

Strategies for Managing Pesticide Spray Drift Webinar

Speakers: Khue Nguyen, Greg Kruger

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>> KHUE NGUYEN: Good morning, everyone. Welcome to today's webinar called Strategies for Managing Pesticide Spray Drift. This webinar is produced by the US EPA's Office of Pesticide Programs. The views expressed by our presenter are for educational purposes only and do not represent the official views of the EPA. During this presentation, your microphones will be muted. You can download this presentation from the handout section on your control panel at any time during the webinar.

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My name is Khue Nguyen. I am a Chemical Review Manager in the Office of Pesticide Programs. I am your moderator today. Here at the Office of Pesticide Programs, we regulate pesticides at the federal level. Because of the nature of our work, we want to educate stakeholders who work with pesticide application equipment on how to reduce spray drift in order to protect non-target organisms and protect natural habitat. In today's webinar, we will present some key strategies for reducing drift.

At this time, I would like to introduce our speaker. Dr. Greg Kruger is a weed science and pesticide application technology specialist from the University of Nebraska-Lincoln. He is the Director of the Pesticide Application Technology Lab at the university, and he has done a lot of research on spray drift. His research covers areas such as droplet size, efficacy, spray drift deposition, canopy penetration, and the influence of nozzle type and other parameters on droplet size. He is also the Weed Science Society of America's liaison to EPA, and he provides technical

expertise to EPA on matters related to pesticide policy. We are very excited to have him here. Please welcome Dr. Kruger.

>> GREG KRUGER: Thank you, Khue. This is an honor. It's great to see a collaboration like this work out so well. It's really nice to see so many people online. I know there are many of you that know me online and many of you that I know online. I just want to thank you for taking a little time out of your schedule today. For a lot of you, this is probably going to be a pretty basic review. For some of you, hopefully I'll be able to put things in a little bit different perspective, a little bit different light. For some of you, hopefully there is some new information. And for some of you, I'm sure a lot of this will be brand new. So we'll try to keep it so that everybody can gain something out of this. It's really exciting to have had this opportunity.

I want to thank Khue first off. She's really done a lot of work to help get this set up. Before I start, the other group that I would be remiss without recognizing is my lab group. I will tell you, in terms of university lab groups, I've got the best one in the country. I've got a lot of really good folks in my group, a lot of good students that have come through. Really, if it hadn't been for them, I wouldn't be able to give the information that I've got.

Those of you that do know me know I absolutely hate starting with definitions, but I thought for today's purposes that we ought to start with a definition just so that everybody's on the same page. So the definition of drift is the movement of spray particles and vapors off-target causing less effective control and possible injury to susceptible vegetation, wildlife, and people. You can see this definition was adapted from the National Coalition of Drift Minimization.

Really, the point that I want to drive home and I want you to focus on in terms of this talk is there are really two types of drift. The first one is vapor drift, which is associated with volatilization, so gases or fumes moving off-target after those droplets have deposited in the target area. The other is physical particle drift and that's what we're going to focus on today. Physical particle drift is the movement of those spray particles at or shortly after the time of application off-target before that droplet is deposited in the target area. So as we go throughout the next 40 or 45 minutes, kind of keep those definitions in the back of your mind.

Now, to start, I really want to start with what I call the big four in terms of particle drift. The first one is wind speed. To keep it simple, I kept it at wind speed, but it really is both wind speed and wind direction. The direction is absolutely critical in terms of drift and off-target movement of physical particles as well. So when we think about wind speed and the importance it has, this is some work from a meta-analysis conducted at Mississippi State University. When they put this together, what they did is they took all of the drift studies that they could get data from, put it into a large database, and then looked at the factors that were most important for off-target movement.

What they found is that when the wind speed doubles, there is a 700% increase in the drift at 90 feet downwind. So as we start thinking about making pesticide applications and making sure that we get on-target applications, that wind speed and wind direction become critical. If we think about a lot of the pesticides that we're seeing come forth, they have some sort of maximum wind speed recommendations. In some cases, minimum wind speed information, too. But certainly we're seeing that maximum wind speed on the label. That's because we know that wind speed is absolutely critical for mitigating off-target movement.

Now when we talk about wind speeds, I think it's really important to note that the wind speed measurements and what is going to affect the droplets are the wind speeds where those droplets are released. You can see in this figure, the depiction of how wind speed increases as we get farther and farther off the canopy or surface. Making sure that we accurately capture the wind speed at the boom height becomes critical for these applications. I really often encourage applicators to have some sort of measurement device in their sprayer or their tractor or whatever they're using to make applications and check that wind speed during the application process because we know that at that time of application, that wind speed can be quite different than what it would be at the local weather station that they might get information from through an online weather source.

The next one, this next slide or next couple slides are really geared around showing the importance of wind speed. This is some work that we conducted in our lab in the low-speed wind tunnels. What you see are some tomato plants that were growing up in the greenhouse. These particular tomato plants were sprayed with dicamba. The plants that you see were sprayed with an XR 110015 nozzle at 40 psi. That top picture shows you what kind of damage we get at a 5 mile an hour wind versus an 11 mile an hour wind. I

think it's really important that you take home that this isn't necessarily reflective of how much drift there might be in those but the relative comparison of the importance of wind speed in terms of off-target movement here. So, if you look, the plants to the left-hand side of the pictures were placed at six feet downwind, from there going to 9, 12, 24, and 36 feet downwind. The distance to that application becomes important. If you look at the two pictures, though, you'll see a dramatic difference between plants that were placed in a 5 mile an hour wind versus an 11 mile an hour wind; again, going back to that general rule that wind speed and wind direction are paramount to making sure that we get on-target applications.

This next picture is illustrating the importance of drift reduction technology. In this particular case, we kept everything the same except for we've now used an AIXR nozzle instead of an XR nozzle and we've moved from a fine spray to a coarse spray now. And you'll see that the relative differences of the plants in this picture versus the previous picture, we do have plants surviving at those near-field or short distances away from the nozzle which we didn't have with the XR nozzle. But, again, the take-home message when you're looking at this shouldn't be that if I use a low drift nozzle, I don't need to pay attention to wind speed, because you can see clear differences between the 5 mile an hour wind and the 11 mile an hour wind.

Now when we go to this next slide, this next slide is now an AI nozzle or an air induction nozzle, and we've got the exact same thing. Again, if you look particularly at those plants at 6, 9, and even 12 feet downwind, you can see a clear difference in the amount of injury that we see on those tomato plants. It's really again illustrating the importance that while we can use low drift nozzles and things like that, it's important that we have a good handle on the wind speed and wind direction, even with these very coarse to extremely coarse sprays.

Now this last slide is just to show you those relative differences between the different nozzle types. We've got our XR, AIXR, and AI nozzles. While I've really tried to emphasize how important wind speed is, also the spray droplet size, you can see, is a very important factor here.

Now next on my list is boom height. I generally don't spend a lot of time talking about boom height, but we would be remiss without talking about it, at least recognizing the relative importance of boom height. So if we go back to that same meta-analysis that was conducted by Mississippi State University, when

they did that meta-analysis, they found that at 90 feet downwind, the same downwind distance we were looking at with the wind speed, we see a 350% increase in drift when the boom height doubles. In my example here, I say from 18 to 36 inches, but that could be from 24 to 48 inches or whatever, we see that response. Obviously it's not 700%, so it's not as critical as the wind speed and wind direction, but still absolutely critical in terms of on-target movement. Making sure we get the boom height is absolutely important.

And before I transition into my third one, I do want to point out, too, that boom height, while we're talking about drift today, particle drift today, boom height becomes important for patterns and for efficacy as well. Too often we see applicators that are complacent and willing to spray at 6 or 8 or 10 feet off the ground with ground sprayers, or we might see aerial applications that go out at 16 or 18 feet, and that does have an impact on that off-target movement as well as the patterns and the relative efficacy of those products that are being applied.

Now number three on my list is distance to susceptible vegetation. I sum this up in one word. That word is going to be buffers. We will see that with new pesticide labels, buffers become more and more common because we do know that having a safe area for those particles to deposit before we get to sensitive areas is important. When we think about buffer zones, and we go back to that same meta-analysis, we see that that becomes an important factor as well. Looking at that meta-analysis, what we see is an 80% decrease at 200 feet downwind when that buffer zone or that distance doubles. Not probably as important as wind speed and wind direction, not as important as boom height, but still an absolutely critical piece.

The last one that I'm going to talk about today - and I know it seems like we're just getting started and it's hard to be on that last point already - but the last one on my list is spray particle size. I put this last on the list not because it's the least important or anything like that. It's the one I like spending the most time talking about. With wind speed and wind direction, we can monitor that but we can't control it. When we think about boom height, that we've got a lot of automated boom height sensors and things like that, our experienced applicators are very good at making sure they maintain boom height.

In situations where we have a hard time maintaining boom height, if we're spraying fields that have a lot of contour to them or things like that, we have the option of slowing down.

Boom height becomes pretty straightforward and self-explanatory. That buffer zone or that distance to susceptible vegetation, we can't really control whether we've got sensitive areas around us or not. We certainly need to monitor that. We've seen people get very complacent about not making sure they understand what's around them and that's a recipe for disaster. But in terms of who puts something around us or whether there's a sensitive area next to our field or our application site, we have very little control over that.

Spray particle size on that list of four is the one I've got the most control over, so I like to spend the most time talking about that one for that reason. Now when we talk about spray particle size, we're talking about microns most of the time, and so I thought it's good to just kind of give everybody a little bit of a refresher in terms of what different micron size droplets look like. So if we think about a pencil lead, the lead on a pencil is about 2,000 microns in size. If we think about the tip of a staple, it's about 420 microns in size. If we think about the diameter of a human hair, it's about 100 microns in size. And when we start thinking about many of our ag applications, we're talking about making applications between 150 or 200 up to 450 or 500 microns in size.

Certainly with some of the newer technologies, we're pushing that envelope and trying to get larger droplets to further minimize drift. And we might see some of our row crop herbicide applications go up to 850 or 900 microns. When we start talking about the air-blast sprayers and things like that, we're probably in that range of 200 microns or less. If I have anybody out there making aerial applications for vector control or things like that, we're probably even smaller than that in that 100 or maybe even 75 micron range. When we talk about spray droplet size, most of the time we're talking about something extremely small. The smaller we get, the more difficult it becomes to get those droplets to deposit in the target area. The smaller the droplet size is, the more cautious I'm going to need to be to make sure I don't have off-target movement.

So this next slide always brings a little chuckle from my students. They see me standing at the computer lab, and what you see in that top picture is a picture of our wind tunnels. I thought it would be good to just spend a moment talking about how we measure droplet size. My students chuckle because they know I have absolutely no idea how to run this equipment, but somehow I got elected to be photographed anyhow. But what you see is our low-speed wind tunnel. Down in the bottom right-hand corner, you

can see a picture of that spray nozzle inside the wind tunnel. We're using in this case laser diffraction to measure the droplet size, and what that allows us to do is look at a combination of different factors. We can look at nozzle type, application volume or spray solution, orifice size, and pressure to determine what the impact each of those different factors are on off-target movement, and it gives us a distribution curve kind of like what you see on that right-hand side.

When we talk about droplet size, there are really three things that I think are important to focus on. One is where you see that blue line. That's our Dv90 value or the 90th percentile, so to speak, of the droplet size of the spray volume. And the reason I get interested in that is because I want to make sure that we don't have these extremely large droplets that aren't going to be effective. I want to make sure that that value is in a range that those droplets sizes that are being produced are still going to work. They're not going to run off or be ineffective for some reason.

The second point or part of the curve I'm interested in is that left tail. On that left tail of that curve is where all of our small fines are. And, so, from a drift management standpoint, this is the part that becomes absolutely critical because we want to minimize the small fines without moving that droplet size to a point where the application is no longer effective. It really takes us to that third point on the curve which is where you see the red line or that Dv50 value. And the Dv50 value is important because I'm going to tailor my applications to be in a size that is going to optimize whatever pesticide I'm applying. Now before we get lots of questions related to that online, I want to point out that the optimum droplet size for a particular application is going to depend on the product that I'm applying, the target pest, as well as the environment I'm making those applications in. It is quite a complicated little scenario. Maybe Khue and I can get together at some point and develop another seminar with a lot more detail as it relates to that. We're not going to go down that path very far today.

I want to go through a little exercise in terms of droplet size management for a few minutes. And, so, what you see on this slide is a droplet size distribution curve. On the X axis, we have droplet sizes getting from small and getting larger as we go from left to right. I've taken those values off because I really want the focus to be around how we manage droplet size and minimize the driftable fines. In this particular example, we have an XR flat-fan, 110 degree nozzle, with a 0.25 gallon per minute

nozzle at 40 psi. Additionally, what we see here is a nozzle at 60 psi. That's a high pressure for applications with this particular nozzle. We're at the very top end range of - pressure range for this particular nozzle. And what we have here is when we look at this 26% of what we spray is fines less than 150 microns, so we're really looking at that area underneath the curve left of that vertical black bar.

When I talked about mitigating driftable fines, it's really how do I minimize that area under that left tail. The first thing we want to talk about for ground applications - I am going to emphasize at this point this is for ground applications - the first thing I can do is lower pressure. When I drop the pressure in this particular scenario, I go from 26% to 15% fines less than 150 microns. When we talk about off-target movement from a droplet size perspective, this is a monumental change, a 10% change. The fraction of driftable fines is tremendous. The first thing I do with a live audience with applicators is I ask them, what is the cost of this? A lot of times we think that this comes with no cost. But it does have a cost associated with it, because as I drop pressure, I have also got to drop my ground speed so that I make sure I maintain my flow rate. Unfortunately, time is money for a lot of our applicators and application systems. So, as I am slowing down, I'm covering less acres. As I cover less acres, that costs me in terms of time. That has a monetary value on my operation.

The next question becomes, what can I do to continue to mitigate drift but yet get my time back? That really leads us to the next slide. We move from a small orifice nozzle to a large orifice nozzle. So, in this case, we kept the 30 psi now and we've jumped from an 0.25 nozzle to now an 0.5 orifice nozzle or a half gallon per minute nozzle at 40 psi. Again, by doing that, we've now jumped from 15th percent fines to now close to 7.5 percent. In terms of making my application, this is, again, moving me in the direction I want to go. This one does have a monetary cost associated with it, though, because I've now got to buy a new set of nozzles. I oftentimes get into conversations about how expensive nozzles are. I'm of the belief that the nozzle is the last point where I have any control over that application. Once it comes out the nozzle, we're kind of left to environmental conditions and fate to what's going to happen with that droplet. The cost of that last management point is almost insignificant in that application process. At 7.5% fines, we're doing great, but there is certainly room for improvement.

The next thing that we looked at was the nozzle design, so here we changed from an XR now to a Turbo Tee nozzle. And you can see we've gone from 7.5% to just a little over 2.8%. Nozzle type or nozzle design is absolutely critical. [audio cuts out 00:25:46]. Can everybody still hear me? Okay. I apologize. I thought we had lost the feed for a second. When we think about the importance of the Turbo Tee nozzle, this nozzle was widely promoted and widely adopted in the late '90s and early 2000s for glyphosate applications when Roundup Ready came out, the reason being that we knew that Roundup, being a systemic herbicide, would work well with large droplets. The larger the droplet size, the less drift potential we have, and so we were able to manage drift while keeping that application in a droplet size range where we weren't giving up efficacy and maybe even gaining a little bit of efficacy in terms of having that larger droplet size. Like I said, this nozzle became a very critical nozzle in terms of our applications, not that there aren't other nozzles out there that would produce a similar droplet size range.

Today, we're fortunate we have air induction technology on top of some of these low drift nozzle designs. So what we did is we just, in this particular example, took that Turbo Tee nozzle, added an air induction port, we've now got a Turbo Tee induction nozzle and we're at 0.2% fines, so less than 150 microns. Absolutely great for drift control. We're probably as good as we can get in a lot of cases at 0.2% fines. Two things I really think we ought to point out here. We still have 0.2% fines, so we're not at a situation where we have zero. The other thing is that if you follow the peaks of those curves as we've gone through this stepwise example, you see the droplet size - the peak of those curves moving from left to right. When we get to that TTI11005 at 30 psi, for a lot of the pesticides that we apply, this droplet size is too large to get effective control out of that pesticide. You've got to be real careful and cautious that we're doing things to reduce driftable fines. We may be pushing that application in a direction we don't want to go.

That really leads me to this next point. When we talk about the relationship between drift and efficacy, a lot of times when we do things to increase efficacy, it means making smaller droplets or increasing drift reduction. As we do things to drop drift reduction, it potentially compromises the efficacy that we're going to get out of that pesticide application. I jokingly tell somebody that if they put 1,000 gallon droplet in the middle of a field, it's probably not going to drift off-target, but they're probably not going to be very happy with the pest control. Vice-versa, if we sprayed everything with an ultra-fine

spray, we're probably going to get really good coverage. A lot of our pesticides will work extremely effectively in that case. Not all but a lot of them. But the drift potential is it might be hard to get any of that pesticide down on the field.

Now for my folks out there in the ag-retail and adjuvant industry, I'm not leaving you out. I'm just slowly getting to it. We do know that what we put in the tank also plays a role in terms of droplet size. This is some work that we did in conjunction with Winfield. What we did is we looked at 21 different tank solutions and how those solutions impacted droplet size. Number 21 is water by itself. What we did is we picked a nozzle and a pressure that would give us a medium droplet size based on the nozzle we selected out of the catalog. We went and looked up the catalog that says medium droplet size.

What I've done is I've put two vertical red bars on this slide to represent the lower and upper balance of that medium spray quality. So, any of those horizontal blue bars that stop between the two vertical red bars, those would be medium sprays. If you look at treatments 11 and 12, though, you can see what we put in the tank there actually moved us from a medium spray to a fine spray. Treatments like one through six and a few others up through there are actually pushing that spray quality into a coarse spray quality. What we put in the tank does have the ability to move that droplet size over a pretty considerable range. Here you can see water by itself with a 207 micron droplet. Based on what we put in the tank, we could move anywhere from 160 micron VMD up to a 244 micron VMD.

Now this next slide really gets at the heart of making sure that we understand the relationship and the interactions that exist between nozzles and tank solutions. This is a little bit of work put together by my predecessor, Bob Klein. What you see here on the Y axis is we have droplet size and microns and percent fines. Across the X axis here, what we have are a set of different tank solutions for five different nozzles. I'm going to focus in on this first one to start with, and that's that XR11005. We've talked a little bit about the XRs. You can see a picture of it now. With that nozzle running straight water through, what you see in the yellow bar, you can see we get about a 280 micron VMD with 11% fines. This time less than 105 microns.

As we add Roundup to the tank or we go to that second bar, that orange bar, what we see is a decrease in droplet size and an increase in fines. It's just something very well-known in the industry that when we add Roundup to the tank, we're going to see

a smaller droplet size. If I'm concerned about drift, which in a lot of cases I am, I'm going to make sure that I do everything I can to minimize drift. If I'm using this particular nozzle, I can look at a drift retardant. In this case, we have a polymer, an invert emulsion, and a micro emulsion. When we add those three to the tank, you can see the VMD or that average droplet size for all three of those are around 300 microns. However, I do want to point out that not all products are created equal.

If we look at the percent fines of that polymer, we had about 12% fines, whereas with the invert and micro emulsion, we were around 3% to 4% fines. In this particular case, if I'm interested in managing drift, the invert or micro emulsion products are going to be better for that particular application. Before we get all set to go buy invert and micro emulsions, I do want to point out that if we look at the next nozzle type, that's a Turbo Tee, you can see with water, we've got now about a 430 or 440 micron droplet with 4% fines. If I go to that second orange bar on the table, you can see we've now got a decrease in droplet size when we add Roundup, just like we did with the XR.

Interestingly enough, the three different drift retardants behave very differently in the tank this time. So, you can see when we put the polymer in, the droplet size went up and the driftable fines went down to 3%. When I look at the average droplet size and the driftable fines for the invert and micro emulsion, we can see no reduction in the fines and a decrease in the average droplet size. Those two types of products are not going to help me with drift control if I'm using this particular nozzle type. It's really important that we check our applications when we're making them to make sure that we don't have something like this happen. Oftentimes people ask, how do I know if the nozzle I've got is compatible with the drift retardant I'm using? In this particular situation, we've got almost 100 micron change in the VMD. I can see that if I'm paying attention to my application. While it's easy to hop into a sprayer, push buttons, and away we go. In this particular case, if I'm looking at the spray pattern and looking at what's happening with that application, I can see that change.

Now the next question that often comes up is, how far will droplets go? And, so, this is a little bit of work that we've borrowed from the Herbicide Spray Drift Extension publication from North Dakota State University. What this table shows is the different droplet sizes ranging from 5 microns up to 1,000 microns. What they've done is they've determined how long it would take that droplet to fall 10 feet for each of those

different droplet sizes. So we look at that 1,000 micron droplet or basically what a fine rain droplet would be. It takes one second to drop 10 feet. For a medium spray droplet, 240 microns, so we're looking at six seconds. When we get to a 20 micron droplet, it takes 4.2 minutes to drop 10 feet. The smaller the droplet size we get, the longer it's going to take that droplet to fall. I've got some aerial applicators on the line and 10 feet is probably a good benchmark for you. For my ground applicators, 10 feet is a lot higher than what I hope any of you are ever at. As you get closer to the ground, those numbers will shrink. From 5 feet, it's going to take that 100 micron droplet 5 seconds to fall instead of 10 seconds.

The other thing I think that's really, really important to note from this is that they also projected how far those droplets would move off the target in a 3 mile an hour wind. When we look at that 1,000 micron droplet, though, we're looking at less than 5 feet. When we look at that 100 micron droplet moving off-target in a 3 mile an hour wind that would drop from 10 feet, we're looking at a 44-foot movement. When we look at that - you can see that the 20 micron droplet, we're now over 1,100 feet, just like the 10-foot - if we get close to the ground, that number is going to go down. With wind speed, as that number goes up, we're going to see those numbers go up. These are really just to give you a relative approximation for what might happen from a theoretical standpoint.

Now when we talk about droplet size, I also always like to point out that when we talk about droplet size, we're talking about the diameter or volume of a sphere. So when we cut that diameter in half - in this particular example, we go from a 500 micron droplet to a 250 micron droplet - we don't end up with twice as many droplets, we don't end up with four times as many droplets. We end up with eight times as many droplets. There is this complex relationship that exists. The smaller we get, we're exponentially increasing the number of droplets.

This picture is a picture from some work that we conducted in the North Platte area last year. This particular site, what we had is a stationary boom set up to look at how much off-target movement we got from dicamba tolerant soybeans. I don't really want to go into specific pesticides today, but this study really gave us a good sense for how important both boom height and nozzle selection are in our application process. So what we did, you can see we've got the area of dead soybeans, that's where that sprayer was mounted, and then you can see the wind was coming from the bottom left corner of this picture and going up

those soybean rows, so you can see the drift going out away from that. You can see that area and the drift going out away from that application.

This next slide is just an overhead, a drone image of that field site. What we see are the different treatments that we looked at. I just want to spend a little time walking through this. The first one is - on the left-hand side right here is Xtendimax. This is Monsanto's new dicamba product. And what we have here is a TT11004 nozzle at 24 inches. You can see we've done a very good job of managing the drift. That drift plume is very short, a very short drift plume. If we go over to the middle here, you can see Engenia with a TT11004, 24 inches, a very similar drift plume. Both of those two applications would be on-label, very similar droplet size, very similar dispersion patterns. As we start thinking about the importance, we said how much influence does boom height have? If we go to the far right-hand side now and look at this last box on the right-hand side, you see a TT11004 now at 48 inches, off-label in terms of boom height, but we still have an on-label application from a nozzle standpoint. You can see, comparing back to that first box or that first treatment, there is a huge difference in the amount of drift just from doubling that boom height. That's where that 350% value that we talked about earlier would come into play.

We look at some of these others. You'll see a combination of different nozzles that are off-label or boom heights that are off-label. The one I want to point out in particular, we get to this second box over here, this is the Xtendimax with an XR11004 at 48-inch boom height. We're now off-label both in terms of nozzle and boom height. You can really see if you look at this picture how that application moved out away from the stationary boom.

This next slide, you can see in the background a depiction of the second rep. This is some work that was conducted across the multiple states and multiple different faculty, some work sponsored by Monsanto to really understand how far these droplets would move. What we see here is a reflection of the distance off-target. We had various different injury amounts. Again, if we look at that first box in red, that's off-label in terms of boom height as well as nozzle selection. I've got a red box around the on-label application. You can see a significant difference in terms of the distance off-target that these droplets are moving.

Real briefly, we want to talk about the labels. Knowing the label is important. The label is the law. I've picked a few

different labels to talk about. I by no means intend to endorse them, just like the previous slide, but really it's a reflection of how can you look at those labels and pull information related to the application to maximize those applications. So, this first one that I've selected is Laudis. In that label, if I take a little bit of time to study it, I find that the Laudis label recommends the use of medium spray droplets. It says a flat-fan nozzle is recommended, 30 to 60 psi. Do not use fine or extra coarse spray droplets, 10 gallon per acre minimum. Air induction nozzles should be used at or near 80 psi.

Instantaneously, I look at this and I can start to gather information about how this product works. When it says use a medium spray droplet, do not use a fine, the reason they don't want me to use a fine application or a fine spray droplet is just because of off-target movement. But you can see it also says do not use an extra coarse spray droplet. The reason being here is that we know that as we get extra coarse spray droplets or coarser, coverage becomes a limiting factor in terms of that application. Making sure that we get that medium spray droplet becomes important for this product. The 10 gallon per acre minimum is set in there for a very similar reason. We know that the lower the volume we have, the less coverage we're going to get. Some really good information in terms of how to optimize the product.

The next one I brought up is Sharpen. If I look in the Sharpen label, there is some really good information in terms of managing droplet size from very good practices. I think that you'll see that they fall in line with the things that we've talked about this morning in regard to droplet size, spray volume, and pressures. If I dig a little bit farther into that label, I'm going to find information that looks like this. It says use medium to coarse spray droplets. Again, we want to make sure that we've got coverage with these. This also says apply or make applications in wind speeds of 10 mile an hour or less. Also, this has got a 50-foot setback zone from the downwind edge of susceptible species. You can see that they're really hitting, in just those three statements, three of the four major factors in terms of managing off-target movement.

Okay. The next one on my list, this is an Aim label. I know that we've just gone through registration, so I probably need to update my site a little bit. But this is the older label. And the reason I pull it up is because this really shows the specificity of some pesticide labels in terms of droplet size. Here you can see a statement pulled directly off that Aim label in regards to

what VMD is and how it's expressed. What I want to highlight is that last statement on the slide regarding the optimum Aim EW spray cloud. It should be 450 microns or fewer than 10% of the droplets being 200 microns or less. They've given extremely specific information in terms of what droplet sizes to use for this product and how to minimize the fines or the drift potential. If I've got any FMC folks on the line, I apologize. This would be extremely hard to follow in a lot of ways, though, because a lot of this information is not readily available to my applicators. But it does show the importance of mitigating the driftable fines.

Okay. Real briefly as we're rolling into the end of this, this is a slide I borrowed from a colleague of mine, Dr. Joe Luck. He tells me that the equipment is not getting any smaller. What we're seeing is bigger and bigger equipment. As we get bigger equipment, it gets harder and harder to make applications in the optimum way. Ground speed and things like that become a very important factor in those applications. Now if we think back, this is a slide I love to use talking about applications because it really shows that the applications have not changed a lot over time. This was taken in 1945 off the research center in North Platte where I'm at. What we see here is a sprayer. We see the nozzles. We see the hoses and the lines. We see the boom structure. We've got a tank. In this case, I've been told that this is a two horse self-propelled sprayer.

Today's equipment, no different, other than today we've got much more sophisticated equipment. The rate controllers and electronics that we have at our disposal really give us a lot of instantaneous feedback on that application. For example, this is a picture from a self-propelled sprayer that we have on the research farm. What you see in this picture, you can see the dark blue on the screen where we've had some overlaps and things like that. You can see the gray area where we haven't sprayed in the field. So we've got lots of information. The one thing that you don't see in this picture is the spray boom and the nozzles in operation. For my guys running this type of equipment, whether you be in the air or on the ground, it's really important to look at what you're doing and continue to study the application in addition to relying just on the electronic systems.

This is another slide I commonly use. This really illustrates how the pesticide application process can work. Here you can see two pictures of systems that are set up to move some sort of a product from one point to another. They look very different. Their efficiency may be different. In much the same way, that

pesticide application process can be done a lot of different ways to reach that same endpoint.

So this slide is really just to show us how complicated that pesticide application process is. We've got our spray tank where we're going to put our pesticide in. We're looking for biological control or the effect from the biological side. You can see a series of steps in there that are going to influence that biological effect. As we continue to progress through this, you can see all of the different things that are going to influence each of those different steps from atmospheric conditions to chemical reactions to the leaf surface droplet interface. And we also have a whole series of things coming out of the application process. This is a diagram that we've borrowed from Ebert et al. I apologize. The citation is cut off at the bottom of the slide here for some reason. You can see how complicated and how many different things there are going in and out of that application process, influencing how effective that biological control is going to be.

This is a slide - shout-out to my nozzle guys out there - showing how to select different nozzles. This is a TeeJet table but we have the same thing for Greenleaf, HyPro, and Wilger, as well as the other nozzle manufacturers out there. Really what I'm looking for is, how do I optimize that pesticide application? So I'm looking in this particular table for that good+ or in other tables that excellent rating for applications. What is going to be the best nozzle for my application? That's going to vary by the product I'm applying and things like that.

Okay. So we've talked a lot about drift. I want to spend just a few minutes before we wrap up and open up the questions talking a little bit about efficacy. We've talked about how droplet size is important from a drift management standpoint. This is some work done by a student of mine, Tommy Butts. And what he did is he looked at the different droplet sizes with the exact same tank mix, in this case applying glufosinate at five gallon per acre. The pictures you see in this slide were taken at 14 days after application. And what we see is really how important droplet size is for that application. Here I need to be around a 300 micron droplet to optimize control. As we get smaller or larger from there, you can see the control really starts to drop off for this product. Now I do recognize for a product like this, this is a five gallon per acre, this is below label recommendations and below what we would ever want to see in the field, but it does illustrate the importance of droplet size.

When we look at this next slide, the next slide is the same setup except for now we've got dicamba. And when we look at this, you can see that control is a little bit lower at that 150 micron versus the 300. But from about 300 microns up to that 750 microns, the control is fairly similar. Now do keep in mind that this is only 14 days after application. These products haven't taken full effect. But if we look at that 900 micron droplet at five gallon per acre, the control has completely dropped off. This application is no longer effective on Palmer amaranth. This is part of the reason - if you think about particularly the new dicamba products where we're pushing towards that 850 to 900 micron droplet size range, that's why we don't see five gallon per acre applications with this product. As we get 10 and 15 and 20 gallon per acre, you're going to see that we can actually get those larger droplets to work a little bit better. But even with a product like dicamba, we can get the droplet size too large and that's what we're really trying to illustrate here.

So, with that, we are almost to the end of our hour. I've got some just general take-home messages for any of my practitioners out there. I don't want to read these. I do want to point out that as long as we're making applications, drift is going to happen. We need to take every step we can to mitigate drift, and there are a lot of different ways we can do that. In an hour's time, we don't have nearly enough time to discuss all those. Maximizing the control of those products and mitigating drift is absolutely essential no matter what pesticide we're talking about.

Okay. I think we'll go ahead and open it up to questions. I think there are a few questions coming in.

>> KHUE NGUYEN: Okay. So now is the time to submit your questions using the question pod on the bottom right. We'll begin our Q&A session in just a moment.

>> KHUE NGUYEN: Okay. So if you have friends or colleagues who would be interested in viewing this webinar, the recording will be posted on our website a few weeks after the presentation at the link shown on the screen.

To help us improve future webinars, we ask that you complete a brief online evaluation. A link will be emailed to you one hour after the conclusion of the webinar. Upon submission of the evaluation, you will be launched directly into the completion

certificate link. A lot of people are asking us if their state will accept this webinar certificate for continuing education credit. The requirements for certified applicators vary from state to state, so you will have to ask your state contacts.

In a few weeks, a document with the questions received today and the answers for each question will be provided on our website along with links to additional resources. If we didn't get to your question today, we will respond as part of the Q&A document to be posted on our website. So now we will go through your questions.

So the first question is 5 miles per hour and 11 miles per hour at what height? I think this is referring to an earlier slide when you were talking about dicamba drift damage to tomatoes.

>> GREG KRUGER: Yeah. Thank you for the question. I went through that rather quickly trying to get through everything in an hour's time. That nozzle height would have been approximately 24 inches above the target or above the top of those tomato plants.

>> KHUE NGUYEN: The next question: No untreated control or velocity contribution from the sprayer, i.e. no wind but sprayer at 5 miles per hour versus 10 miles per hour.

>> GREG KRUGER: I don't understand-- maybe the question that was asked related to the untreated control or velocity contribution. When we did that, we did it in the wind tunnel, so we did have a laminar flow. That wind flow would have been consistent. At some point maybe that person can reach out to me and we can talk about it more.

>> KHUE NGUYEN: The next question is: Is doubling of boom height plus the increase in wind speed a cumulative effect on drift distance?

>> GREG KRUGER: So, yeah. If you think back to the slide that I showed from the field application - and that's a great question - we do see a cumulative effect. Both boom height and wind speed are major factors for off-target movement. As we increase boom height and increase wind speed, we're going to see an aggregate effect there.

>> KHUE NGUYEN: The next question is a clarification question. Did Greg say that aerial applicators use the smallest droplet size? It seems counterintuitive.

>> GREG KRUGER: No. I think maybe something was missed there. In terms of aerial applications, just like ground applications, we want to use as large a droplet size as possible to mitigate drift. In terms of the differences between ground and aerial applications, pressure becomes a very different factor. So for ground applications, we really push applicators to use lower pressures to get larger particle sizes. For aerial applications, we're going to push our aerial applicators to use higher pressures to get larger particle sizes.

>> KHUE NGUYEN: The next question is: Will water and/or air temperature affect droplet size and potential for drift before it reaches the target?

>> GREG KRUGER: That's an interesting question. The answer is no. When we're measuring droplet size, we're measuring that a lot of times for ground applications at 12 inches off the nozzle. When we're measuring droplet size for aerial applications, we're 18 to 36 inches off the nozzle. Those droplets are moving at the velocities of 30 miles an hour or greater, and so we're not seeing an evaporation effect or anything like that in a fraction of a second. In terms of droplet size measurements, no.

>> KHUE NGUYEN: The next question: You have talked about various nozzles that help reduce drift. What is the approximate cost of a set of nozzles? Also, do applicators typically have multiple sets of nozzles? And how frequently do they change them out to spray a specific pesticide? Also, how long does it typically take to switch them out?

>> GREG KRUGER: I love that question. There is a lot to it. Nozzles are very important to our applications we discussed. The cost of a nozzle can vary depending on what nozzle type we have and how many nozzles we have on a sprayer. If I've got a 6 or 10 nozzle sprayer, the cost is going to be pretty low in terms of changing those out. If I've got a 160-foot boom sprayer, I'm going to have a lot more nozzles on there, so the cost is going to go up significantly. It's really hard to answer that question. Roughly for a lot of our self-propelled sprayers, I think most people are going to budget somewhere between \$400 and \$1,500. We can find them cheaper than that. We can find them more expensive than that. Answering that question specifically is really difficult.

The part do applicators typically have multiple sets of nozzles? I sure hope so. I think maybe there are some of them out there that rely on one nozzle for every application. It makes me cringe just a little bit. There are a lot of tools out there to help applicators change nozzles, to effectively change nozzles in a rapid manner. For example, for our self-propelled or pull behind ground sprayers today, we have a turret on there that we can load up as many as five different nozzles at a time. We can just go down the line and rotate those on that turret to get whatever nozzle type we want. That can be done in a matter of a few minutes, changing out nozzles if we have a system like that. If we've got a nozzle body that's only got the capacity to hold one nozzle at a time, it can take a little bit longer. In terms of the value gained versus the cost of the time changing those nozzles, even if I have to manually go down the boom and change the nozzles, it's absolutely critical that I do that to optimize my applications.

>> KHUE NGUYEN: The next question: Does coarse or fine define only the size of the droplet or does it also reference a characteristic of surface tension?

>> GREG KRUGER: Another good question. It does not reference surface tension at all. It's really related to the size of the droplet.

>> KHUE NGUYEN: The next question: Clearly the addition of surfactant decreases surface tension forming smaller droplets, so is there a correlation to surfactant type?

>> GREG KRUGER: I love the question. Some really good questions. Surface tension is going to influence droplet size. There are a lot of other factors that influence droplet size as well. If we look at some of the stuff that the Spray Drift Task Force has done, for example, there is not 100% correlation there to surface tension and droplet size. It's much more complicated than bearing down on one single liquid physical property to estimate droplet size or even the potential effect of change in droplet size.

>> KHUE NGUYEN: Next question: Will an air-blast fan reduce droplet size?

>> GREG KRUGER: Yeah. So, good question. For our air-blast sprayer operators out there, the fan speed or the speed of that air coming out of the nozzle or out around that nozzle will

influence droplet size. We get what we call a shear effect when we start getting wind speeds of 45 to 55 mile an hour. Most of our air-blast sprayers are operating well above that. The speed at which that air is coming out of that air-blast sprayer will influence droplet size.

>> KHUE NGUYEN: Next question: Greg, do you have any comments relative to Redball broadcast spray hoods and their use for drift reduction?

>> GREG KRUGER: Yeah. Yeah. Good question. There are a lot of things out there besides nozzles that can be used to reduce drift. Redball hoods specifically are a type of spray hood. Spray hoods are going to help in drift reduction. We see a lot of compelling evidence particularly in that near-field drift zone that a spray hood is going to help reduce drift.

>> KHUE NGUYEN: Next question: Is there a standard size for fine droplet size?

>> GREG KRUGER: Yeah. The question I believe is really relating to the fact that I continue to jump from 150 microns to 105 microns to 141 microns in terms of referring to driftable fines. There are standards. The ASABE S572 standard tells us how to classify sprays in terms of a fine, medium, coarse, very coarse, extremely coarse, and ultra-coarse spray. That standard is really telling us information about the size classification and not necessarily the drift potential. I should have pointed out during the seminar that the droplet size for drift potential can vary depending on the environmental conditions in which those droplets are released. For example, if I've got a 30 mile an hour wind, the size of droplets that are going to move off-target will be quite different than what will move off-target if I've got a 5 mile an hour wind. I tend to jump around from different droplet sizes for percent fines because I think too often we get fixed on one specific number and we lose sight of how drift really occurs and which droplet sizes can really drift off-target.

>> KHUE NGUYEN: Next question: Regarding droplet size, should we recommend a given droplet size only if we have data to prove the efficacy?

>> GREG KRUGER: That is a great question. I wish we had data for every single tank mix out there, every potential tank mix and every single application condition. I would contend that there is probably a lot of information about optimized products from an efficacy standpoint. I don't know that we're ever going to have

data for every single possible scenario. I think that we can oftentimes find trends in the data and finding those trends is what becomes important. One of the biggest things I'm an advocate of is post-emergence or post-application scouting. I think it's really critical for applicators and practitioners when they make spray applications to go back out and see how effective that application was. If it's not effective, then look at why wasn't it effective and maybe changing nozzle types or changing droplet size or something else along that line will help make that application more effective.

>> KHUE NGUYEN: Okay. Next question: What's the share of air injection nozzles built on sprayers in the U.S.?

>> GREG KRUGER: I'm not sure I understand the question in terms of what the share of air induction nozzles built in the U.S. are on sprayers. But we certainly know that a lot of sprayers now have air induction nozzles. If we're talking about market penetration, I don't have those exact numbers. But they've become extremely common in the last ten years.

>> KHUE NGUYEN: Next question: You talked about smaller versus larger droplet sizes. Will larger droplet sizes take more time to absorb than smaller ones? If so, will it affect vapor drift?

>> GREG KRUGER: Yeah. So that question really doesn't pertain to what the topic was today, so I would probably have to defer to my colleagues that have done a lot more work on vapor drift than I have.

>> KHUE NGUYEN: Okay. Next question: Much of this is geared toward ground applications in row crops. How much translates to air-blast, right-of-way, or aerial applications?

>> GREG KRUGER: Yeah. Good question. We've talked a little bit about air-blast sprayers and aerial applications. Good practices are good practices. Whether I'm using an air-blast sprayer, a ground application sprayer, or an aircraft, as the wind speed goes up, the drift potential is going to go up. As I increase that release height or things like that, the drift potential is going to go up. A lot of what we talked about, while I focused on ground applications and row crops, these general principles and practices are going to transcend the crop or the sprayer type. I think good general practices are going to apply on a lot of different application situations.

>> KHUE NGUYEN: Next question: How do environmental conditions influence off-target movement?

>> GREG KRUGER: Another really good question. Environmental conditions will absolutely have an effect on off-target movement. Again, I'm going to go back to wind speed and wind direction being the major driving factor there. We know that the application process is complicated and it's really important to be cautious of all environmental conditions in which we're spraying. If we think back to that slide that we had from Ebert et al, you certainly see that environmental conditions were one of those factors listed there. That one is absolutely critical.

>> KHUE NGUYEN: Next question: Are there any special considerations you care to mention for hand-held equipment; for example, backpack sprayers?

>> GREG KRUGER: Good question. From a drift management standpoint, again, just like the aerial applications or the air-blast sprayer applications, good general practices apply. One thing I don't want to do if I'm concerned about off-target movement or physical particle drift with a backpack sprayer is keep that sprayer running as I'm lifting that boom up into the air. Again, from a physics standpoint, the same general practices and principles are going to apply.

>> KHUE NGUYEN: Okay. Next question: Has giving nozzles to growers raised awareness about proper nozzle selection?

>> GREG KRUGER: Another good question. One that I don't have any data on. I certainly hope so. I hope that we continue to get the right nozzles for the right applications into practitioners' hands in any way possible, but we don't have any data on how effective that is.

>> KHUE NGUYEN: Next question: Have you been able to test different drift control spray drift adjuvants for change in particle size, consistency in size, particle drift, et cetera, between these products and the different makers? And this is particularly for roadside application use.

>> GREG KRUGER: Another good question. I'm glad we've got - I think we're starting to get close to covering all the different application types out there. For roadside use, we haven't done a lot of work there. We have looked at a few flood and high-volume type nozzles. The larger the droplet size gets, generally the less impact we see on droplet size from tank solution effects. I

think that general principles and practices are going to apply. I went through it a little too fast. But on the one slide, we did have a flood nozzle, showing kind of one of those types of right-of-way area nozzles on the slide. As a general rule, we've seen the same trends. But, again, a lot of times with roadside or right-of-way applications, we're dealing with the far end of ultra-coarse sprays, and adjuvants are going to have less impact because of that.

>> KHUE NGUYEN: Next question: Have you done any trials on tree fruit using an air-blast sprayer?

>> GREG KRUGER: Yes. Yes. We have done some air-blast sprayer trials.

>> KHUE NGUYEN: Next question: At what temperature and droplet size do you expect to have evaporation?

>> GREG KRUGER: Good question. We've got a lot of sharp individuals asking difficult questions today. I'm very appreciative of that. The evaporation and things like that are going to be dependent on the tank solution. There is no easy way to answer this question. It's going to be dependent on the physiochemical properties of that spray that's coming out of the nozzle. Also very dependent on the environmental conditions. It's a very difficult, challenging question, for which there is no straightforward answer.

>> KHUE NGUYEN: Next question: Does humidity affect drift if done by aerial application?

>> GREG KRUGER: Yeah. The concepts for humidity affecting applications for aerial are going to be the same as ground applications.

>> KHUE NGUYEN: Next question: For aerial application, what is the ideal wind speed to avoid drift? This is for herbicides versus insecticides.

>> GREG KRUGER: This is, again, the same principles and practices apply as ground applications. The higher the wind speed, the more off-target movement we're going to get, whether we're applying an herbicide or an insecticide or a fungicide. General core principles of physics are going to apply in all situations.

>> KHUE NGUYEN: Next question: What is the most important factor for particle size management?

>> GREG KRUGER: Yeah. That's a nice softball question. I needed one of those to answer. The nozzle selection is the overwhelming driving factor in terms of droplet size that we're going to get from an application. I don't want to discount what pressure or tank solutions are going to do in terms of droplet size. But, again, nozzles, nozzles, nozzles.

>> KHUE NGUYEN: Okay. So we're starting to wrap up our Q&A session here. We have time for just a couple more questions. Next question: Pesticide labels often reference the ASABE S572.1 standard for droplet size. What does ASABE stand for and what does this mean?

>> GREG KRUGER: Yeah. This is great. ASABE is the Association for Agricultural and Biological Engineers. S572 is the standard which references spray quality. That standard has really helped to facilitate facilities comparing data from one location to another. That standard is what set the spray classifications as we know them, the fine, medium, coarse, very coarse, extremely coarse, and ultra-coarse.

>> KHUE NGUYEN: Okay. Last question of the day: Is zero off-target movement a feasible goal?

>> GREG KRUGER: Yes. Great question to finish on. I'm really appreciative of having this question. As we talked about earlier, zero off-target movement with today's tools and technologies is not a feasible goal. On my last slide I had a statement that said drift will happen. Mitigating the amount of drift that we see is absolutely critical. It really takes us again back to those core fundamental processes that drive off-target movement. I think it's a great way to capture things. So, again, drift will happen. Mitigating drift is absolutely essential.

>> KHUE NGUYEN: Okay. So I think that will be the last question for today. We're going to wrap up the webinar now. Thank you for joining us. We really appreciate it. Make sure you fill out the webinar evaluation. Let us know if it's helpful. Let us know what other topics you want to learn about in the future. We will investigate the possibility of organizing more webinars of this type. Thank you for joining us. Have a nice day.