J. Agr. Sci. Tech. (2012) Vol. 14: 285-298

Determination of Optimal Spot Roundness Variation Interval for Droplet Size Analysis on Water Sensitive Paper

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ABSTRACT

To determine the droplet characteristics of agricultural spray nozzles through Water Sensitive Paper (WSP), the non-circular and overlapped spots appearing on the water sensitive paper surfaces are eliminated. In the conventional approach, the procedure is done according to the subjective self determined estimation of the operator. The objective of this study was to develop a practical alternative to the conventional approach to Spot Elimination (SE) from WSP surfaces. Droplet samples were taken through application of seven different spray nozzles. Papers were placed within and outside the domain of spraying area and scanned at 600 pixels per inch resolution following their collection. The diameter and roundness values of each spot on multiple WSP samples were determined through image processing software. The overlapped spots and the non-circular ones were manually eliminated by the operator. Spot Roundness (SR) ranged from 0.051 to 6.283 and from 0.130 to 6.283 prior to, and following SE, respectively. Results indicated a linear relationship between minimum SR value and volume median diameter of the droplets. Regression analysis revealed the optimal SR variation interval to be between 0.765 and 2.356 for SE. Characteristics of the spots remaining out of this range were compatible with the characteristics of the droplets conventional SE (when the spots subjectively eliminated). When the volumetric diameters (D_V) in the conventional SE approach were compared with the optimum SR variation interval (for 10, 50 and 90 percent ratios) their absolute relative error ratios and confidence intervals at 95% level of significance level found as 2.8%±1.4, 1.8%±0.9, and 3.8%±1.5, respectively.

Keywords: Image processing method, Droplet diameter, Spot diameter.

INTRODUCTION

Water sensitive papers (WSP) are widely employed for a determination of droplet diameters (Bayat and Bozdogan, 2005), droplet spectrum (Soysal and Bayat, 2006), spray coverage (Salyani and Fox, 1999) and droplet densities (Womac *et al*., 2001) of agricultural spray nozzles.

Laser light beam based measuring instruments are employed for droplet characterization of agricultural spray nozzles (Matthews, 2000). Droplet spectrum is commonly scrutinized under controlled conditions of laboratory, at a temperature of 20ºC and relative humidity of 60-70% (Nuyttens *et al*., 2007). Strainers with restriction effects are not used in the laboratory experiments and nozzles are positioned at a constant height of 0.50 m above the measuring point of the instrument (Womac *et al*., 2001; Nuyttens *et al*., 2007). Water Sensitive Paper (WSP) method is practically useful in determining droplet spectrum of agricultural spray nozzles under natural ambient conditions (Soysal and Bayat, 2006). The droplets transferred to target areas are analyzed in this method, due to drift of fine droplets (less than 100 µm)

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[DOR: 20.1001.1.16807073.2012.14.2.11.3]

(Bode *et al*., 1983; Bayat and Bozdogan, 2005). Therefore, this method can provide one with the important needed information regarding spray deposition efficiency under ambient conditions.

Water sensitive papers are placed on either an artificial target (Womac *et al*., 2001) or plant leaves (Coates and Palumbo, 1997) for capturing the spray solution. Such unsuitable factors as: ambient temperature and humidity of the environment (below 10ºC and humidity above 80% respectively), dirty and/or humid target surfaces, unnecessary contact of the operator with the paper surface are among the factors which affect processing quality of spots on WSP in a negative way (Anonymous, 2008).

Spray droplets stain the WSP coating and the resulting spot sizes can be assessed through an image processing method. Spaces occupied by droplets over the paper surface can be appraised according to color differences observed between WSP surface and spots, giving the percentage areas covered. Spot density can be determined by the number of spots per unit area of WSP.

Scanners can be used to quantify WSP images (Franz, 1993; Coates and Palumbo, 1997; Sumner *et al*., 2000; Womac *et al*., 2001). To determine the properties of each of the pixels making up the digital image, different software applications are employed (Sánchez-Hermosilla and Medina, 2004; Marçal and Cunha, 2008). But, the current image analysis systems are not sensitive enough to accomplish the measurement of spot density on WSP, when coverage is greater than about 30 to 40% (Fox *et al*., 2003).

Selection of the threshold levels of scanned WSP in image processing analysis can be accomplished through estimation by an operator previously trained in analyzing the image with the aid of an optical microscope (Salyani and Fox, 1999). However, Sánchez-Hermosilla and Medina (2004) reported that the threshold level for each WSP image depends on the level of its being gray. Panneton (2002) used a single threshold intensity for a set of WSP samples and reported that the absolute error was limited to ±3.5% of the WSP experimentally covered area.

Water sensitive papers present a proper estimating feature in the determination of spray application performances of spray nozzles (Degré *et al*., 2001). The most crucial factor which limits the spot size analysis on WSP images is the distance between, and the overlapping of the droplets (Fox *et al*., 2001). Spots which are not suitable for spot size analysis on WSP image should be appropriately eliminated. In the conventional approach, non-circular spots are eliminated as judged by the overal subjective estimation of the operator. Shape features of most spots to be eliminated cannot be easily chosen on WSP images, when spot density is high. Therefore this study was carried out to eliminate the subjective method of estimation.

The objective of this study was to eliminate the operator subjective method of approach in spot elimination, through development of a practical alternative method for droplet size analysis of on WSP reflected images.

MATERIALS AND METHODS

Standard flat fan pattern nozzle (Tecsi SRL 11002, Treviglio (BG), IT), hollow cone pattern nozzle (Tim D2-25, Timsan Ltd., Ist., TR), low pressure air induction nozzle (Agrotop 11002 GmbH, Obertraubling, DEU), low drift flat fan nozzle (Albuz ADI 11002, Ceramiques Techniques Desmarguest, Exreux, FRA), twin jet with air induction nozzle (Albuz AVI TWIN 11002, Ceramiques Techniques Desmarguest, Exreux, FRA), low volume applied spinning disc nozzle (Micromax®, CDA, Micron Sprayer Ltd., Bromyard, UK) as well as rotary atomizers (Proptec™, Ledebuhr Industries, Inc., MI, US) were employed in the study (Table 1).

Meteorological measurements (Table 2) were made through a wireless air station (Davis Vantage Pro2™ Plus 06162EU,

[DOR: 20.1001.1.16807073.2012.14.2.11.3]

Table 1. Spray nozzles and some of their operational conditions.

Operational properties	Hydraulic nozzles	Micromax™ CDA	Proptec™ Atomizer
Flow rate (L min^{-1})	0.88	0.66	1.32
Pressure (kPa)	400	150	150
Travel speed (m s^{-1})	1.7	1.5	1.6
Application rate (L ha^{-1})	175	59	98
Space of nozzles (cm)	50	110	140
Spray height (cm)	50	30	70
Position angle (°)	0	30 [a]	45 [b]
Disc speed (rpm)	-	4500	3500
Air speed (m s^{-1})	-	-	5.6-7.0

[a] Backwards to the direction of travel. [b] Forwards to the direction of travel.

Table 2. Meteorological data summary.

Meteorological data	Droplet samples transferred to target		Droplet samples transferred to outside of target	
	Mean	Range	Mean	Range
Temperature (ºC)	24	20-29	29	24-35
Relative humidity (%)	26	13-44	25	16-40
Wind speed (m s^{-1})	0.8	0.0-3.6	1.2	0.0-4.0
Wind direction	West-Southwest		Northeast	

Davis Instruments, CA) and all the measurements were taken from an equal spraying height similar to those in the spray application tests.

The experiments were conducted, using a completely randomized design of three replications. Trials were carried out on concrete. Water sensitive papers (WSP, 26×38 mm, Novartis, Syngenta Crop Protection, Basel, CH) were used to take droplet samples in two trials at different time periods. In the first trial, WSP sheets were placed within the spraying area with the droplet samples (transferred to target surface) being taken. Twenty pipes (Ø21.3 mm, length 400 mm) were used to place the WSP sheets within the spraying area. In the trial areas, posts were placed within distances of 0.7×5.0 m (between rows×across rows) on a 4×5 grid. WSP sheet samples were attached to metal sheet plates (1.0×10 cm) mounted on top, middle and bottom of posts using clips as presented in Figure 1. Samples at the bottom area were placed at a position not contacting the ground. In the second trial, WSP samples were placed outside the spraying area and droplets transferred to outside of the target area through drift were estimated. Nine posts were employed to take droplet samples transferred to outside of the spraying area as presented in Figure 2. Posts were placed on a 3×3 grid that were 4, 6 and 8 m apart and of 1 m distance. WSP samples were attached using clips in 40 cm heights parallel to the vertical.

Laboratory gloves were used during samples collection to prevent paper samples from any inadvertent human contact. Papers collected following spray application were protected by being put into plastic cases. In total, 1,449 WSP samples were collected.

A scanner (HP Scanjet 4850, Hewlett-Packard Development Company, LP) was employed to transfer the WSP images into computer. The scanner was set to a resolution of 600 pixels per 25.4 mm giving a 42.3 µm of any spot, as mentioned in Uremis *et al*. (2004). Mean gray level of each WSP was determined through an image processing software "UTHSCSA Image Tool" Windows version 3.0 developed by The University of Texas Health Science Center. Threshold level of each of the WSP

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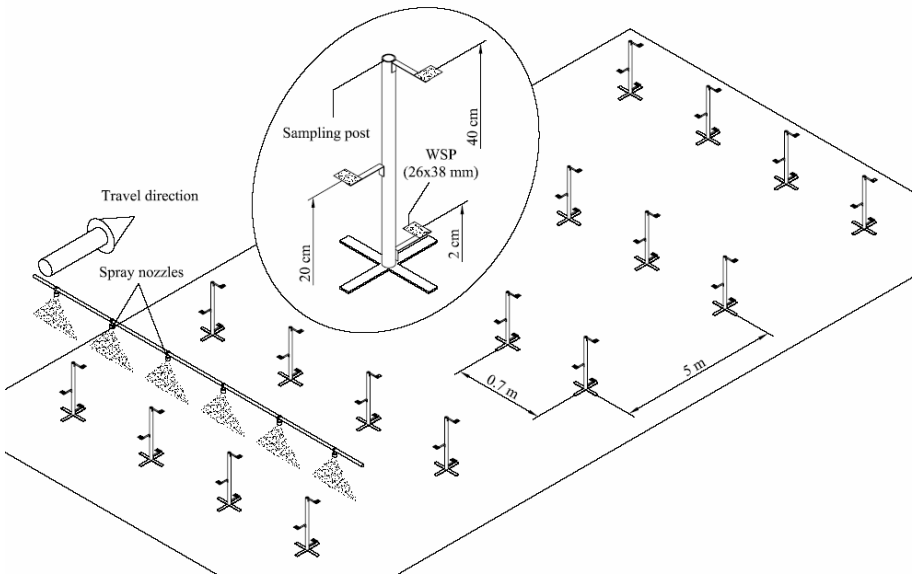

Figure 1. The location of WSP samples and posts within the spraying area.

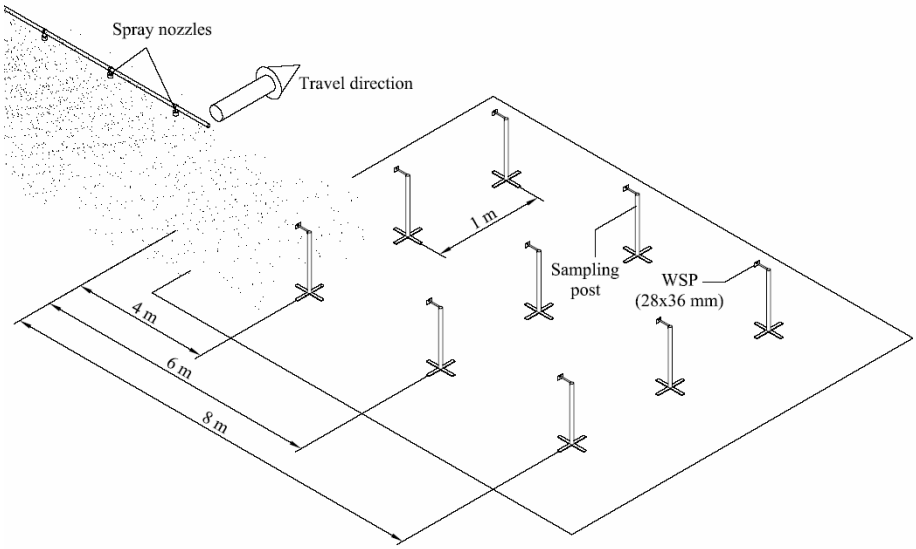

Figure 2. The location of WSP samples and posts outside the spraying area.

images after scanning was calculated using a linear equation between threshold and mean gray levels with an adjusted R^2 of 0.91 (Sánchez-Hermosilla and Medina, 2004). After threshold, secondary images were saved as picture file with their tiff extension. Spot diameter, spot roundness, spray coverage and spot density on secondary images were determined using the software.

Spot roundness value is calculated by the following equation through the software. If the ratio is equal to 1, the spot is considered as a perfect circle, while as the ratio decreases or increases from 1, the spot is considered as departing from a circular form.

Spot roundness= (4.π.spot area)/Perimeter^2

Spot density was determined by dividing the total spot number on WSP surface to the total surface area of the WSP. The number of spots on WSP surface was automatically determined through the image processing software.

Macro module was written in Microsoft® Excel'07 to estimate droplet characteristics. To determine the droplet diameter, the spot diameters were inserted into the following calibration equation obtained by using the

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table values in the WSP manufacturer's catalogue (Syngenta, 2002):

$D_r = 1.033 \times D_s^{0.879}$

where:

D_r= Actual droplet diameter (µm),

D_s= Spot diameter (µm).

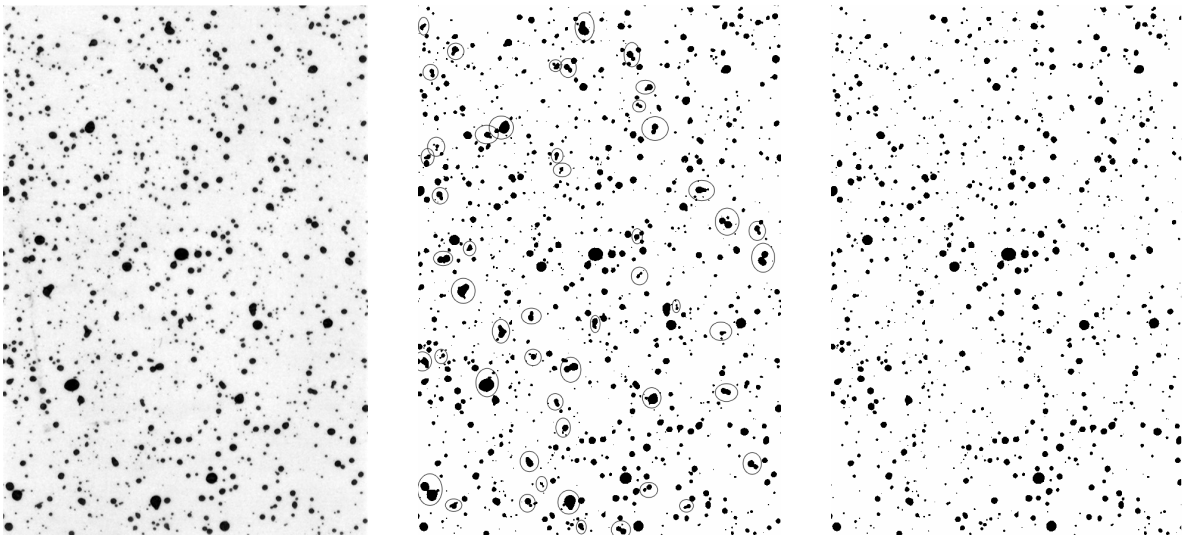
Analyses of droplet characteristics were made within 20 differing diameter class ranges. In the software, mean droplet diameters (D_{10}, D_{20}, D_{30}, D_{32}), volume median diameter ($D_{V0.50}$), diameter values corresponding to 10, 25, 75 as well as 90% in volumetric distributions ($D_{V0.10}$, $D_{V0.25}$, $D_{V0.75}$, $D_{V0.90}$), numerical and volumetric percentage ratios of droplets with 100, 150, 200 and 250 µm in diameter and coefficient of homogeneity ($R= [D_{V0.90}-D_{V0.10}]/D_{V0.50}$) were calculated (Nuyttens *et al*., 2007).

Spot elimination (SE) procedure was not initially conducted on WSP's. Spot analysis was directly done on the papers, the results being defined as "pre-SE". Secondly, the SE procedure on the same WPS's was performed by the operator. Overlapping and non-circular spots were eliminated through judgment of the operator (Figure 3). Spot elimination procedure was carried out through GIMP 2.4 Image Manipulation Software. The remaining spots were then evaluated for their droplet characteristics. In this evaluation, the analyzed spots were defined as "post-SE".

For each of the spots at pre- and post-SE, droplet diameters as well as roundness values were determined. Shape and size features of the spots eliminated by the operator were investigated according to the numerical distribution in the data tables. Eliminated spots by the operator were then compared with the pre-SE. To develop a practical alternative to the conventional approach, different strategies were adopted. These strategies are discussed in the results and discussion section.

RESULTS AND DISCUSSION

A negative linear relationship was found between gray level of WSP images and spray coverage (coefficient of Pearson correlation, r= -0.968; significance level, P<0.0000). Gray level decreased with increase in spray coverage as presented in Figure 4. To determine spray coverage in WSP sample, mean gray level of image can be taken as a reference. Sánchez-Hermosilla and Medina (2004) have stated that the relationship between the threshold and mean gray levels of WSP image is statistically significant.



Original WSP image | Before spot elimination | After spot elimination

Figure 3. Spot elimination process on WSP sample.

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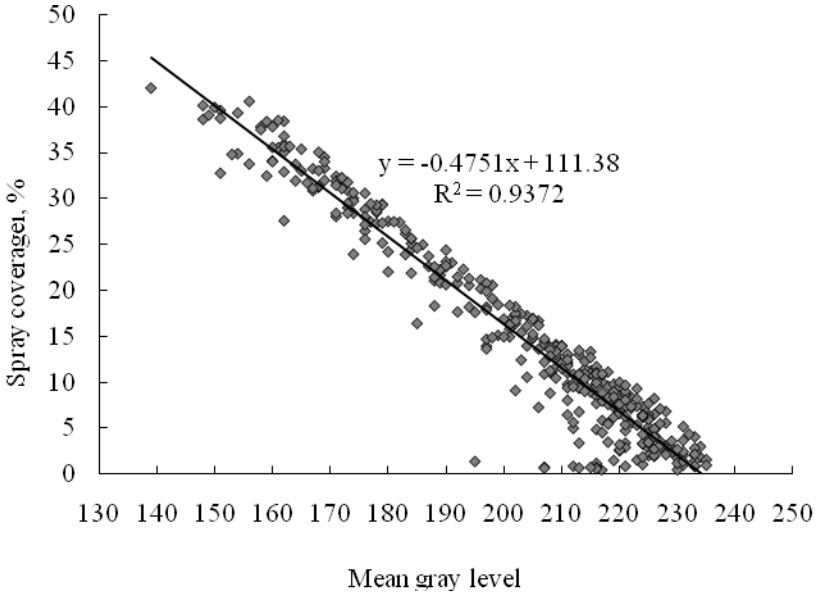

Figure 4. Relationship between spray coverage and mean gray level of WSP images (n= 372).

Spot density and spray coverage measured on WSP samples at pre- and post-SE are given in Table 3. Due to the droplets of bigger diameter, spot density within the target surface was lower than that outside of the target surface. However, spray coverage within the target surface was greater than that outside the target surface. Spot density at post-SE decreased at levels of 16.3% and 8.5% within and outside the target surfaces, respectively. Spray coverage at post-SE was also decreased at the levels of 66.2% and 28.6% within and outside the target surfaces, respectively. Because of the contrast between the stained and unstained area on WSP surface is not strong in situations of high spray coverage (Panneton, 2002; Fox *et al*., 2003), all of the overlapping spots on secondary image obtained after threshold were eliminated by the operator. Additionally, the non-circular spots were eliminated as according to the subjective estimation of the operator. These situations decreased the spray coverage and spot density calculated from post-SE.

Numerical distribution (%) of the spot number *vs.* roundness class range is shown in Figure 5. Spots eliminated by the operator were mostly in the range of 0.0-0.8, so that the numerical distribution ratio of these spots decreased as compared with post-SE. The numerical distribution (%) of the spots in the range of 0.8-1.2 was higher than that in the other roundness class ranges. Spots in this class range were in circular form. Although no spots were detected in 2.4-6.0 class range, the spots in the range of 6.0-6.4 consisted of 5.25% and 10.62% of the total

Table 3. Spot density and spray coverage at pre- and post-SE on WSP samples (Mean±SD).

	Droplet samples transferred to target surface		Droplet samples transferred to outside of target surface	
	Spot density [a] (number cm^{-2})	Spray coverage [b] (%)	Spot density (number cm^{-2})	Spray coverage (%)
Pre-SE	104±52	21.6±10.2	283±166	6.3±4.7
Post-SE	87±46	7.3±1.9	259±145	4.5±2.7

[a] Ratio of total spot number to sampling area.
[b] Ratio of black pixel coverage spots in secondary image to WSP surface.

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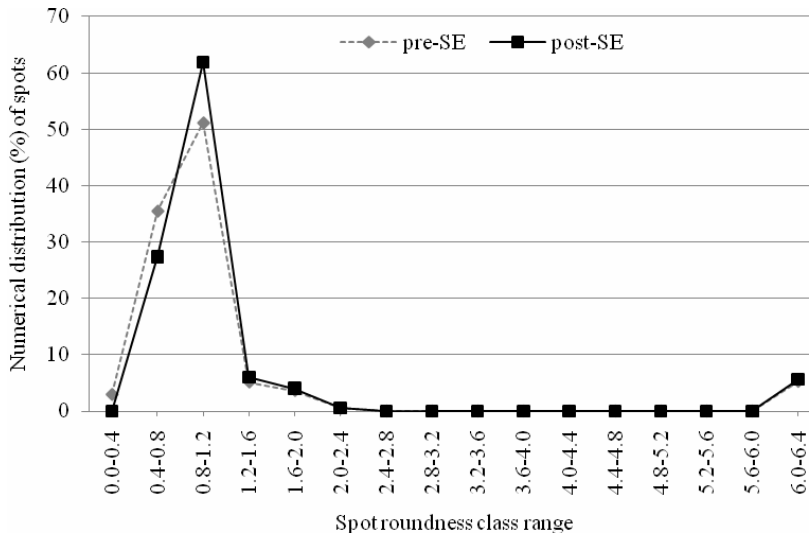
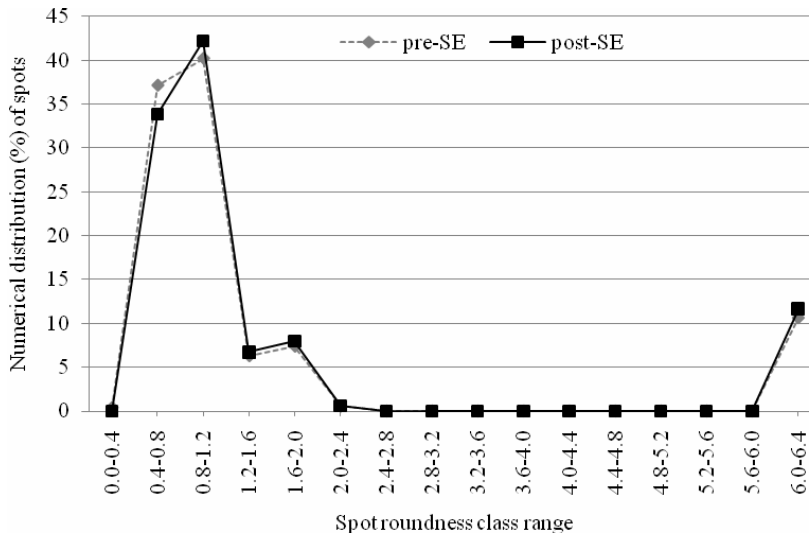


(a)



(b)

Figure 5. Numerical distribution (%) of spots analyzed at pre-SE and post-SE according to SR class range (a) Droplet samples transferred to target surface, (b) Droplet samples transferred to outside of the target surface.

spot number, within and outside the target surfaces, respectively. All spots falling within 6.283 in the range of 6.0-6.4 were quite larger than 1 which is acceptable as ideal.

Numerical distribution ratio (%) of the spot number according to the droplet diameter class range is given in Table 4. In the conventional spot elimination approach, roundness values of spots eliminated by the operator were observed to be in the range of 0.051-0.715 and 0.177-0.850 intervals, within vs. outside of target surface, respectively. Diameters of the droplets falling within these intervals were greater than 900 and 400 µm within and outside of the target surfaces, respectively. Most of these spots which were overlapped and non-circular could have been eliminated by the operator. The numerical distribution ratio

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Table 4. Numerical distribution (%) of droplets analyzed at pre- and post-SE according to droplet size class range.

Droplet size class range (µm)	Droplets transferred to target surface			
	Pre-SE		Post-SE	
	%[a]	SR range[b]	%	SR range
50 <	15.2±5.9	0.785-6.283	17.5±6.3	0.785-6.283
50-100	22.2±7.6	0.312-2.156	25.8±7.7	0.312-2.156
100-150	17.7±1.2	0.196-1.480	20.6±1.9	0.143-1.480
150-200	14.5±5.5	0.229-1.246	16.3±7.6	0.130-1.246
200-300	17.0±6.3	0.192-1.146	14.8±5.8	0.349-1.833
300-400	6.9±2.1	0.146-1.047	3.4±2.1	0.383-1.047
400-500	3.0±1.3	0.107-0.997	0.8±0.9	0.374-0.997
500-600	1.5±1.0	0.130-0.956	0.2±0.3	0.579-0.956
600-700	0.8±0.6	0.086-0.928	0.0±0.0	0.606-0.928
700-800	0.5±0.4	0.087-0.858	0.0±0.0	0.675-0.858
800-900	0.3±0.3	0.059-0.903	0.0±0.0	0.773-0.903
900-1000	0.2±0.2	0.102-0.667	0.0±0.0	0.000-0.000
> 1000	0.3±0.4	0.051-0.715	0.0±0.0	0.000-0.000
Droplet size class range (µm)	Droplets transferred to outside of target surface			
	Pre-SE		Post-SE	
	%	SR range	%	SR range
50 <	25.8±6.1	0.785-6.283	27.9±5.8	0.785-6.283
50-100	51.2±6.3	0.288-2.156	54.4±5.5	0.412-2.156
100-150	17.4±6.5	0.162-1.480	15.2±6.6	0.378-1.480
150-200	4.2±3.6	0.237-1.246	2.2±3.2	0.340-1.246
200-300	1.2±1.8	0.075-1.146	0.4±0.9	0.517-1.146
300-400	0.1±0.3	0.153-1.018	0.0±0.0	0.732-1.018
400-500	0.0±0.0	0.177-0.850	0.0±0.0	0.000-0.000
500-600	0.0±0.0	0.166-0.461	0.0±0.0	0.000-0.000
> 600	0.0±0.0	0.358-0.358	0.0±0.0	0.000-0.000

[a] Numerical distribution of droplet size in class range. [b] Minimum and maximum spot roundness values.

(%) of droplets within diameters greater than 200 and 100 µm decreased as compared to pre-SE, within and outside of target surfaces, respectively. Shape features of these spots showed variability because of the spot size spectrum within target surface being wider than that outside of target surface. This state enhanced the process of elimination made by the operator. The operator has also eliminated droplets with diameters less than 200 µm, as observed from the spot size spectrum outside of target surface being narrower than within the target surface. Minimum roundness values increased at post-SE stage whereas maximum roundness values did not change. This means that non-circular shape spots could have been eliminated by the operator. Because of the shape features of droplets (with diameters of less than 50 µm) on WSP surface not being observed, these spots could not be eliminated by the operator. The roundness values of these spots ranged from 0.785 to 6.283.

In order to develop a practical alternative to the conventional approach for spot elimination procedure on WSP surfaces, some assumptions were made. According to these assumptions, the spots falling within 6.283 roundness values were completely eliminated because of their shape features not being circular. The maximum roundness value of the remaining spots after elimination by the operator was at the rate of

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2.356. The increasing of minimum roundness value of spots at post-SE as compared to pre-SE showed that an improved method can be devised for the spot elimination procedure.

To determine the most favorable minimum spot roundness value for each of the spray nozzles, standard series were selected (0.60-0.65-0.70-0.75-0.80-0.85-0.90-0.95-1.00). Spots below minimum spot roundness values in each of the standard series were eliminated at pre-SE for each of the spray nozzles. Maximum spot roundness value was also taken as 2.356. Volume median diameter of each spray nozzle was found out for each of the standard series following elimination. Thus, linear regression equations were found between the standard series of roundness values and the volume median diameters calculated for each of the spray nozzles (Table 5).

Volume median diameter determined from post-SE, for each spray nozzle, was inserted into regression equation and the most favorable minimum spot roundness value was determined for each of the spray nozzles. Mean, minimum and maximum spot roundness values for each spray nozzle are given in Table 6. Mean spot roundness value was found close to 1, which is accepted as ideal, following spots below minimum spot roundness values being eliminated. Spot roundness interval ranged from 0.765 to 2.356 in either of the trials. In this method, samples analyzed were defined as "spot samples analyzed in SR variation Interval (SRI)". Minimum spot roundness value for each spray nozzle was ranged from 0.743 to 0.785 in either trial. Mean spot roundness value was also ranged from 0.959 to 1.031 within the target surface and ranged from 1.023 to 1.057 outside of it.

Spot roundness values at pre-SE, post-SE, and SRI are given in Table 7. It is expected that mean roundness value would decrease with post-SE. But, because of shape features of droplets of small diameter (less than 50 µm) on WSP, they could not be observed by the operator. These spots were not eliminated and mean spot roundness values of the spots at post-SE increased as compared to pre-SE. Hence, the roundness values of spot samples with small diameters and outside the target surface were greater than those within, at post-SE.

The number of the spots and the ratio of eliminated spots at post-SE as well as SRI are given in Table 8. The ratio of eliminated spots at post-SE was at the levels of 16.5% and 7.8%, within and outside target surfaces, respectively. Spots analyzed in the range of spot roundness interval, the ratio of eliminated spots was at the levels of 27.5 and 23.2%, within and outside of the target surfaces, respectively. Based upon these results, the shape features of spots of small diameters on WSP surface could not be observed. Because of the spot shape spectrum, within the target surface, being wider than that outside the target surface, the decision of operator on spot selection may have been affected in a negative way.

Regression analysis also showed that optimal spot roundness variation interval stood between 0.765 and 2.356. When spots remaining outside this variation interval were eliminated, $D_{V0.10}$, $D_{V0.50}$ and $D_{V0.90}$ diameters as well as coefficients of homogeneity calculated for each of the spray nozzles were found compatible with those at post-SE (Figure 6).

Differences between post-SE and SRI are described through absolute relative error ratio (Table 9). Absolute relative error ratio in $D_{V0.90}$ diameter between post-SE and SRI was found to be higher than in diameters of $D_{V0.10}$, $D_{V0.25}$, $D_{V0.50}$ and $D_{V0.75}$. The highest absolute relative error ratio (%) in numerical *vs.* volumetric distributions, in droplets with diameters less than 100 µm was found to be 7.2 and 5.4%, respectively. Although shape features of overlapping droplets of big diameters could be easily observed, they could not be distinguished due to the spot density and this making the selection process more complicated. Relative error ratio (percent) of droplet diameters corresponding to 10, 50 and 90% of volumetric distribution were found to be at 2.8, 1.8, and 3.8% respectively. In both post-SE and SRI, the

[DOR: 20.1001.1.16807073.2012.14.2.11.3]

Table 5. Regression equations established between minimum spot roundness series and volume median diameter.

Spray nozzles	Regression equation[a]	Coefficient of regression
FF	y = - 0.0053 x + 1.9867	R^2 = 0.984
DC	y = - 0.0052 x + 1.8988	R^2 = 0.996
AI	y = - 0.0019 x + 1.3448	R^2 = 0.996
AD	y = - 0.0024 x + 1.4933	R^2 = 0.980
AVI	y = - 0.0024 x + 1.5388	R^2 = 0.994
CDA	y = - 0.0074 x + 2.3308	R^2 = 0.997
PA	y = - 0.0105 x + 3.0370	R^2 = 0.990

[a] *y*= Minimum spot roundness, *x*= Volume median diameter ($D_{V0.50}$).

Table 6. Minimum spot roundness values calculated from regression equations, mean and maximum spot roundness values after spot elimination.

Spray nozzles	Droplet samples transferred to target surface			Droplet samples transferred to outside of target surface		
	mean SR	min SR	max SR	mean SR	min SR	max SR
FF	1.008	0.743	2.356	1.023	0.743	2.356
DC	1.007	0.775	2.356	1.052	0.775	2.356
AI	1.004	0.754	2.356	1.031	0.754	2.356
AD	1.031	0.785	2.356	1.057	0.785	2.356
AVI	1.020	0.772	2.356	1.043	0.772	2.356
CDA	0.959	0.784	2.356	1.047	0.784	2.356
PA	1.019	0.743	2.356	1.032	0.743	2.356
Mean	1.007	0.765	2.356	1.041	0.765	2.356

Table 7. Spot roundness values at pre-SE, post-SE, and SRI (Mean±SD).

	Droplet samples transferred to target surface	Droplet samples transferred to outside of target surface
Pre-SE	1.180±0.154	1.530±0.156
Post-SE	1.286±0.148	1.600±0.138
SRI[a]	1.007±0.023	1.041±0.012

[a] Spot samples analyzed in SR variation interval.

Table 8. The number of spots and the ratio of eliminated spots at post-SE and spot roundness interval range.

	Droplet samples transferred to target surface		Droplet samples transferred to outside of the target surface		
	Total	%[b]	Total	%	Total
Pre-SE	198371		363365		561736
Post-SE	166097	16.5±3.7	333304	7.8±3.1	499401
SRI[a]	143082	27.5±7.2	278974	23.2±3.6	422056

[a] Spot samples analyzed in SR variation interval. [b] Spot elimination ratio.

absolute relative error increased with increment in the numerical distribution of droplets (with small diameters of less than 100 µm) in droplet spectrum.

It can be concluded that mean minimum SR value to determine droplet diameter and droplet spectrum in WSP samples was 0.765±0.018 (Mean±SD). Confidence interval at 95% of significance level was

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Table 9. Mean absolute relative error±standard deviation and Confidence Interval (CI) in 95% significance level of droplet characteristics between post-SE and optimal SR variation interval.

Droplet characteristics	Droplet samples transferred to target surface		Droplet samples transferred to outside of target surface		Droplet samples	
	Mean ± SD	CI, 95%	Mean±SD	CI, 95%	Mean±SD	CI, 95%
D_{10}	3.5±1.7	1.2	5.1±1.4	0.9	4.3±1.7	1.2
D_{20}	2.8±1.6	1.1	4.8±1.1	0.7	3.8±1.7	1.2
D_{30}	2.2±1.5	1.1	4.6±0.9	0.6	3.4±1.7	1.2
D_{32}	1.5±1.2	0.8	4.1±0.7	0.5	2.8±1.7	1.1
V_{100}	7.8±7.0	4.9	6.6±4.3	3.0	7.2±5.6	3.9
V_{150}	4.2±3.5	2.4	3.6±1.9	1.3	3.9±2.7	1.9
V_{200}	2.6±2.6	1.8	1.0±1.4	1.0	1.8±2.2	1.5
V_{250}	3.0±2.0	1.4	0.6±1.1	0.8	1.8±2.0	1.4
N_{100}	7.4±5.1	3.5	3.5±1.9	1.3	5.4±4.2	2.9
N_{150}	4.1±3.3	2.3	1.2±0.8	0.6	2.6±2.8	1.9
N_{200}	2.0±1.7	1.2	0.3±0.5	0.3	1.1±1.5	1.0
N_{250}	1.1±1.0	0.7	0.1±0.1	0.1	0.6±0.9	0.6
$D_{V0.10}$	1.3±1.3	0.9	4.3±1.7	1.1	2.8±2.1	1.4
$D_{V0.25}$	1.1±0.8	0.6	2.7±1.6	1.1	1.9±1.5	1.0
$D_{V0.50}$	0.9±0.9	0.6	2.7±1.1	0.8	1.8±1.3	0.9
$D_{V0.75}$	1.8±1.5	1.0	3.4±0.8	0.6	2.6±1.4	1.0
$D_{V0.90}$	3.1±2.5	1.8	4.5±1.4	1.0	3.8±2.1	1.5

Table 10. Optimal SR variation interval and confidence interval (CI) in 95% significance level.

Spot roundness	Droplet samples transferred to target surface		Droplet samples transferred to outside of target surface		Droplet samples	
	Mean±SD	CI, 95%	Mean±SD	CI, 95%	Mean±SD	CI, 95%
Minimum	0.765±0.018	0.013	0.765±0.018	0.013	0.765±0.018	0.012
Mean	1.007±0.023	0.016	1.041±0.012	0.009	1.024±0.025	0.017
Maximum	2.356±0.000	-	2.356±0.000		2.356±0.000	-

determined to br ±0.012. Maximum SR value was found to be constant at 2.356 for all the treatments (Table 10).

CONCLUSIONS

It was shown in the current study that the roundness values of spots can be employed for an elimination procedure of overlapped as well as non-circular spots on WSP surface. The optimal spot roundness variation interval was found in the range of 0.765-2.356 throughout the study. When the spots were analyzed within the range of the spot roundness interval, the droplet characteristic values were found to be compatible with the values determined from spot elimination procedure adopted by the operator. This method does not only standardize the spot elimination process, but also ensures that the elimination procedure could be carried out practically as well as rapidly. Thus, the differences between and among miscellaneous spray applications could be clearly scrutinized because of there being no subjective estimation approach involved in spot selection in WSP test samples. Further studies are needed to be conducted to compare the differences

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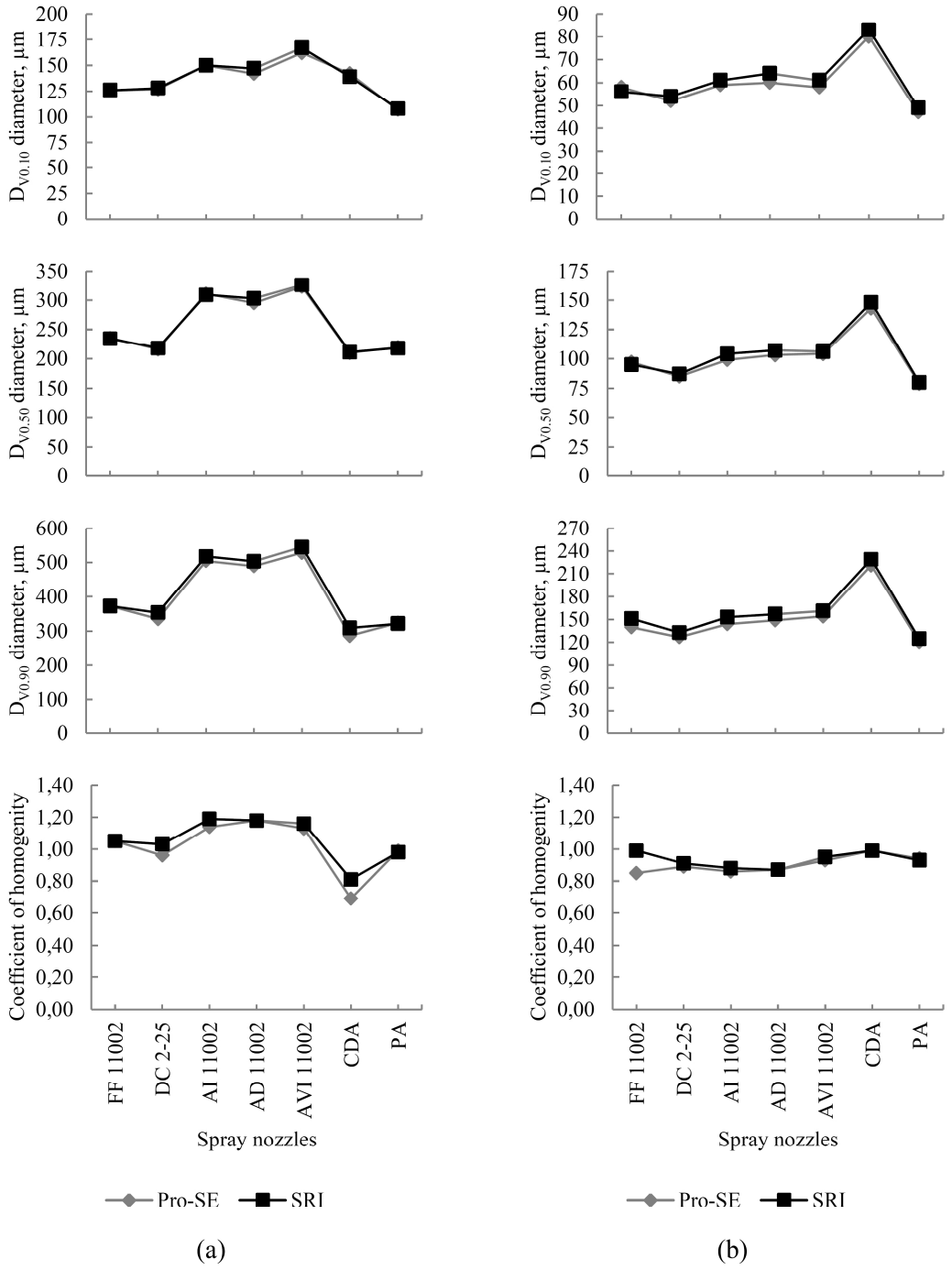

Figure 6. Volume droplet diameters and coefficient of homogeneity estimated at post-SE, and SRI. (a) Droplet samples transferred to target surface, (b) Droplet samples transferred to outside of the target surface.

[DOR: 20.1001.1.16807073.2012.14.2.11.3]

between droplet characteristics concluded from the instrument (through laser light beam) and the spots eliminated as based on the optimal spot roundness interval range on WSP surfaces.

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[DOR: 20.1001.1.16807073.2012.14.2.11.3]

تعیین بازهٔ تغییرات مربوط به گردی مطلوب لکه برای تجزیه و تحلیل اندازهٔ قطرات (خروجی از افشانک) با استفاده از کاغذ "حساس در مقابل آب" (WSP)

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چکیده

برای تعیین خصوصیات قطرات خروجی از افشانک سمپاش، لکه‌های غیر دایره‌ای شکل و لکه‌های همپوشانی پیدا کرده را از سطح "کاغذ حساس در مقابل آب" حذف می‌کنیم. اینکار در روش رایج با بهره‌گرفتن از ارزیابی نظری اپراتور انجام می‌شود. هدف از این تحقیق این بود که روشی عملی (برای جایگزینی روش "رایج") برای حذف لکه‌ها از سطح کاغذ (حساس در مقابل آب) ابداع گردد. نمونهٔ قطرات با بهره‌گیری از هفت افشانک متفاوت سمپاش انتخاب شدند. کاغذهای حساس در درون و همچنین در حاشیهٔ محدودهٔ سمپاشی قرار داده شدند و پس از جمع‌آوری، قطرات با حساسیت ۶۰۰ dpi مکان‌یابی شدند. با بهره‌گیری از پردازش تصویر (Image processing) قطر و گردی هر لکهٔ موجود روی هر کدام از قطعات کاغذ حساس به آب مشخص گردید. لکه‌های متداخل و غیر گرد توسط اپراتور حذف شدندف گردی لکه‌ها قبل و بعد از حذف (لکه‌های متداخل و غیر گرد) به ترتیب در محدودهٔ ۶/۲۸۳-۰/۰۵۱ و ۶/۲۸۳-۰/۱۳۰ قرار گرفت. نتایج حاکی از وجود رابطه‌ای خطی بین اندازه کمینهٔ گردی لکه و متوسط قطر لکه‌ها بود. نتیجهٔ تجزیه و تحلیل رگرسیون بازهٔ تغییرات گردی لکهٔ بهینه را (بعد از حذف لکه (SE)) بین ۰/۷۶۵ و ۲/۳۵۶ نشان داد. خصوصیات لکه‌های باقیمانده (خارج از این بازهٔ تغییرات) با خصوصیات لکه‌های حذفی به روش رایج مطابقت داشت. مقایسه اقطار حجمی (استفاده از روش حذف رایج) با محدودهٔ تغییرات، گردی بهینهٔ لکه‌ها (نسبت‌های ۱۰ و ۵۰ و ۹۰ درصد)، بازهٔ خطای نسبی مطلق و بازهٔ اطمینان (Confidence interval) در سطح احتمال ۹۵ درصد به ترتیب ۱/۴ ± ۲/۸٪ ، ۰/۹ ± ۱/۸ و ۱/۵ ±۳/۸٪ برآورد گردیدند.

[DOR: 20.1001.1.16807073.2012.14.2.11.3]