Spray Droplet Analysis of Air Induction Nozzles Using WRK DropletScan™ Technology

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Abstract

With the growing concern of drift in the crop protection/application industry, researchers are trying to understand how to better utilize the development of new nozzle technology for increasing the efficacy of crop protection products while minimizing the drift that may be created during the application process. Several new nozzle designs are being using in the application of crop protection products, specifically herbicides. The most recent development is the air-induction/venturi nozzle. The adoption of this nozzle type is widespread and without adequate knowledge of performance or good operating parameters. This study of air-induction/venturi nozzles involves some initial research utilizing the WRK DropletScan™ software system as a means to evaluate nozzle spray quality. It is hopeful that systems of this type may be useful in helping the industry sort out some very important questions regarding use parameters for the different nozzles.

This study analyzes four air-induction/venturi nozzles in comparison to three new technology but older style nozzle types for droplet characteristics using the WRK software. The standard nozzle types used in this study were the XR flat-fan, the turbo flat-fan, and the turbo flood flat-fan. The later two nozzle types use a preorifice arrangement and turbulation chamber to better manage spray droplet size. The four air-induction/venturi nozzles were: the TurboDrop XL from Greenleaf, the AI from Spraying Systems, the Ultra-Lo-Drift from Precision/Lurmark, and the Raindrop Ultra from Delavan.

The study was designed to apply product at 76 L/A (20 GPA) while operating at 138, 276, and 551 kPa (20, 40, and 80 psi). The application was made with a John Deere 6500 Hi-clearance sprayer equipped with a 3.5 m (10-foot) boom set up with four nozzles at 76 cm (30-inches) spacing and located 51 cm (20 inches) above the target. The speed traveled was adjusted at each pressure to maintain the same application rate. All nozzles selected were the same orifice size, i.e. 1.5 L/A (0.4 GPM) at 276 kPa (40 psi).

The major findings of this study were that differences did occur with the droplet spectrum between the older technology and the air-induction/venturi nozzles at all the studied pressures. The air-induction/venturi nozzles were able to reduce the amount of material in the smaller droplet size categories. However, except for the lower pressure range, the air-induction/venturi style nozzles exhibited little differences in the droplet spectrum characteristics. Based on the findings in this study it is hard to recommend any of the air-induction/venturi

nozzles over the others. Supporting field efficacy and swath adjustment data is necessary for that purpose.

The WRK DropletScan™ software system does appear to be a useful tool in making quick field operation based evaluations for the droplet spectrum used. With more data analysis of this type a greater level of confidence is expected. A weakness in the system at this point is with heavy application rates. At heavy rates there is not enough separation between droplets to make an accurate spectrum analysis. However, at lower rates of application and for use with swath displacement it would appear to be a very valuable tool.

Introduction

With the advent of herbicide tolerant crops the issue of spray drift is taking on new meaning for growers and commercial applicators. As we all know, when applying crop protectant products there is always a chance some will escape from the target area resulting in inefficient application and otherwise costly problems that are detrimental to the application industry. Besides improved record keeping, the reduction of spray drift will force the industry to take more care in the application of certain herbicides.

Droplet size and spectrum has been identified as the one variable that most affects drift (SDTF, 1997). Over the last several years there has been an increased interest by nozzle manufactures to engineer nozzles that will effectively reduce the volume of driftable fines found in spray droplet spectrums. This is being successfully accomplished with the use of a preorifice and also with turbulation chambers (Wolf, 1997).

A new trend with spray nozzle design is with the use of ‘air-assist’ or ‘air-induction/venturi’ to lessen the drift potential. Several nozzle manufacturers are including this new design as a part of a marketing campaign for drift control. Early research would indicate that the air-induction/venturi nozzle is producing larger spray droplets (Womac, 1997, Ozkan, 1998). Some would contend that the increased droplet size may reduce the effect of the crop protectant product used. A major focus for field research with the air-induction/venturi nozzle design is to determine if in fact, while reducing drift, a desired level of efficacy can be obtained.

A basic understanding of droplet size effects on crop protectants is important when selecting techniques for foliar application. Hall and Reichard (1985) indicated deposition efficiency of droplets on target is affected by several variables including droplet size, droplet velocity, and target surface. The relationship between droplet size and the resulting coverage on the target is complex resulting in several common misconceptions regarding droplet size and foliar application. For example, it is generally believed that applying small droplets at high spray pressures will provide increased control with low volumes of spray solution. Research data, as well as a study of particle dynamics, does not substantiate this theory (Bode and Butler, 1983). Bode and Butler also indicated that atomizing a known amount of spray solution into smaller droplets will increase the coverage possible, but you must also consider evaporation, drift potential, canopy penetration, and deposition characteristics.

One of the issues surrounding the development of new technologies, specifically nozzles, to reduce drift is the associated need to achieve the desired control level with a crop protectant product while minimizing spray drift. Deciding the desired droplet spectrum each individual application is the challenge before the application industry today. An optimum droplet size should result in maximum control while creating a minimum of contamination to the environment (Himel, 1969). Specific knowledge about crop protection product performance for each target with different nozzles will be necessary information for the future application decisions. Many of the tips assessments reported by manufacturers are based on test sprays of water and only report volume median diameter (VMD) for a given nozzle parameter. Also reported is an indication of a volume or percentage of spray droplets in a spray class smaller than a critical micron size, i.e. 100, 141, or 200 microns (Womac, 1997). As is indicted in the work by Womac, 1997) the droplet spectrum varies with every combination of tip style, size, operating pressure, and spray liquid. The detailed droplet information will be important to equipment manufactures, chemical company representatives, university research and extension personnel, crop consultants, and private and commercial applicators.

DropletScan™ System

DropletScan™ is a software program that will allow accurate and rapid measure of spray droplet impressions on water-sensitive paper. This program may also be used with any other material that provides a good color contrast (i.e. white surfaces and dark dyes). The process can be used to determine several useful spray drop statistics. For example, the percent coverage, the spray deposition rate (GPA), drift profile, single swath pattern width, and multiple pass uniformity are all easily determined. Droplet statistics such as VMD ($V_{(0.5)}$, Volume Median Diameter), $V_{(0.1)}$, and $V_{(0.9)}$ are automatically calculated for each drop card scanned. A printout with a histogram of the drop sizes (by droplet number and percent of spray volume in each category) along with a graphic record (in color when a color printer is used) of the spot cards are provided by the software (see appendix A & B).

The system was designed after a software program developed by Devore Systems, Inc., Kansas State University, and is modeled after a software program, Crumb Scan, which can evaluate the flour effects of bread. Crumb Scan is used in a similar fashion to determine the hole sizes in slices of bread (Whitney, 1997).

Elaborate testing has been conducted to determine the accuracy of the DropletScanTM system. Comparisons against known sizes have been verified through controlled droplet applications by using a microscope for analysis. Droplets were also tested against a camera and digitizing system at the KSU Wind Erosion laboratory using standard USDA software for digitizing. The drop diameters from all three methods (microscope, digitizing, and droplet scan) compared favorably with and R^2 of 0.85 or better. Algorithms have been written to help analyze droplets of various sizes and shapes including the ability to accommodate drops that hit the card and smear into teardrops to touch each other (Whitney, 1997).

The resolution of the scanner is such that stains as small as 50 microns or smaller in diameter can be measured. Drops that size are too small to be seen without the use of magnification. Since the smaller droplet portion of the spray spectrum is important to consider for drift management, then this software system can provide valuable information relative to drift potential. The droplet size data measured and recorded using the DropletScanTM system accurately represents the drop sizes that actually impact a target rather than the droplet sizes that are being released from the nozzle (Whitney, 1997)

Franz, 1993, found that using water-sensitive cards and a handheld scanner to monitor spray distribution in field situations was very operator sensitive, especially in field situations where variations in humidity levels existed. On card and card to card contrast was not easily maintained. However, he summarizes that water-sensitive cards subjected to varying humidity conditions can be analyzed for relative comparisons using a scanner and software.

The stains measured using DropletScan™ are very sensitive to spread factor. The droplet spread factor is very hard to determine for each material and collection material. This problem is more pronounced with larger droplets and should not pose a large error with driftable fine measurements.

System Requirements and Processes

Basic System Requirements

The DropletScanTM system requires and IBM compatible PC based on a 486 or higher microprocessor with a math coprocessor, running in windows 95, 98, or NT, and a high resolution HP ScanJet flatbed scanner. The latest version of the software has been written to operate with a HP ScanJet 6200Cse. The equipment used in this study was a Gateway 9100XL notebook computer (366 MHz), HP ScanJet 6200Cse flatbed scanner with USB port, and either an HP DeskJet 890C color printer or an HP LaserJet 2100 black and white printer.

Basic System Processes

The main process involves the acquiring of images from the water-sensitive paper, or other collector with dyes or a means of developing a color contrast, that has been placed on the scan bed. A two-step acquisition occurs. The first scan pass is low-resolution and is used to locate the spot card position and provide a preview image to the computer screen. The number of spot cards shown must equal the number of cards on the scanner bed. The spacing and ordering of the cards is critical. If the cards are too close together the scanner may interpret two cards as one. The second pass follows the display of the preview scan and is taken from a predetermined area within each spot card. (see figure1). The region to be scanned should not be on the spot card edge and should avoid any unusual drops. The software allows for adjustments to the scanned area. The information taken is from the area inside the marked boxes.

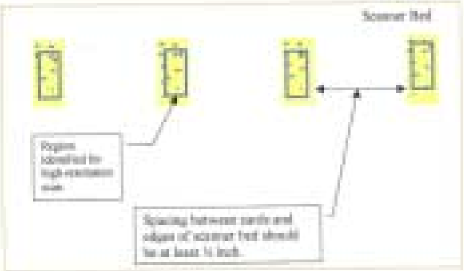


Figure 1

The operator can enter data and comments regarding the collection including weather and other critical spray pass information to be recorded on the final printouts. Visual examples are found in appendix A and B. Several different report options are available. Typical reports will include coverage (percent area), deposition (Volume/area), histograms, images of cards, calculated best swath, minimum swath, and vertical and horizontal drift or swath displacement.

OBJECTIVES

This study was conduced with the following two objectives in mind:

1. Gather spray droplet size information comparing conventional and new air-induction/venturi nozzles at different operating pressures using a field sprayer.

2. Determine if the DropletScan™ software will provide quick and useful information about various nozzle types.

MATERIALS and METHODS

This study was designed to evaluate various new nozzle technologies compared to what is considered to be standard foliar application nozzle types. The standard nozzle types used in this study were the XR flat-fan, the turbo flat-fan, and the turbo flood flat-fan. The later two nozzle types use a preorifice arrangement and turbulation chamber to better manage spray droplet size (Wolf, 1997; Ozkan, 1998). Each of these nozzle types was from Spraying Systems Company. The new technology nozzles included in the study were the new design air-induction/venturi style nozzles. There were four air-induction/venturi nozzles included for comparison. The four nozzles were: the TurboDrop XL from Greenleaf, the AI from Spraying Systems, the Ultra-Lo-Drift from Precision/Lurmark, and the Raindrop Ultra from Delavan (see figure 2). Table 1 summarizes the equipment and settings of the study.

Table 1. Equipment and Settings	
Sprayer	JD 6500 Hi-clearance sprayer
Nozzles	XR 11004, TT11004, TF-02, TD11004XL, AI11004, LU12004, and RU4-110 (see figure 2)
Nozzle Spacing	76 cm (30 in) and 51 cm (20 in) above the target
Spray Solution	Water
Volume	76 L/A (20 GPA)
Pressures	138, 276, 551 kPa (20, 40, and 80 psi)
Collection Medium	Spraying Systems/Ciba Water Sensitive Paper

Figure 2

The study was designed to apply product at 76 L/A (20 GPA) while operating at 138, 276, and 551 kPa (20, 40, and 80 psi). The application was made with a John Deere 6500 Hi-clearance sprayer equipped with a 3.5 m (10-foot) boom set up with four nozzles at 76 cm (30-inch) spacing and were located 51 cm above the target. The speed traveled was adjusted at each pressure to maintain the same application rate. All nozzles selected were the same orifice size, i.e. 1.5L/A (0.4 GPM) at 276 kPa (40 psi).

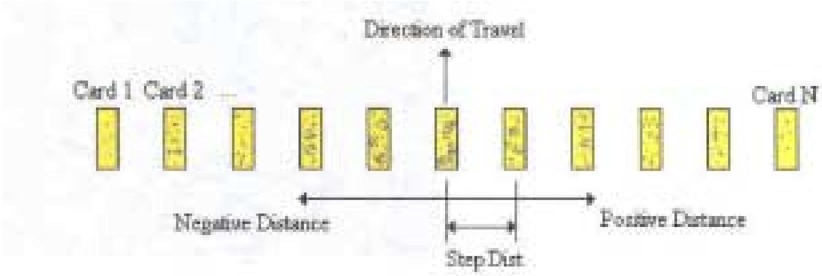


Figure 3

A collection was completed for each nozzle at each studied pressure by passing the sprayer over a board with clips holding five water-sensitive papers uniformly distributed across the 3.5 m (10-foot boom). For this collection process water only was sprayed. Figure 3 represents a model used in setting up the collection system. A display of information collected on a single pass over the collector is shown in figure 4. Figure 5 shows a display of all the collections made for this study.

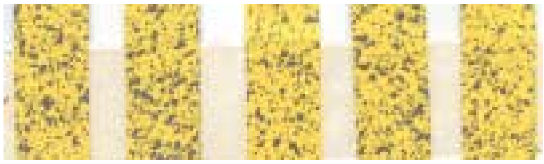


Figure 4

Figure 5

After collection was complete the cards were analyzed with the WRK DropletScan™ software using the process described previously. For each test an analysis was provided and a printout was made. Examples of the reports are included as appendix A and B. Summary data were assembled for analyzation of the study.

RESULTS and DISCUSSION

The use of the water-sensitive cards for collecting under-the-boom information from a ground sprayer at higher volume applications is a challenge. The 76 L/A (20 GPA) rate used in this study at the lower pressures for the air-induction/venturi nozzles provided a very heavy coverage with many large droplets overtop each other. In general, an overview of the visible differences can provide some information regarding how pressure will affect the droplet spectrum created by the different nozzle designs.

Table 2 summarizes a DropletScan™ analysis for the seven nozzles in the study. For each nozzle and pressure the VMD $_{(0.5)}$, VD $_{(0.1)}$, and VD $_{(0.9)}$ are given. As expected the VMD for each nozzle type got smaller with increased pressure. Of the three conventional nozzles; XR flat-fan, TT flat-fan, and TF flat-

Table 2. Droplet Scan Analysis of Air Induction/Venturi Nozzles

Tip		138kPa			276kPa			551kPa	
* microns	VMD*	VD 0.1*	VD 0.9*	VMD*	VD 0.1*	VD 0.9*	VMD*	VD 0.1*	VD 0.9*
XR 11004	506	312	661	484	285	666	350	225	504
TT11004	565	299	715	507	263	684	465	249	639
TF-02	574	284	752	565	297	734	557	348	712
TD11004XL	664	382	825	582	363	767	559	327	721
AI11004	633	381	788	620	391	767	582	341	745
LU12004	733	446	869	618	338	779	579	330	748
RU4-110	618	368	771	578	321	745	555	314	703

fan; the TF flat-fan maintained the more constant VMD throughout the studied pressure range, i.e. from 574 microns at 138 kPa (20 psi) to 557 microns at 551 kPa (80 psi). It is also shown that all the air-induction/venturi nozzles exhibit larger VMD's at all pressures studied. At 276 kPa (40 psi) the differences between the conventional and air-induction/venturi nozzles were not as pronounced. At 551 kPa (80 psi) the XR and TT both exhibited lower VMD's than any of the other five nozzle types. In fact, the TF flat-fan at 276 and 551 kPa (40 and 80 psi) maintained very similar VMD to the air-induction/venturi nozzles (see figure 6). For the air-induction/venturi nozzle types a greater amount of variation in VMD occurred at 138 kPa (20 psi), but as pressures increased the VMD's became more similar. The LU12004 exhibits the most variation within the pressure ranges studied (see figure 7).

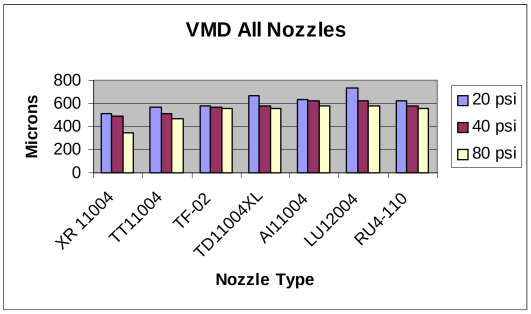


Figure 6

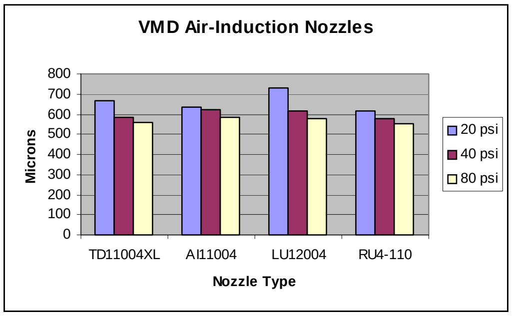


Figure 7

An analysis of the $VD_{(0.1)}$ for each nozzle type is shown in figure 8 below. An analysis of the air-induction/venturi nozzle indicates that at 138 kPA (20 psi) the TurboDrop and AI TeeJet have a very similar droplet spectrum. The raindrop Ultra created the smallest droplet spectrum and the Lurmark nozzle produced the largest droplets. In all cases the $VD_{(0.1)}$ was larger for the air-induction nozzles than the conventional nozzles. As pressure increased the $VD_{(0.1)}$ of each air-induction/venturi became more similar. The lowest reported at 276 kPa (40 psi) is with the Raindrop Ultra at 321 microns and the largest reported is with the AI TeeJet at 391 microns. At 551 kPa (80 psi) the lowest reported was again with

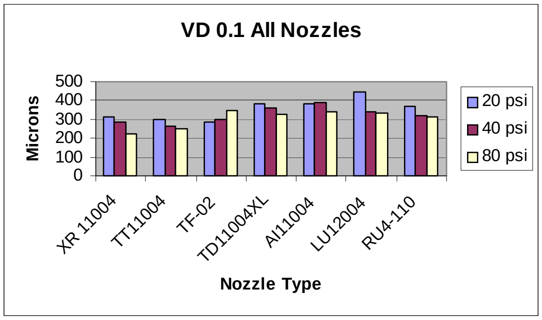


Figure 8

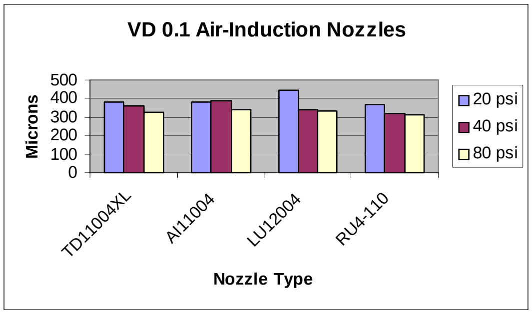


Figure 9

the Raindrop Ultra at 314 microns and the highest was with the AI TeeJet at 341 microns (figure 9). At 551 kPa (80 psi) the TF flat-fan nozzle exhibited the largest $VD_{(0.1)}$ at 348 microns (figure 8).

The analysis of the $VD_{(0.9)}$ for the air-induction/venturi nozzles at all pressures is displayed in figures 10 and 11. In all cases the air-induction/venturi nozzles had larger measured droplet sizes. The reported difference from all nozzles did not exceed 250 microns. In fact, the variation across the nozzle types and pressures were minimal with slight decreases shown as pressures increased.

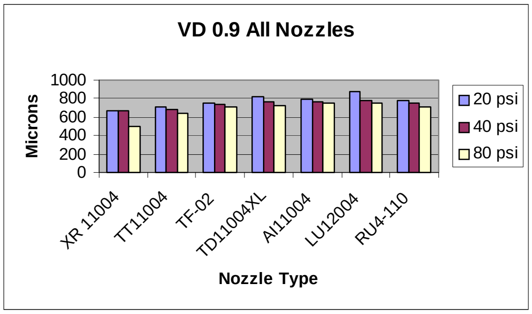


Figure 10

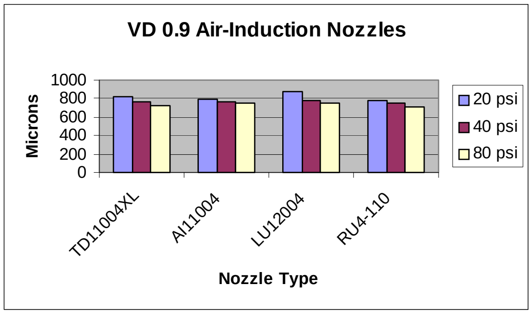


Figure 11

An additional analysis of benefit from the DropletScan™ system is the quantification of the number of droplets and percent volume of droplets into various size categories. Tables 3, 4, and 5 show the percent volume data for all nozzles while Tables 6, 7, and 8 show the number of droplets in the same categories. Each of the tables is followed with a graphic summarizing the data for all the nozzles and the air-induction/venturi nozzles (figures 12 through 23). An important understanding from this data is that the percent volume and number of droplet curves appear as near mirror images. This is easily understood knowing that less larger droplets can account for a higher amount of the volume where it takes a very high number of smaller droplets to maintain the same volume. The charts showing the data for all nozzles at the three studied pressure ranges studied follow each table.

Table 3. Percent Volume of Droplets by Droplet Size Category at 138 kPa

microns	0-100	101-200	201-300	301-400	401-500	501-600	601-700+
XR11004	0	0	8	20	22	25	25
TT11004	0	2	8	12	16	22	40
TF-02	0	2	11	12	14	16	45
TD11004XL	0	0	1	8	12	15	64
AI11004	0	0	4	8	13	20	55
LU12004	0	0	1	3	10	12	74
RU4-110	0	0	6	10	14	16	54

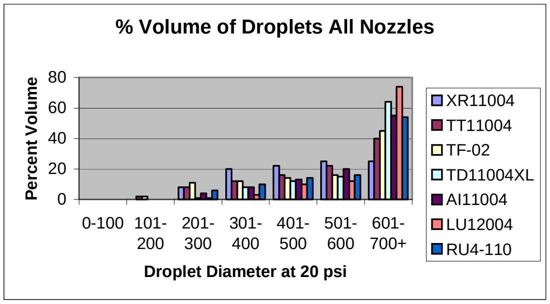


Figure 12

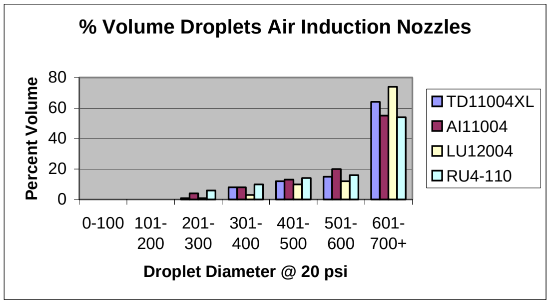


Figure 13

Table 4. Percent Volume of Droplets by Droplet Size Category at 276 kPa

microns	0-100	101-200	201-300	301-400	401-500	501-600	601-700+
XR11004	0	3	8	18	25	22	24
TT11004	0	3	12	15	19	23	28
TF-02	0	2	8	10	16	24	40
TD11004XL	0	0	5	10	15	25	45
AI11004	0	2	5	8	14	16	55
LU12004	0	2	6	8	14	16	54
RU4-110	0	1	6	11	14	20	48

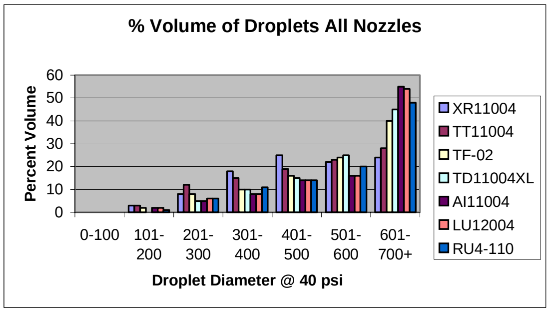


Figure 14

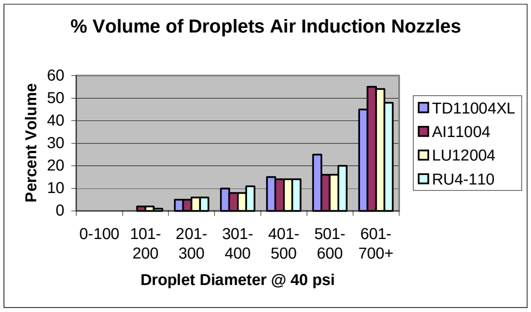
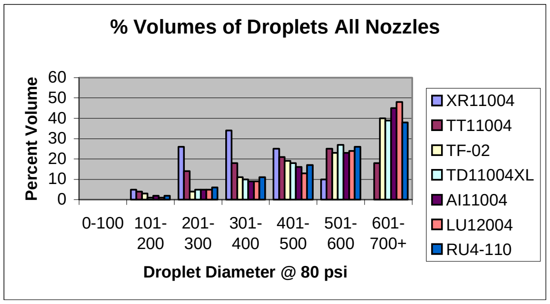


Figure 15

Table 5. Percent Volume of Droplets by Droplet Size Category at 551 kPa

microns	0-100	101-200	201-300	301-400	401-500	501-600	601-700+
XR11004	0	5	26	34	25	10	0
TT11004	0	4	14	18	21	25	18
TF-02	0	3	4	11	19	23	40
TD11004XL	0	1	5	10	18	27	39
AI11004	0	2	5	9	16	23	45
LU12004	0	1	5	9	13	24	48
RU4-110	0	2	6	11	17	26	38



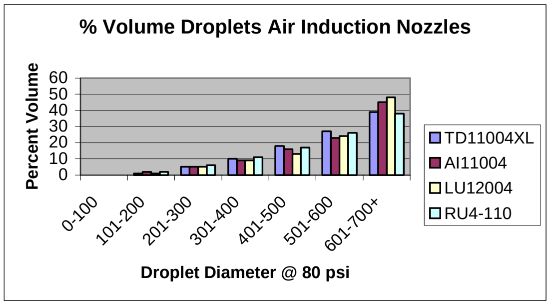
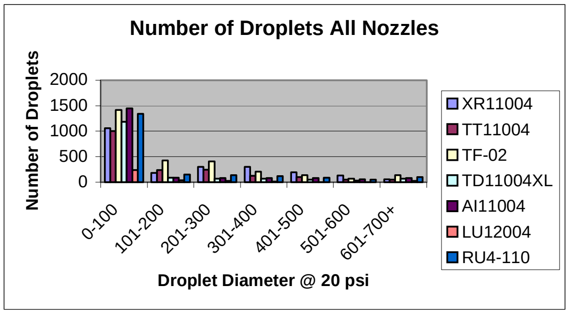


Figure 16

Figure 17

Table 6. Number of Droplets in Each Droplet Size Category at 138 kPa							
microns	0-100	101-200	201-300	301-400	401-500	501-600	601-700+
XR11004	1060	185	300	300	195	132	60
TT11004	999	240	248	125	100	50	50
TF-02	1415	425	410	210	141	70	141
TD11004XL	1181	89	70	70	50	30	70
AI11004	1450	90	85	80	80	60	80
LU12004	240	40	25	15	5	5	25
RU4-110	1340	150	140	120	90	50	100



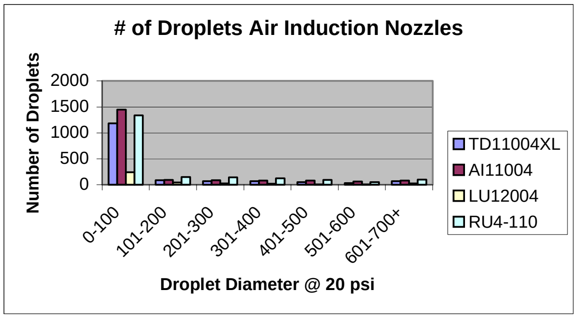


Figure 18

Figure 19

Table 7. Number of Droplets in Each Droplet Size Category at 276 kPa							
microns	0-100	101-200	201-300	301-400	401-500	501-600	601-700+
XR11004	1760	880	260	440	300	120	80
TT11004	1440	720	720	360	180	150	90
TF-02	2800	800	500	340	180	160	100
TD11004XL	1315	250	180	160	140	140	120
AI11004	2950	290	220	140	160	130	170
LU12004	2350	410	290	120	100	50	110
RU4-110	2115	450	400	210	160	130	150

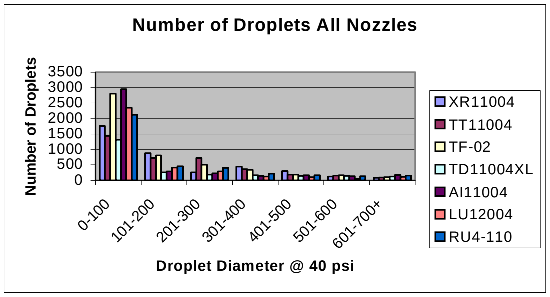


Figure 20

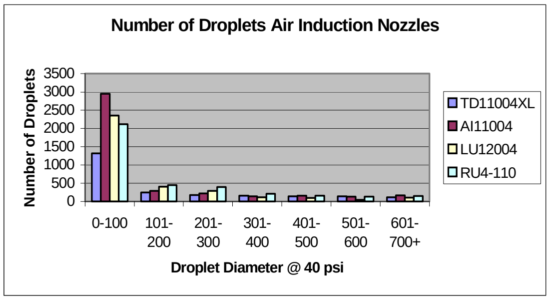
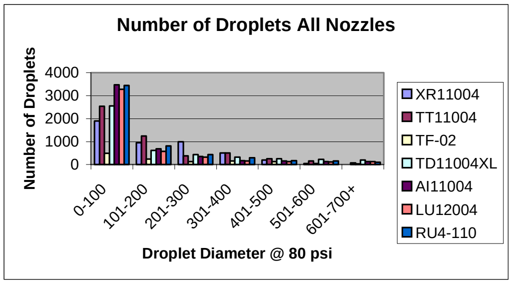


Figure 21

Table 8. Number of Droplets in Each Droplet Size Category at 551 kPa							
microns	0-100	101-200	201-300	301-400	401-500	501-600	601-700+
XR11004	1890	950	1000	500	200	50	0
TT11004	2530	1250	380	500	250	160	70
TF-02	490	245	130	150	130	50	40
TD11004XL	2545	620	440	320	250	230	200
AI11004	3475	690	350	170	150	130	130
LU12004	3275	570	330	160	130	120	130
RU4-110	3435	810	430	300	170	150	100



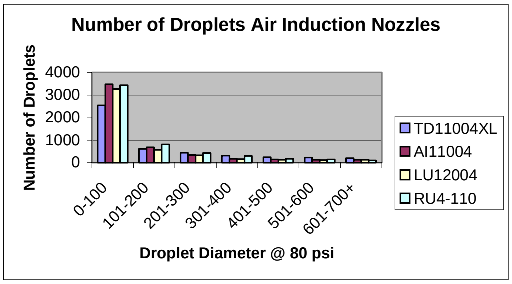


Figure 22

Figure 23

CONCLUSIONS

This paper represented some initial field collection procedures using the WRK DropletScan™ system to analyze the spray quality from field application nozzles at field rates. The study was a comparison of three conventional boom sprayer nozzles with four new technology air-induction/venturi nozzles at three pressures all at a similar application rate. The purpose was to gain information about each nozzle under the studied parameters to enable the application industry to make better application decisions specific to individual targets, crop protection products, and while attaining adequate efficacy, minimizing off-target movement of materials.

In general, the air-induction/venturi nozzles compared to the conventional nozzles, do provide a higher quality spray in reference to what is known about drift potential. In all cases the droplet spectrums were larger with a smaller portion of the spectrum in that portion of the spectrum considered highly drift prone. In this study there were no major differences reported through all pressures and all droplet statistics that would differentiate that any air-induction/venturi nozzle will out perform another. Based on the droplet spectra of the air-induction/venturi nozzles at 138 kPa (20 psi), a caution is expressed regarding a uniform spray pattern and the lack of adequate spray coverage for certain application situations. At 276 and 551 kPa (40 and 80 psi) minimal differences in the droplet spectra were observed for all the air-induction/venturi nozzles. Coverage on the target and reduced driftable fines for these new nozzle designs would indicate the potential adequate efficacy while minimizing drift. However, judgement on performance should be reserved until adequate efficacy data and drift data are collected to place beside the droplet data.

The use of the WRK DropletScan™ system to analyze field developed droplet spectrums may proof to be very useful to the application industry. The ease of using the system and the feedback information available in the report could provide a good basis for making sound application decisions for increasing the efficacy and reducing the drift potential. As more data of this type is analyzed then better information will be available about individual nozzle types as it relates to various crop protection products. Additional research using these new nozzle types in the field to evaluate control levels and the measuring of off-target deposition will support the decision making process. The continued use of the WRK DropletScan™ system to analyze aerial application will bolster the value of the the measurement technology to quickly evaluate the swath displacement characteristics of different nozzle types under many different operating parameters including tank mix.

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