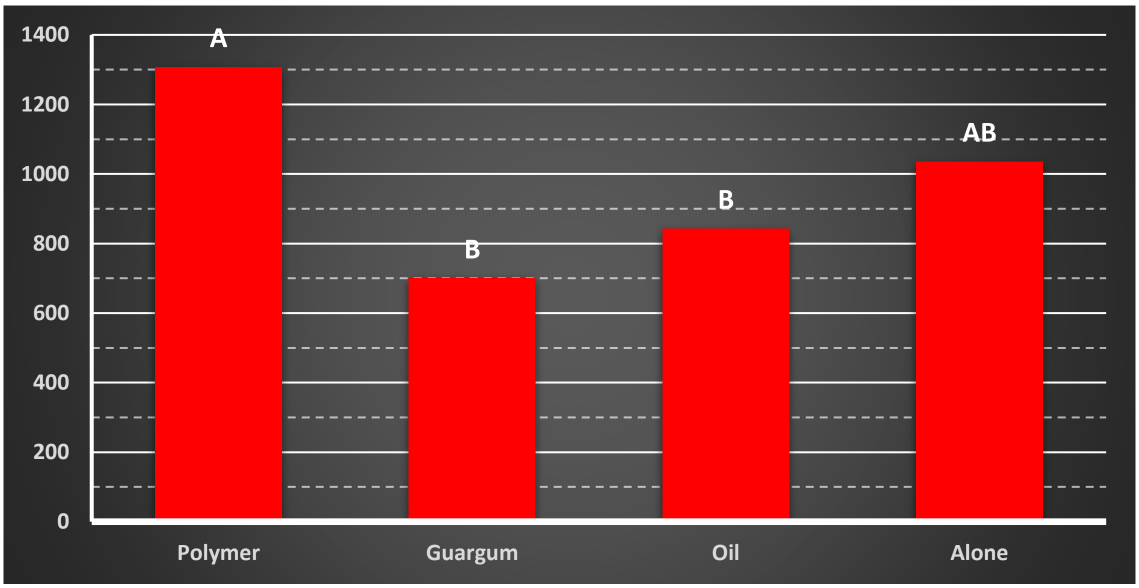

Figure 11. RFU values for deposition aids at position 3 (30 cm below the top of the crop canopy).

There were no significant interactions at position 4 (45 cm from the top of the crop canopy) between herbicide and deposition aid. Also, there were no significant effects associated with herbicide or deposition aid alone. Relative fluorescence unit values ranged from 505-1371 depending on the treatment (data not shown).

Wind tunnel portion of herbicide study

Field-applied herbicide combinations were also used in the wind tunnel to determine droplet size. The VMD of spray droplets was significantly affected by both the herbicide combination as well as deposition aid.

Treatments containing Liberty + MON 76832 resulted in the greatest VMD of all herbicide treatments. Interestingly, the lowest spray droplet VMD also contained MON 76832; however, in this instance it was combined with Flexstar. Treatments containing MON 76832 + Liberty and MON 76832+Flexstar VMD's were 455 and 410, respectively (Figure 12). Treatments containing Liberty + Flexstar produced a VMD of 422, while treatments containing Liberty + Enlist Duo produced droplets with a VMD of 432 (Figure 12).

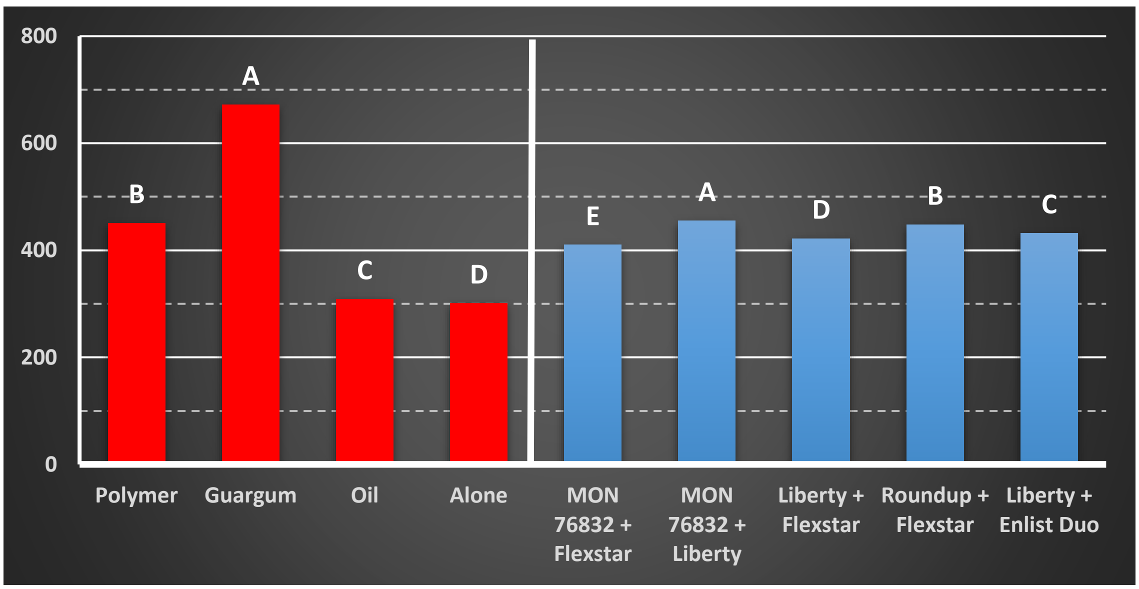

Figure 12. Volume mean diameter (VMD) values of spray droplets when applied with deposition aids and herbicide combinations.

Deposition aids impacted spray droplet VMD produced during the application. Treatments containing the guar gum deposition aid had the greatest droplet size compared to spray droplets utilizing other deposition aids. Treatments containing the oil deposition aid resulted in significantly greater spray droplet VMD than that of treatments receiving no deposition aid, but also had a significantly lower VMD than that of droplets produced by applications containing the guar gum and polymer deposition aids.

Although significant differences were present when evaluating the effect of herbicide combinations on relative span of spray droplets, the differences were minimal (data not shown). However, significant differences were also present with respect to relative span of spray droplets due to deposition aid. Treatments applied absent of deposition aids had a significantly greater relative span when compared to all other treatments. Treatments containing the guar gum deposition aid had a significantly lower relative span when compared to all other treatments. Although significant differences were present between the oil and polymer deposition aids with respect to relative span of the spray droplets, the differences were minimal (Figure 13).

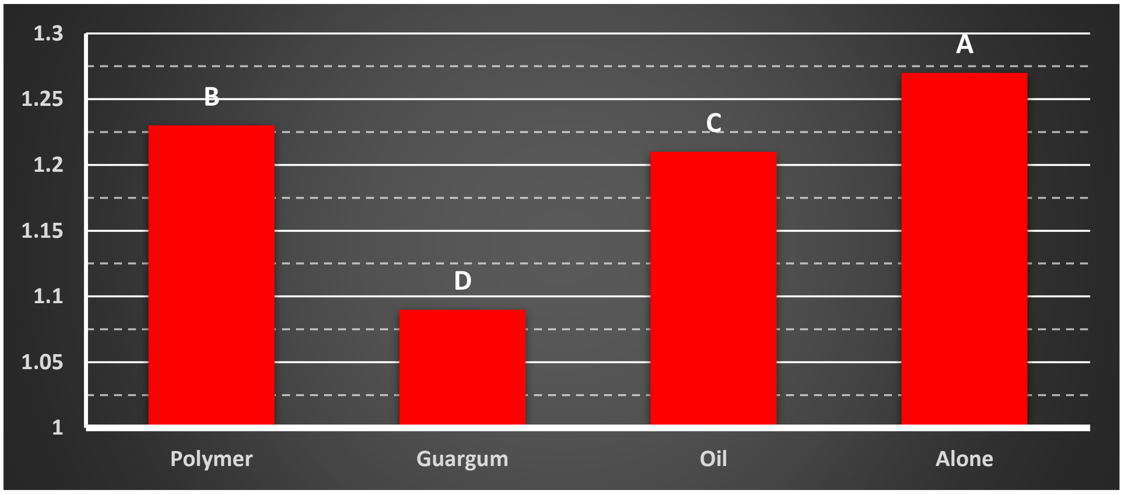

Figure 13. Effect of deposition aids on the relative span of the spray application.

Herbicide combination and deposition aid impacted the number of driftable fines produced during the application process. Herbicide combinations containing Liberty resulted in significantly more droplets < 150 µm (Figure 14). Liberty + Flexstar produced significantly more driftable fines than Liberty + Enlist Duo and Liberty + MON 76832. Interestingly, of the three Liberty-containing combinations, significantly fewer driftable fines were produced when MON 76832 was co-applied with Liberty.

Overall, significantly fewer driftable fines were produced when Flexstar was co-applied with MON 76832 or when Flexstar was co-applied with Roundup (Figure 13) compared to other treatments. From the standpoint of the deposition aids, all deposition aids reduced the level of driftable fines produced when compared to treatments that did not receive the addition of a deposition aid. Applications containing a guar gum deposition aid reduced the number of driftable fines when compared to all other deposition aid treatments. The number of driftable fines produced from inclusion of oil deposition aids and no deposition aid were similar.

Results suggest that, although a coarser droplet was produced with the guar gum deposition aid, this did not aid in canopy penetration. Furthermore, canopy deposition was maiximized with droplets greater than 400 µm in size based on RFU values produced in the field study. Treatments containing MON 76832 + Flexstar produced the smallest droplet of any of the herbicide combinations tested. Additionally, this combination also produced the greatest level of canopy penetration observed at position 2. The guar gum-containing treatments had significantly reduced relative span but did not improve deposition into the plant canopy.

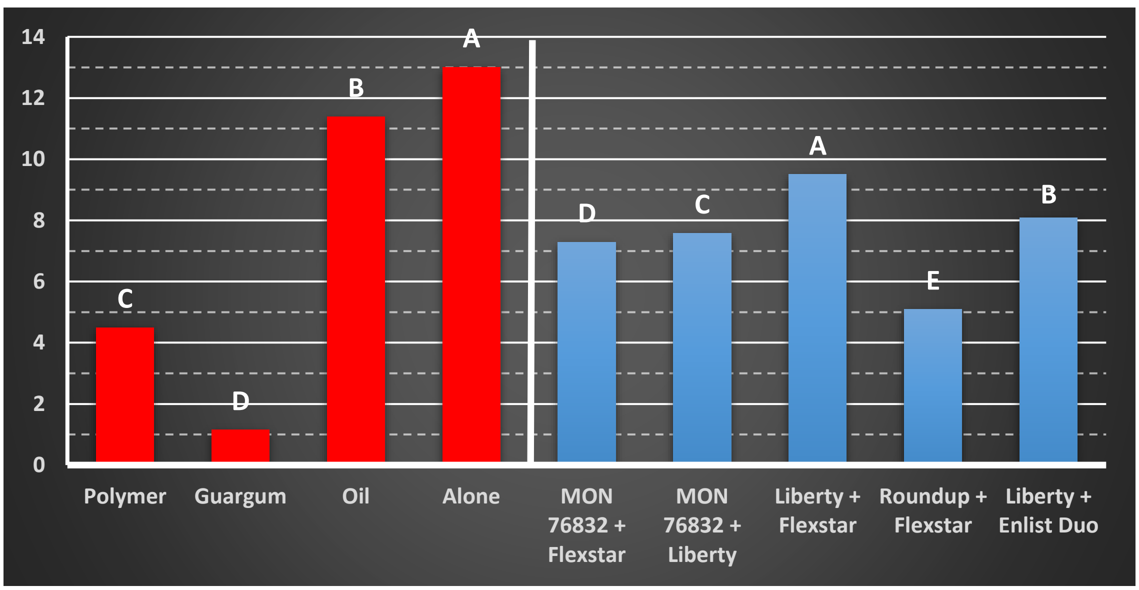

Figure 14. Effect of deposition aids on the relative span produced during application.

CONCLUSIONS

In conclusion, there are several aspects to consider when making a pesticide application. Of these, canopy penetration only covers a small area of a vastly growing subject. These data prove that not all pesticide applications can be treated as equal. Furthermore, these data suggest that growers should be mindful of what they are applying and what they place in the tank to aid with the application.

Based on these findings, guar gum products applied with herbicides can produce a larger droplet and minimize the number of driftable fines produced, thus reducing the potential for off-target movement. However, this came at a cost of decreased canopy penetration.

Polymer products maximized both areas in these studies. Polymer deposition aids minimized the level of driftable fines produced, but also resulted in greater canopy penetration.

Oil deposition aids tended to reduce the droplet size, which could lead to increased off-target movement.

These data only serve as a building block for future research from an application technology standpoint. A grower should attempt to minimize off-target movement while maximizing canopy coverage and penetration. In some instances, using a deposition aid may cause more problems from an off-target movement standpoint.

For instance, the oil deposition aids reduced droplet size below that of treatments that did not receive a deposition aid in the insecticide study. Growers are encouraged to consider deposition aids on a case by case basis and not use a one-size-fits-all approach.

Given the propensity of auxin herbicides to cause damage when off-target movement occurs as well as potential effects of insecticides on non-target species, growers are strongly encouraged to make applications under the best possible environmental conditions. The inclusion of deposition aids will not stop off-target movement when applications made during poor environmental conditions. Performance of deposition aids appears to be product- and situation-specific, and until each of those situations is clearly identified, the utility of deposition aids appears to be minimal.

For now, the pesticide label should be the guide to adding any additives or deposition aids to spray mixtures.

Literature Cited

Akesson, N.B., W.E. Steinke, and W.E. Yates. 1994. Spray atomization characteristics as a function of pesticide formulations and atomizer design. J. Environ. Sci. Health B29(4):785-814.

Anonymous.2005. Label:Roundup WeatherMax. Web Page: http://www.cdms.net/. Accessed 15 June 2015.

ASTM. 1995. Terminology relating to agricultural tank mix adjuvants. *In* annual book of ASTM standards Vol. 11.05: Biological effects and environmental fate; biotechnology; pesticides. Philadelphia, PA. 966-967.

Bode, L.E., B.J. butler, and C.E. Goering. 1976. Spray drift and recovery as affected by spray thickener, nozzle type, and nozzle pressure. Trans. Am. Soc. Agric. Eng. 19:213-218.

Chamberlain, P. and S.A. Rose. 1998. Effect of non-ionic polyacrylamides on spray droplet size, spray drift, and pesticide efficacy. *In* P.M. Mcmullan ed.Adjuvatns for agrochemicals. Challenges and opportunities. *In* Proc. Fifth int. symp. On adjuvants for agrochemicals. Memphis, TN. 1:463-467.

Farris, M.E. 1991. The effect of penetrator and penetrator plus on pesticide deposition, evaporation, and foliage residue in cotton. *In* Proceedings of the Beltwide Cotton Conference. 2:768-771.

Hall, F.R., R.A. Downer, and J.A. Latting. 1998. Improving herbicide efficacy with adjuvant/ammonium sulfate combinations. *In* P.M. McMullan, ed. Adjuvants for agrochemicals. Challenges and opportunities. *In* proc. Fifth int. symp. Adjuvatnts for agrochemicals. Memphis, TN. 1:475-480.

Hazen, J.L. 1996. United States patent 5,5500,224. Webpage: http:www.uspto.gov/patf/index.html. Accessed 15 June 2015.

Hewitt, A.J. 1998. The effect of tank mix and adjuvants on spray drift. *In* P.M. McMullan ed. Adjuvants for agrochemicals. Challenges and Opportunities. *In* proc. Fifth int. Symp. On Adjuvants and for Agrochemicals. Memphis, TN 1:451-462.

Knoche, M. 1994. Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop. Prot. 13:163-178.

Jones, E.J., J.E. Hanks, G.D. Wills, and R.E. Mack. 2007. Effect of two polysaccharide adjuvants on glyphosate spray droplet size and efficacy. Weed. Tech. 21:171-174.

Lake, J.R. and J.A. Marchant. 1983. The use of dimensional analysis in a study of drop retention on barley. Pestic. Sci.14:638-644.

McMullan, P.M. 2000. Utility Adjuvants. Weed Tech. 14:792-797.

Mueller, T.C. and A.R. Womac. 1997. Effect of formulation and nozzle type on droplet size with isopropylamine and trimesium salts of glyphosate. Weed. Tech. 11:639-643.

Ramsdale, B.K. and C.G. Messersmith. 2001. Drift-reducing nozzle effects on herbicide performance. Weed Tech. 15:453-460.

Richards, M.D., P.J. Holloway, and D. Stock. 1998. Structure-spray retention enhancement relationships for some polymers and polymeric surfactants. In P.M. McMullan ed. Adjuvants for agrochemicals. Challenges and opportunities. In Proc. Fifth Int. Symp. On Adjuvants for agrochemicals. Memphis, TN. 1:79-84.

Spanoghe, P., M. De Schampheleire, P. Van der Meeren and w. Steurbaut. 2007. Influence of agricultural adjuvants on droplet spectra. Pest. Manag. Sci. 63:4-16.

Spray Drift Task Force. 1997. A summary of ground application studies. Webpage:http://www.agdrift.com. Accessed 17 June 2015.