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CHARACTERIZING AMBIENT AND SPRAY MIXTURE EFFECTS ON DROPLET SIZE REPRESENTED BY WATER SENSITIVE PAPER (WSP)

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ABSTRACT Water sensitive paper (WSP) cards are frequently used to provide visual representation of droplet size and density for spray drift and deposition studies. Droplets collected on WSP spread out on the surface of the paper, and standard “spread factor” equations are used to compensate for spread to characterize actual droplet size. To date, no data have been presented to consider the effects of ambient conditions and formulation on droplet size represented by WSP. These data would be useful for creation of more accurate spread factor equations, and significant effects on droplet size could be modeled into new equations to account for these variables. A preliminary study was conducted using a newly constructed enclosed chamber that allows independent control of temperature (T) and relative humidity (RH) to determine the effects of T, RH, formulation, and droplet volume on droplet diameter as represented by WSP. Droplets of a known diameter were placed on several WSP cards using five mixtures of Domark® fungicide, Syl-Tac® surfactant, and water while RH, T, and droplet volume were varied at three levels each. The WSP were optically scanned to obtain droplet size. Statistical procedures were used to determine the effect of T, RH, droplet volume, and spray mixture on stain area, and a model was developed over the droplet size range applied. A useful relationship of the influence of ambient conditions was derived, which indicated a linear relationship between RH and droplet stain area.

Keywords: water sensitive paper, spray droplets, spray sampling, drift measurement

INTRODUCTION Drift measurement and analysis is a complex task because of interrelated multi-dimensional dynamic processes that occur between the time of spray release and droplet deposition. All drift measurements currently require samplers to collect representative samples of drift deposits close to ground level and samplers for collecting airborne spray drift.

The ASABE drift measurement standard S561.1 (ASABE Standards, 2004) specifies that drift deposits be collected on a flat collector, with the exposed surface level and located approximately at the top of the soil surface, grass, or crop that is in the downwind area. This type of collector (fallout sheet) has been widely used (Bouse et al., 1994; Carlton and Bouse, 1988; Hatterman-Valenti et al., 1995; Bui et al., 1998; Kirk, 2000; Smith et al., 2000; Fox et al., 1993, Lan et al., 2008, Thomson et al., 2004, 2005) with several types of sample media that include alpha-cellulose, Mylar, and photographic film.

Mylar sheets have a non-reactive surface that is easily rinsed with small volumes of solvent; therefore, they are well suited for use as sample media. Water sensitive paper (WSP) cards have also been used to quantify spray coverage and droplet size distribution of drift deposits. However, droplet stain diameters must be adjusted through the use of a spread-factor to determine the actual droplet diameters associated with the stain. Degre et al. (2001) concluded that water sensitive cards were useful for qualitative comparisons due to the variability in spread factor associated with very large droplets (1240 µm and 985 µm D). While this variability was probably greater than for droplets less than 200 µm in diameter, field use of water sensitive card data to determine droplet spectra has been suspect because the moisture content of the card affects the spread factor. The size of the droplet on WSP and formulation are also thought to influence actual droplet size. Cards located within the canopy of transpiring plants absorb moisture from the air and produce a larger stain (due to the longer time required to absorb the droplet) than a dry card. Card data are also highly dependent on the color threshold level used when processing the card images to measure the stain areas. Studies by Wolf et al. (1999), Panneton (2002), Sánchez-Hermosilla and Medina (2004) and Hoffmann and Hewitt (2005) highlight the importance of careful image interpretation and analysis of card data. To our knowledge, no data have been presented to determine actual droplet size on spray cards as a function of ambient air temperature and moisture levels, droplet volume, or formulation. These data would be useful for creation of more accurate spread factor equations.

PROCEDURES

Formulations Each of the formulations shown in Table 1 was prepared using 100 ml deionized water. For each, the respective amount of Syl-Tac® surfactant (Wilbur-Ellis, Fresno, CA, USA) and Domark® fungicide (Valent USA, Walnut Creek, CA, USA) was added and the mixture was then stirred until homogeneous. A total of four different formulations were evaluated in addition to a water or control treatment.

Table 1. Formulation percent composition.

	Constituent Composition (%)		
Trt No.	SylTac	Domark	Water
1	1.54	0	98.46
2	1.50	2.26	96.24
3	0.62	0	99.38
4	0.62	0.92	98.46
5	0	0	100.00

Controlled Environment Chamber A controlled environment chamber or a CEC (Model 5506C, Electro-Tech Systems, Inc., Glenside, PA, USA) was used to carry out the experiment. The CEC was an O-ring sealed bench-top chamber equipped with a heating and cooling microprocessor system that automatically maintains the experimental temperature and humidity. To enable automatic control of humidity, the CEC was equipped with a heated-water reservoir, a vacuum pump, and a desiccant (Figure 1).

Figure 1. Controlled Environment Chamber (CEC) and associated hardware

During an experiment, the microprocessor would automatically activate the vacuum pump if an increase in humidity was detected or supply power to the water reservoir to compensate for low humidity. Although the CEC comes equipped with a temperature and humidity readout, two additional hygrometers/thermometers (VWR Model 35519-047, VWR, West Chester, PA, USA) were stationed inside the CEC at different locations.

Prior to establishing the environmental settings, the following items were placed inside the CEC: 26 mm X 500 mm strips of WSP (CIBA-GEIGY, Spraying Systems, Wheaton, IL, USA), the five formulations, an adjustable 0.1 – 2.5 µl volume pipette (Eppendorf Model EW-24505-00, Eppendorf AG, Hamburg, Germany), and replacement micropipette tips. The experiment was performed at five different environmental settings. There were two low temperature settings, (20°C, 40%RH) and (20°C, 80%RH); two high temperature settings, (35°C, 40%RH) and (35°C, 80%RH); and one intermediate setting, (30°C, 60%RH). At both low and high temperature settings, a low (40%) and high (80%) humidity setting was established. Since the CEC took a longer time to adjust from a high to low humidity relative to the opposite direction, low humidity experiments were generally conducted first.

Formulation Application For each treatment at a given (T, RH) setting, three different droplet volumes (0.1, 0.3, and 0.5 µl) were applied to a strip of WSP divided into three sections. Within each section, a minimum of three droplets of a given volume was carefully applied. This was done by ejecting the formulation before touching the pipette tip to the WSP at an optimal angle to minimize smudging. The optimal angle, a subjective parameter, was dependent on the person applying the droplets. The sizes were randomly placed onto the strips. Although more than three droplets were applied per droplet volume, only three droplets with no signs of smudging were analyzed. WSP were allowed to dry inside the CEC for 10 min before removing. For each treatment at a given (T, RH) setting, there were three droplet volumes and three stains analyzed per droplet volume on each of three WSP strips. Frequent breaks were taken during the experiment to reduce experimenter fatigue and hence, the error in the spread of applied droplets.

Analysis of WSP After the experiment was completed, the WSP strips were analyzed for geometrical parameters using an image scanning system. The image analysis system consisted of a JVC CCD camera with RGB output and an Integral Technologies Flashpoint® Intrigue Frame Grabber (Pelco Worldwide, Clovis, CA, USA), mounted in a

Dell Dimension desktop computer running MS Windows 98. WSP were scanned using SigmaScan 5.0 (Aspire Software International, Ashburn, VA) and programmed macros were used to process and export droplet area and diameter to a text file for spreadsheet analysis.

RESULTS Table 2 illustrates the effect of RH, T, Size (droplet volume), and Treatment (mixture) on actual droplet size for a known applied droplet volume. The SAS 9.1.3 procedure PROC mixed (SAS Institute, Inc., Cary, NC, USA) was used to analyze the data and provide a model solution with [RH-TEMP combination X Treatment X Size] set as random effects. Non-significant main effect and interaction terms were progressively dropped out, resulting in final output (Table 2). Treatment (or mixture), RH, and SIZE*TRT (the interaction between droplet size and Treatment) were all significant effects on droplet stain area (p=0.01). Model solutions were developed for all five treatments, and an example for Treatment 1 was determined as:

$$\text{Log (Area)} = -1.7773 + 0.001999 \cdot RH + 0.001970 \cdot TEMP + 0.9472 \cdot SIZE \qquad (1)$$

where

RH = relative humidity, TEMP = ambient temperature, SIZE = Droplet size volume or the known volume of mixture applied to WSP.

Table 2. Effects on droplet area determined from WSP

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   Type 3 Tests of Fixed Effects

           Num     Den
Effect      DF      DF    F Value    Pr > F

TRT              5      63     373.21    <.0001
RH               1      63      20.20    <.0001
Temp             1      63       2.82    0.0980
Size*TRT        5      63      69.07    <.0001
```

Figure 2 illustrates a relationship between droplet volume applied to WSP vs. stain area, along with a representation of the model solution. Log model results illustrate spread of the data at each applied volume, representing the combined effects of RH (40, 60, 80%) and Temperature (20, 30, 35 C). These effects were more pronounced at the larger droplet sizes illustrated but appeared to be consistent if expressed as a percentage of actual stain area.

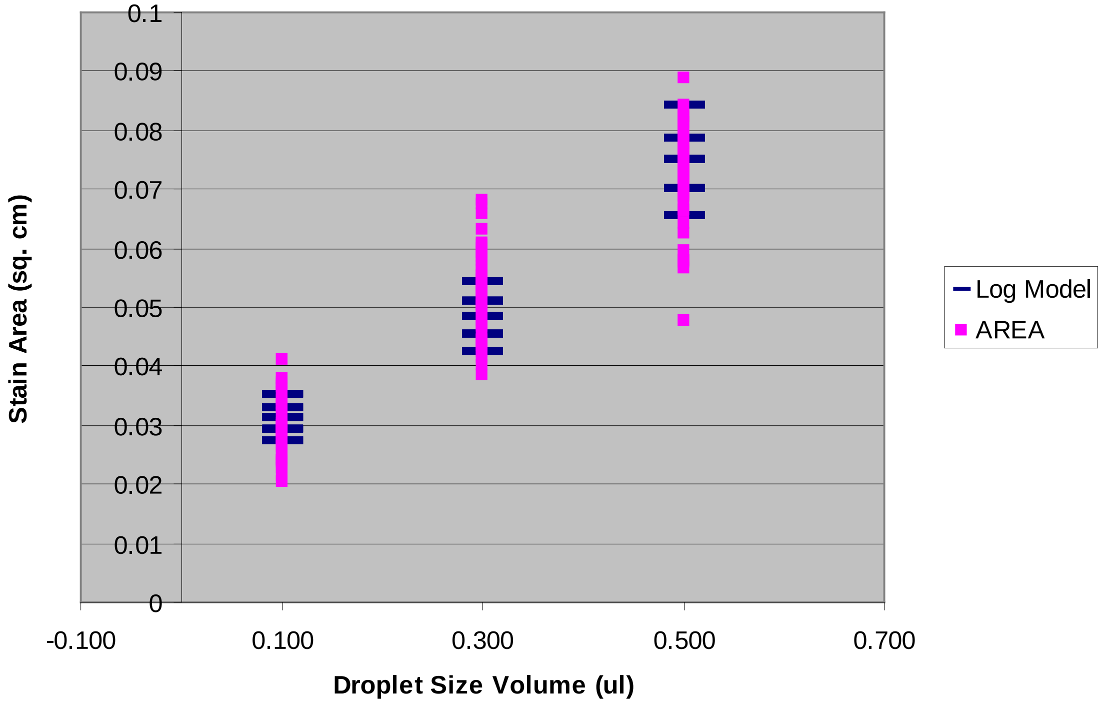

Figure 2. Droplet size volume vs. stain area for Treatment 1.

Although there appeared to be an influence, TEMP did not have a significant effect on droplet stain area at p=0.05 (Table 2). To illustrate a typical response due to RH alone (with TEMP fixed at 20 C), model responses between the extremes of RH, 40 and 80%, are illustrated in Figure 3. For the model fit corresponding to the subset of data shown, percentage increase in stain area caused by an increase in RH between the extremes (40 and 80%) was 20% at all three stain sizes or 0.5%/ 1% Δ RH.

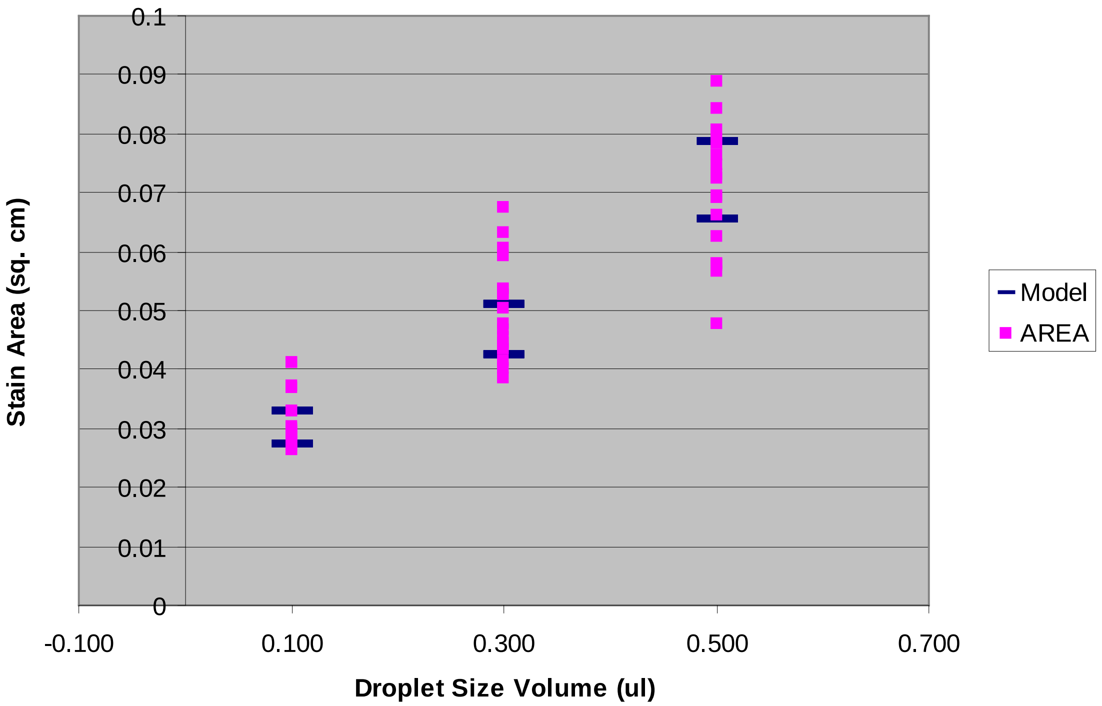

Figure 3. Droplet size volume vs. stain area for Treatment 1 showing actual data and model results between the two extremes of RH (40% and 80%)

Figure 4 illustrates stain diameter for SIZE 1 (smallest droplet) by Treatment pooled across variables RH and TEMP. The trend in droplet size was downward with Treatment, so it would be instructive to determine the range of actual stain sizes between a higher value (Treatment 1) and lowest average stain diameter (Treatment 5). In theory, droplet volumes of 0.1, 0.3, and 0.5 µl correspond with droplet diameters of 576, 831, and 985 µm, respectively. These are all larger than droplet sizes than we customarily work with in spray studies, but we were limited by the smallest volume available using commercial micropipettes.

Droplet spread on the CIBA-GIEGY brand WSP used in this experiment at fixed conditions can be approximated by the equation:

$$y = 0.51 * X + 53\ \mu m \qquad (2)$$

where y = actual diameter and x = stain diameter. Eq. (2) was derived for WSP by Hill and Inaba (1989) with a Decis 5.0 (EC) spray solution at 42% RH. Figure 4 illustrates the same data pooled across RH and TEMP for the smallest droplet volume applied (0.1 µl). After accounting for droplet spread by equation (2), average droplet diameter at 0.1 µl spotted by micropipette was 1051 µm for Treatment 1 and 636 µm for Treatment 5 (water only). The latter value compares well with the theoretical value of 576 µm after considering that Equation 2 is an approximation that does not account for ambient or mixture effects. The Eppendorf pipette used to produce the smallest droplet has a stated accuracy of ± 12.5% and imprecision of 6% at 0.1 µl. We applied the smallest droplet possible from that micropipette. The difference between theoretical and actual droplet size falls within that range of accuracy.

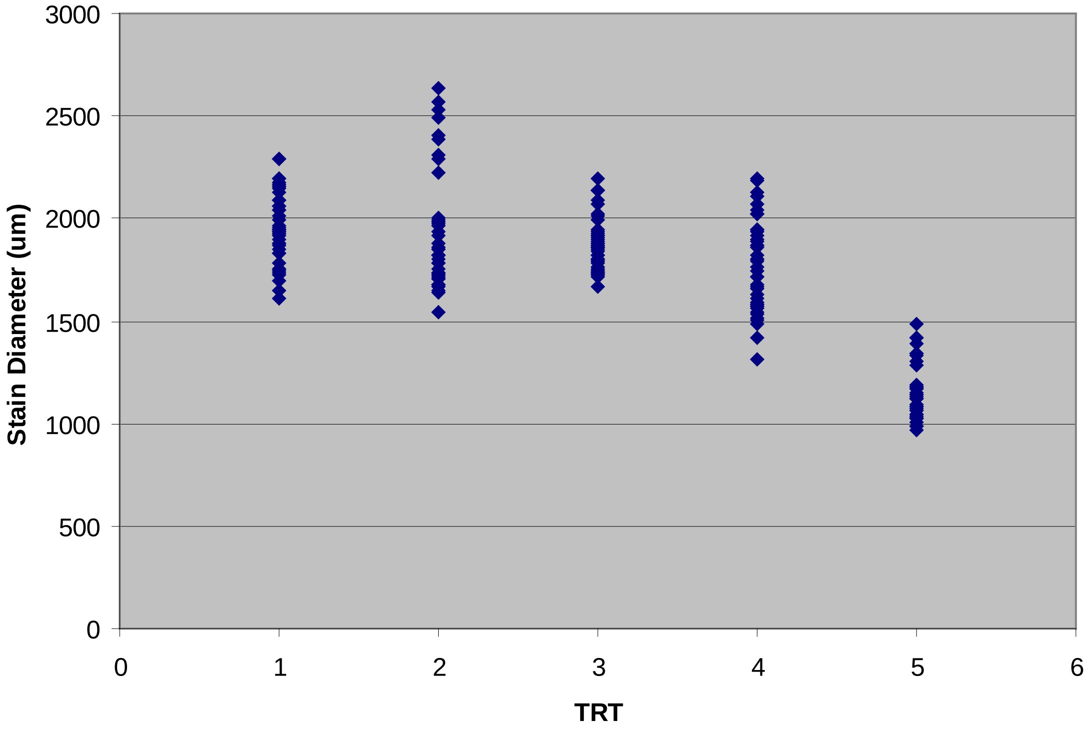

Figure 4. Stain diameter as a function of Treatment for the smallest droplet volume applied to WSP (SIZE=1).

SUMMARY AND CONCLUSIONS Water sensitive paper (WSP) is frequently used in spray drift and deposition studies to characterize size and density of droplets applied by ground or aerial spraying systems. A study was conducted using a controlled environment chamber to determine and model the effects of RH, ambient temperature, spray mixture, and droplet size on droplet diameter obtained from WSP. Results of this study illustrated significant effects of RH, droplet size, and spray mixture on actual droplet area by statistical analysis. Model solutions were developed for the five mixtures tested and an example solution was illustrated. As modeled, the effect of RH on droplet diameter was +0.5%/ 1% Δ RH. Our procedures can be used to develop a final droplet size model, and it may be desirable to supplement testing with smaller droplets. These can be applied in the lab to WSP using microliter syringes for manual application or by precision droplet generator. Based on our experimental and analytical procedures, a protocol can then be established to obtain data for any spray mixture as required for a field experiment. A library of equations could then be developed as new spray mixtures are required.

REFERENCES

ASABE Standards. 2004. S561.1 Procedure for Measuring Drift Deposits from Ground, Orchard, and Aerial Sprayers. St. Joseph, MI: ASABE.

Bouse, L.F., J.B. Carlton, I.W. Kirk, and T.J. Hirsch, Jr. 1994. Nozzle selection for optimizing deposition and minimizing spray drift for the AT-502 Air Tractor. Transactions of the ASAE 37(6):1725-1731.

Bui, Q.D., A.R. Womac, K.D. Howard, J.E. Mulrooney, and M.K. Amin. 1998. Evaluation of samplers for spray drift. Transactions of the ASAE 41(1):37-41

Carlton, J.B. and L.F. Bouse. 1988. Exploring aerial spray sampling with a cylindrical collector. Transactions of the ASAE 31(4):990-997.

Degre, A., O. Mostade, B. Huyghebaert, S. Tissot, C. Debouche. 2001. Comparison by image processing of target supports of spray droplets. Transactions of the ASAE 44(2):217-222.

Fox, R.D., D.L. Reichard, R.D. Grazee, C.R. Krause, and F.R. Hall. 1993. Downwind residues from spraying a semi-dwarf apple orchard. Transactions of the ASAE 36(2):333-340.

Hatterman-Valenti, H., M.D.K. Owen, and N.E. Christians. 1995. Comparison of spray drift during post-emergence herbicide applications to turfgrass. Weed Technology 9:321-325.

Hill, B. D., and D. J. Inaba. 1989. Use of water-sensitive paper tomonitor the deposition of aerially applied insecticides. J. of Economic Entomology 82(3): 974-980.

Hoffmann, W.C. and A.J. Hewitt. 2005. Comparison of three imaging systems for water-sensitive paper. Applied Engineering in Agriculture 21(6): 961-964.

Kirk, I.W. 2000. Aerial spray drift from different formulations of glyphosate. Transactions of the ASAE 43(3):555-559.

Lan, Y., Hoffmann, W.C., Fritz, B.K., Martin, D.E., Lopez, J. 2008. Spray drift mitigation with spray mix adjuvants. Applied Engineering in Agriculture. 24(1):5-10.

Panneton, B. 2002. Image analysis of water-sensitive cards for spray coverage experiments. Applied Engineering in Agriculture 18(2): 179-182.

Sánchez-Hermosilla, J. and R. Medina. 2004. Adaptive threshold for droplet spot analysis using water-sensitive paper. Applied Engineering in Agriculture 20(5): 547-551.

Smith, L.A. J.E. Mulrooney, and C.D. Elmore. 2000. Experimental design and sampling techniques for effective evaluation of spray drift. ASABE Meeting Paper No. 001029. St. Joseph, MI: ASABE.

Thomson, S.J., A. R. Womac, J. E. Mulrooney, and S. Deck. 2004. Evaluation of upwind/downwind boom switching and propeller direction on drift of aerially applied spray. Proceedings of the International Conference on Pesticide Application for Drift Management, Waikoloa, HI, October 27-29, 2004. pp. 340-347.

Thomson, S.J., A. Womac, J. Mulrooney, and S. Deck. 2005. Propeller wash effects on spray drift. Paper No. AA05-007. National Agricultural Aviation Association, Washington, D.C. Available at: http://apmru.usda.gov/Aerial/2005ASAE/AA05-007paper.pdf Accessed 08 March 2010.

Wolf, R.E., D.R. Gardisser, and W. L. Williams. 1999. Spray droplet analysis of air induction nozzles using WRK DropletScan™ Technology. ASABE Meeting Paper No. 991026. St. Joseph, MI: ASABE.