VISUAL AND IMAGE SYSTEM MEASUREMENT OF SPRAY DEPOSITS USING WATER–SENSITIVE PAPER

R. D. Fox, R. C. Derksen, J. A. Cooper, C. R. Krause, H. E. Ozkan

ABSTRACT. *Water–sensitive papers (WSP) were attached to leaves in nursery trees and sprayed with air–blast sprayers. Deposit patterns on the WSP were rated visually for coverage, from 0 (no spots) to 10 (completely blue). Visual counts of spot density (spots/cm^2) were made for cards representing coverage ratings from 1 to 6. WSPs were analyzed with an imaging system; several spot size parameters, number of spots, and area coverage percentage were measured. Visual ratings of 6, 7, and 8 had considerable variability in area coverage percentage. Sample WSPs with visual coverage ratings of 3, 5, 6, and 8 and minimum, median, and maximum coverage percentages are presented. Visually measured spot density was greater than image–system measured spot density for all rating numbers, especially for higher spot densities. Spot density began to decrease at visual rating numbers greater than 7.*

Keywords. *Water sensitive paper, Spot size, Image analysis, Spray coverage.*

Water–sensitive paper (WSP) is an important and useful tool for providing quick evaluation of spray coverage. Several methods have been used to analyze spot patterns on WSP to obtain consistent spray coverage data. Mierzejewski et al. (1988) developed an automated system for characterizing aerial spray deposits using collector cards. Bateman (1993) provided a review of methods of evaluating spray coverage. He also described a scoring system use with spot coverage targets. The system was mainly designed for treatments with fairly uniform spot sizes, but the target score was related to spot density and spot size. Franz (1993) used a hand–held scanner to capture spots on WSP and Kromekote cards. He found differences when several subjects made the measurements. There was a difference in spot size measurements depending on whether small or large spots were used to calibrate the gray–level set point. Count was not affected as much by gray–level set point.

Miller et al. (1992) compared spray deposits on flat card and spherical collectors and discussed several factors that limit measurements of spray distribution by means of spot deposits on collectors. Dark background caused by high humidity affected spot measurements. Wolf and Downer (1995) and Fox et al. (1998) also reviewed several methods for evaluating spray deposits. Manor and Tabak (1999) stapled WSP to cotton plant leaves treated with several different types of sprayers. They used a computerized vision system to measure the size distribution, area mean diameter, number of spots per unit area, area covered by spots, and area covered by enlarged images of the spots at different radial–distances from the individual spots. Panneton (2002) developed a camera/lighting system to measure the percentage of area covered by spots on WSP. He presented a method for calculating a uniform threshold setting for all sample WSPs that minimized the maximum absolute error from an optimum threshold setting for sample WSPs from sparse to dense droplet coverage. He found that the uniform threshold setting was close to the optimum threshold for the WSP with the densest coverage of spots.

The objective of this study was to compare three methods of evaluating spot distributions on water–sensitive paper to determine the utility of each method. The methods were: visual rating, visual counting of spot density, and imaging system measurement of spot characteristics.

MATERIALS AND METHODS

The WSP targets (Spraying Systems Co., Wheaton, Ill.) used in this study were collected as part of a sprayer evaluation study of spraying three rows of young trees in a commercial nursery. See Derksen et al. (1998) for details of sprayers and treatments. All WSPs were placed in the second and third rows upwind of the sprayed row, to reduce the density of spray coverage. There were 190 WSPs available. Three separate methods were used to evaluate the spot coverage. First, the cards were sorted by perceived coverage (visually rated) from worst to best and assigned to 11 classes, from 0 (no spots) to 10 (completely blue). About the same number of samples were assigned to each class (except classes 0 and 10).

Five representative samples were selected from each class from 1 to 6 and spot density (spots per cm^2) were counted by hand. For sparse populations, spots were counted in a 1–cm^2 area that was typical of the spot density on the card. Due to the increase in spot density on cards rated 5 and 6, only a

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0.25– × 0.25–cm area was used. Coverage classes greater than 6 had too many spots to count by eye.

An image analysis system (Fox et al., 1992) was used to capture spots in a 16.22– × 15.41–mm region for a fixed position on each WSP target. The gray–level threshold was set so that the binary image of several spots about 200 µm in diameter were nearly the same size as the gray image of the same spots. The area of each spot larger than 3 × 3 pixels (about 90–µm diameter) was measured and recorded. This size threshold was chosen to eliminate tiny dots that may have resulted from system noise. Next, the percentage of the image area covered with spots, number of spots per target, number, area and volume mean diameters, number and volume median diameters were calculated for each target.

Results

Visual Classification of WSP Spot Patterns

Three examples from each visual rating of 3, 5, 6, and 8 of the visual coverage classes defined for this study are shown in figure 1. Examples shown are the low, median, and high

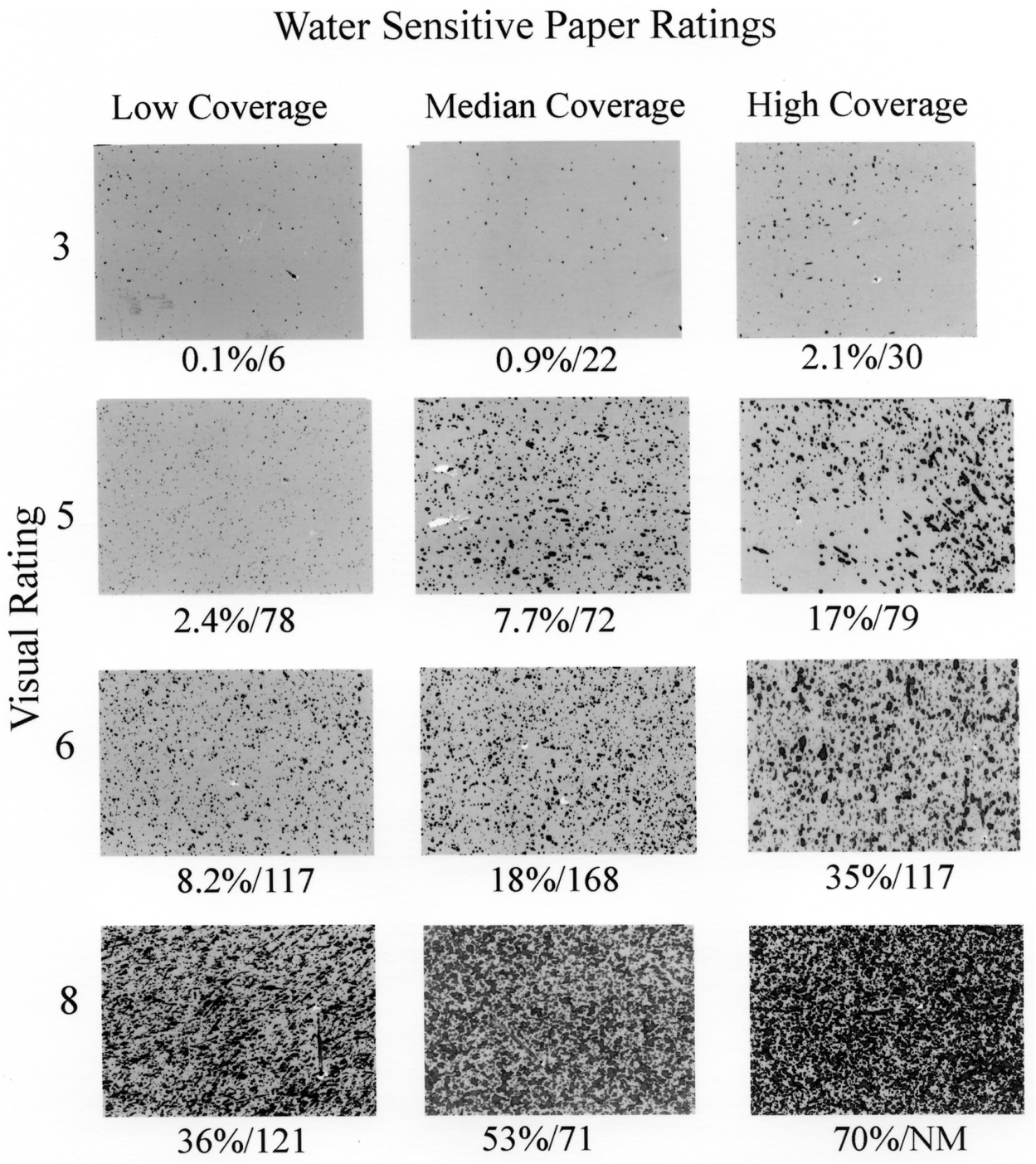

Figure 1. Examples of WSPs with visual coverage ratings of 3, 5, 6, and 8. Percent–area covered with spots and number of spots/cm^2, measured with image analysis, are shown for each example (NM means spot density was too great to be measured by image analysis). WSPs with coverage greater than 20% gave unreliable spot size data measured with image analysis.

area–coverage percentages as measured by the imaging system. These examples will be helpful for others using WSP to select similar coverage ratings for their sprayed samples. Spray applications were made with air–blast sprayers that typically produce smaller droplets than boom sprayer applications. Also WSP collectors were placed in the second and third row upwind from the sprayed row of trees. Thus spray droplets that reached these collectors are probably the smallest fraction of the total size distribution produced by the sprayer.

Comparing Coverage Rating with Percent Coverage from Image Analysis

WSP targets given coverage scores between 5 and 9 by an observer were found to have a wide range of image–measured percent–area covered. The comparisons for all cards in the study are shown in figure 2. The imaging system software could not measure coverage for a few targets with ratings of 9 or 10 because of the complexity of the spot pattern. These samples were not included in the data shown. Any spot size measurements made on WSP with coverage greater than about 20% were not reliable due to the number of spots that were touching or overlapping. Targets given a visual rating of 6 had coverage from about 8 to 35%. It seems that visual rating gave good scores to spray coverage if spots were uniform, with little space between spots. Small spots can achieve this effect with much less of the area covered than can large spots.

Thériault et al. (2001) made a similar comparison of spray deposits on WSP. Their regression is plotted on figure 2 for reference. Spot coverage on the in–canopy, WSP collectors of Thériault et al. (2001) was less than on some of our targets. Therefore their regression was off–set somewhat from our data; however their variation in visual ratings compared to percent area covered measured by image analysis was similar to the variation measured in this study.

Comparison of Visual Rating with Spot Density Measured by Image Analysis

A plot comparing image system spot density with visual rating of spray coverage on the WSPs is presented in figure 4. The fourth order equation comparing the treatments and presented in figure 4 had a correlation coefficient of 0.879.

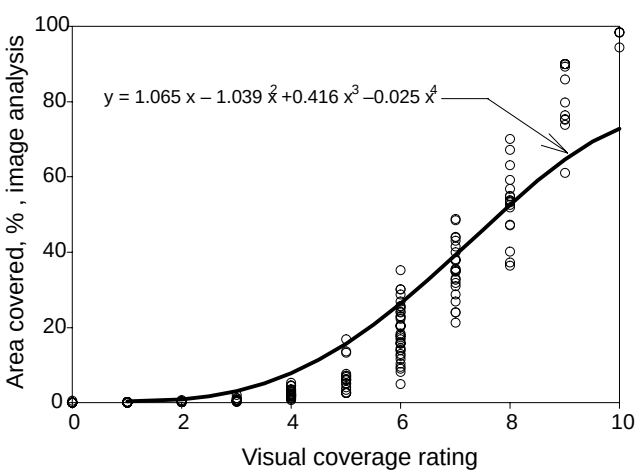

Figure 2. Visual coverage rating as a function of percent of WSP covered with spots, as measured by image analysis. Regression line adapted from Thériault et al. (2001).

Comparison of Number of Spots Measured Visually with Image Analysis

In figure 3, the number of spots on WSPs measured visually is compared with the number of spots measured on the same targets with the imaging system. As spot density increases, spot numbers measured visually becomes nearly twice as great as spot numbers measured by the imaging system. This difference in spot number counts may be due to several factors. First, the image system gray–level threshold was set to give fairly accurate size measurement for larger spots. Such a threshold level often means that some smaller spots were not counted by the imaging system. Second, this image system counted spots that touch as one spot (algorithms are available on some systems to separate some spot overlap). An observer can see that spots are touching and can count them as individual spots. As droplet density becomes greater, more spots touch and this difference becomes greater.

Spot density increases with increasing coverage rating up to a rating of 6 or 7. For coverage ratings of 8, spot density decreases sharply. This is likely due to an increase in overlapping spots at greater spot densities.

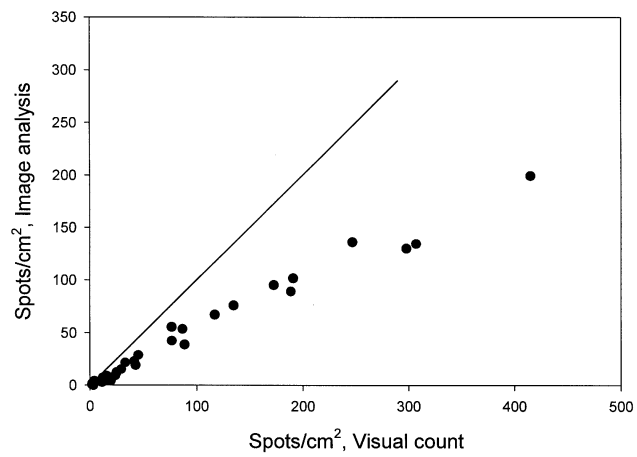

Figure 3. Comparison of number of spots/cm^2 as measured visually and with image analysis; spots were counted on 5 WSP samples for visual coverage ratings from 1 to 6.

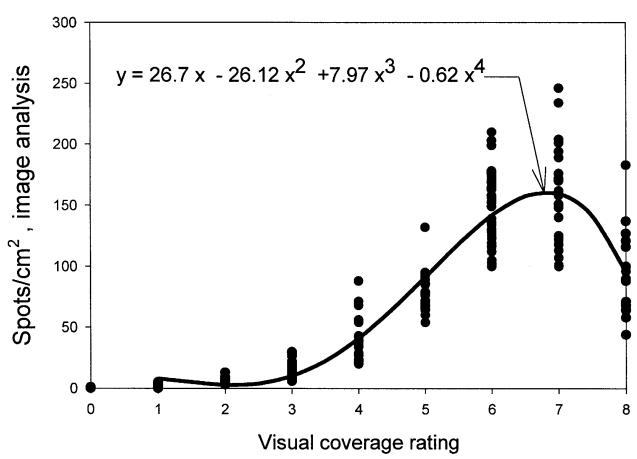

Figure 4. Spot density as measured by image analysis as a function of visual WSP spot coverage rating. Regression line had a correlation coefficient of 0.879.

Discussion and Conclusions

We have presented results of a method of visually rating spray coverage on WSP. These visual ratings have been compared to image analysis measurements of the same WSP targets. A major consideration with spray coverage measurements is not how to rate the sample collectors, but variation among replications for almost all spray applications. We can define what is considered 'satisfactory coverage' on WSP collectors. However, if several replications are made with collectors in the same location (stapled to the same leaf), there are often differences of four or five classes among visual ratings for the replicate applications.

In this study we have found that imaging systems are not effective in accurately measuring spot density when coverage is greater than about 40%. Even for coverage from 20 to 40%, imaging systems underestimate the number of spots on WSP targets compared to those counted by an observer. However, image analysis systems do give fairly consistent measurements of coverage and drop size information, within the limits of consistent target background and spot population density. Observers rated some target coverage as 'good' for area coverage as low as 2%. These unexpected ratings usually occurred when spray droplet sizes were about 100 µm or less, with uniform coverage of spots over the WSP target.

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