W1358

Using Water Sensitive Paper to Assess and Refine Pesticide Applications: A Guide for Producers, Extension Professionals and Researchers

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Water sensitive paper (WSP) is a tool that can help growers determine if they are achieving their pesticide application objectives. WSP changes color from yellow to dark blue when it comes into contact with liquid (Fig. 1). The purpose of this publication is to educate growers, researchers and Extension professionals about the handling and use of WSP for the visualization and quantification of spray characteristics and to provide insight into WSP application methods. Ultimately, the goal of this publication is to help nursery and orchard producers and those who advise them to successfully use WSP to refine spray applications so that pest control is achieved with the most efficient pesticide application possible. By reducing overspray, non-target applications and drift, producers can minimize financial losses as well as negative environmental impacts caused by off-target pesticide movement. WSP is placed on crops and in non-crop locations within and outside of blocks prior to spraying.

Figure 1*: WSP cards change color from yellow to blue when contacted by liquid. Cards are secured to branches with clip assemblies.*

Following the spray, WSP is collected and analyzed to assess the spray distribution and to characterize the spray application for the intended coverage as well as drift. WSP is commercially available as 1 × 3-inch (25 × 76-mm) cards, 2 × 3-inch (52 × 76-mm) cards, 1 × 19.7-inch (26 × 500-mm) strips as well as 9.5 × 11.8-inch (240 × 300-mm) sheets (Fig. 2). WSP is sensitive to high moisture, so avoid using it when relative humidity is more than 80 percent or under foggy conditions.

Figure 2*: WSP is available in many shapes and sizes from multiple manufacturers. Each brand has slightly different characteristics. Use WSP from a single manufacturer for consistent results.*

Handling and Storage

To effectively utilize WSP, it is important to handle and store WSP properly. **Always wear moisture-resistant gloves** when handling WSP. Naturally occurring oils from your skin will cause the color reaction and leave smudges and fingerprints, making the WSP unusable. Unopened packages of WSP should be **stored in a dry, climate-controlled environment**. Open packages of WSP should be stored in air-tight resealable plastic freezer bags. To prevent moisture in the air from causing cards to change colors, it is ideal to store several packets of desiccant alongside WSP in each plastic bag.

Placement

Placing WSP on plants in different rows within a block and on different areas of an individual plant can help inform growers if spray applications are reaching all rows and target locations on plants. This insight can be used to make changes to the sprayer or tractor travel speed to more accurately apply pesticides to target areas for more effective control. For example, to treat newly hatched scale insects, applications should be made to trunks and inner branches, including portions that may be partially blocked by branches and leaves. For many foliar pests like potato leafhoppers and aphids, however, applications to the outer canopy are sufficient, as only tender young growth is susceptible.

WSP can also reveal areas where spray droplets move unintentionally. **This off-target pesticide movement leads to non-target applications. Non-target applications** occur when spray droplets land somewhere other than the intended target, i.e. crop plant. This can lead to pesticide contaminating non-target organisms such as natural vegetation, ground cover, beneficial insects and even humans. Non-target applications may occur as spray landing within or beyond the edges of production blocks, or as droplets that **drift**, carried by wind at the time of application to areas outside of the production blocks. Placing WSP on trees in adjacent blocks, on nearby structures or on ground boards within a block can help determine if spray is landing in unintended areas.

Finally, WSP can also help growers tell if they are applying too much pesticide to crops. Pesticide labels often recommend spraying until the spray solution runs off leaves which is commonly referred to as "spraying to runoff." Such gallon per acre rates are often much higher than needed for control of target organisms. Reducing excess application not only decreases an operation's environmental impact but also saves money otherwise spent on pesticides through reduced spray volumes.

The Federal Insecticide, Fungicide and Rodenticide Act

permits applicators to apply pesticides at dosages, concentrations or frequencies less than those on pesticide labels provided the label does not specifically prohibit these deviations.

Growers and researchers may use specialized techniques and products to secure WSP cards in place. **Clip assemblies** can be constructed using stainless steel alligator (electrical) clips attached to lengths of 12- to 14-gauge single conduit wire (Fig. 3A). These assemblies allow growers to attach WSP cards to branches of all sizes in tree canopies for **foliar** applications and adjust the angle of the WSP to be perpendicular to the direction of the spray cloud (Fig. 3B). Clips can hold a pair of cards back-to-back and can be secured to branches on trees in increasingly interior rows within a production block to determine how well spray is penetrating the block when spraying from both sides. Spray applications to trunks can be assessed by making **trunk wraps** from 1 × 19.7-inch (26 x 500-mm) strips of WSP, clear vinyl sticker adhesive and double-sided tape (Mathews et al. 2025) (Fig. 3C). These wraps can be affixed to tree trunks, removed and analyzed without damaging trees. Quantifying trunk applications is important, as some contact insecticides suggest that complete coverage is required to effectively control trunk-boring pests. Cards can be secured to small **boards with binder clips** (affixed on the sprayer-facing side), placed within the block or outside of the block, and secured to the ground to assess the amount of spray that lands on the ground within or outside of production blocks as non-target ground applications (Fig. 3D). **Drift** can be measured by affixing WSP cards to trees in adjacent blocks or by temporarily installing structures with clip assemblies outside of the production block (Fig. 3E). Finally, **ground mats** [Application Detection Aid Mats (ADAM)] consist of sheets of WSP cut to size and glued to discs made of coconut coir (Fig. 3F). These mats can be wrapped around the base of tree trunks to determine the amount of spray that reaches the soil beneath trees. Placing WSP in a variety of places both inside and outside of production blocks can give growers and scientists a detailed understanding of where spray is landing and inform adjustments that increase application efficiency and reduce off-target movement.

A Successful Test Spray

To obtain the best results from using WSP, make applications on sunny, calm days with low humidity. Clean the spray tank and fill it with water in preparation for the spray test. Though liquid pesticide solutions will cause the color reaction, the objective is to use WSP to make corrections prior to filling the spray tank with pesticides to prevent waste and eliminate the need to wear PPE. Even when spraying water from a clean tank, it is advisable to use chemical resistant gloves when making sprayer adjustments to avoid contact with pesticide residues. If water-only applications are not feasible, worker protection standards on the pesticide label must be followed when collecting WSP targets and while handling and analyzing WSP that has been exposed to pesticide.

Figure 3*: Growers and researchers use specialized tools and equipment such as clip assemblies (3A), boards (3D) and drift structures (3E) to distribute water sensitive paper cards (3B), strips (3C) and sheets (3F) throughout production blocks to help determine where their spray is landing.*

Figure 3A. Clip assemblies:	Figure 3B. Foliar:	Figure 3C. Trunk wraps:
Using the wrap pattern shown in the image will secure clip assemblies so that they do not move when sprayed, keeping the card perpendicular to the direction of the spray cloud. Clips left in place overnight should be checked for moisture from dew and affixed to the short edge of cards. Clips should cover as little surface area as possible while still securely holding the card. This area should be consistent across all cards as it can affect coverage calculations. If assemblies are left in place, wires should be loosened periodically to prevent girdling branches as they grow in diameter.	Cards can be secured to branches of trees in increasingly interior rows within a block to determine how well spray is penetrating a block. Cards can also be placed on individual trees on the exterior or interior portion of their canopy, or both. Cards can be placed back-to-back in a clip, a good technique if growers suspect a difference in coverage among trees in multi-row blocks. When hanging cards back-to back, the humidity can be greater where the two are clipped together due to the slight decrease in air circulation and sunlight penetration.	Trunk wraps can be cut to a customizable length to accommodate different caliper sizes. Wraps that are stored flat and those with extra length or that are too short for the trunk caliper tend to unravel quickly after installation, compromising the accuracy of the spray characteristics detected on the wrap. Matching the wrap length to the caliper and storing wraps coiled for at least 2 weeks rather than flat can reduce unravelling (Whaley et al. 2024).

Figure 3D. Boards:	Figure 3E. Drift:	Figure 3F. Ground mats:
A board outfitted with a card can be placed within rows between two trees or at the base of a tree, to assess the amount of spray that is being applied to the nursery floor, i.e., non-target ground applications. Boards can also be placed outside of production blocks to assess off-target movement in areas adjacent to those being sprayed. Affixing the card with a binder clip on the side of the board closest to the sprayer and an electrical clip glued to the opposite side (not shown) will prevent the card from flipping upward when sprayed. Boards may need to be secured to the ground with large pins to prevent them from flipping over when sprayed.	PVC pipe or electrical conduit can be cut to length and secured vertically with rebar to measure aerial drift. Clip assemblies can be installed at multiple heights. Ground boards with cards can be placed at the base of these structures to quantify drift that reaches the ground outside the block.	Application Detection Aid Mats: ADAM can be made from WSP glued to coconut coir discs traditionally used as weed mats. Placing these at the base of trees allows spray operators to quantify the amount of pesticide that runs down tree trunks or lands on the ground at the base of trees.

It is important to consider the nature of WSP when placing cards and wraps in the block before spraying. For example, cards stored in pockets can undergo the color reaction from sweat. Deploying numerous cards is time consuming, so it is necessary to begin securing them with clip assemblies well before spraying unless a team of people are available to help. Additionally, securing clip assemblies to the appropriate branches can be time consuming; therefore, this should be done in advance of a planned spray, especially if many cards are being used. In the southeastern U.S., putting cards out in advance of a spray can cause them to undergo the color reaction due to high humidity. Rotating clip assemblies so that cards temporarily face the sun can prevent this, allowing numerous cards to be placed in the block early. Card positions close to the ground and cards that are clipped in back-to-back pairs are particularly prone to the effects of humidity. Direct sunlight should be used to aid the drying process whenever possible. In humid environments such as Tennessee, cards sprayed heavily late in the day will change colors almost regardless of the precautions taken. WSP in the strip form appears to be more sensitive to ambient humidity than the card form of this product, which makes minimizing the time between installation and spraying even more important when deploying trunk wraps and other artificial targets made from WSP strips.

Collection and storage

After WSP is sprayed, it must be collected, stored and transported for analysis. Alternatively, if a small number of WSP cards or wraps are deployed, growers may find it more practical to visually assess coverage and make adjustments based on their observations. Syngenta, a WSP manufacturer, provides a guide and droplet counting aid to ease this process (Syngenta 2002). Growers count droplets through windows as large as 1 cm^2 on the droplet counting card. While this can be a handy tool for estimating coverage, it is not as accurate as analyzing WSP with imaging software and is not practical for large numbers of cards.

When collecting cards, it is important to wait until the WSP has thoroughly dried as wet cards placed in storage bags may overwhelm desiccant and continue to change colors from high humidity in the bag. Drying can be expedited by rotating cards to face the sun.

As when deploying WSP prior to spraying, it is imperative to wear moisture-proof gloves when collecting WSP as oil from hands will turn WSP blue. Ensure that gloves are dry after touching the ground, especially when collecting low targets as the ground may be wet from morning dew or the spray itself. When collecting high targets, also avoid allowing sweat or spray in the canopy to drip onto lower WSP. Collecting low cards first can help prevent this problem.

When many pieces of WSP must be collected, it is helpful to do so in an organized fashion, such as in the same order and to have pre-labeled envelopes arranged in that order, especially when there are multiple targets on a single tree. Providing a printed key to the labeling scheme can help ensure those collecting place cards in the correct envelope.

Because WSP can continue to change colors in humid environments, caution must be taken to collect and store targets in a timely manner after drying. WSP cards can be stored in the same labeled 2.25 × 3.5-inch (5.72 × 8.89-cm) coin envelopes that they are placed in at collection to streamline recordkeeping, handling and transportation, while WSP wraps can be affixed to pre-labeled sheets of computer paper and stored in 9 × 12-inch (22.86 × 30.48-cm) envelopes or paper lunch bags. In the southeastern U.S., WSP is stored in plastic resealable bags with desiccant packets due to the high humidity. In less humid areas, storing cards in paper bags, such as brown paper lunch bags, can be superior to a sealed plastic bag because the ambient environment can be drier than a sealed bag with desiccant containing a sprayed card.

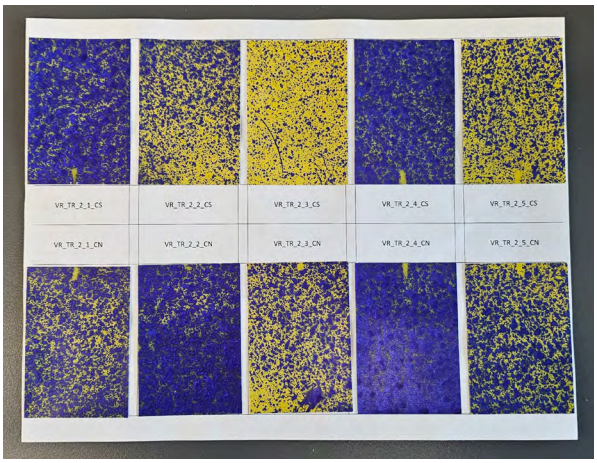

Figure 4*: WSP cards affixed to labelled paper can be scanned to expedite the analysis process. The labels are coded to identify card locations in the block.*

Labeling

Growers will likely conduct fewer sprays with WSP, deploy fewer targets and dispose of cards after making a field assessment, greatly simplifying labeling needs. However, researchers may deploy hundreds of cards on a given date and will analyze them later and over a period of time at another location, then store the cards for years. WSP should be labeled with the date, WSP position, treatment, replication and any other information that is necessary to identify that unique card after spraying. A small number of WSP cards can be labeled on the non-reactive side using a pencil. If coin envelopes are used, they should be prelabeled before collecting cards to avoid labeling cards in the field. Once cards have dried, they can be easily inserted into the appropriate envelope. Envelopes can be handled without a gloved hand and stacked together, simplifying transportation. When collecting back-to-back cards, the orientation of the cards can be related to the seam-side of envelopes so that cards are always collected in the same manner and are assigned the correct label once digitized. For example, when back-to-back cards are facing north and south, they can be collected so that the south-facing card always faces the side of the envelope with the seam. Cards can also be prelabeled by adhering stickers to the non-reactive side. This is only recommended in environments where cards are not prone to being turned by ambient humidity and in other situations that minimize the need to replace cards with freshly labeled ones just prior to a spray because they will need to be re-labeled in the field. Alternatively, stickers can be added to the backs of cards as cards are being collected.

Analysis

Growers using a limited number of cards may conduct a visual assessment by counting droplets in a representative, limited area of the card as described in the collection and storage section above. Alternatively, they can scan them one at a time in their office, home or with a portable business card scanner in the field, then analyze the digitized images. When scanning large quantities of cards, it may be helpful to use a flat-bed scanner to scan multiple cards or wraps at a time (Fig. 4). The resulting images can then be cropped into images of single cards or wraps and analyzed individually.

Coverage: the percentage of the WSP area covered by spray droplets. Percent coverage is useful information when applying contact-insecticides to tree trunks and can help determine if growers are spraying canopies too heavily.

Deposit density: the number of droplets per cm^2 on WSP (1 cm^2 = 0.16 $inch^2$). Deposit density is most useful during applications of herbicides, fungicides, and when spraying contact insecticides for foliar pests. Coalescing spots can lead to misleading results when coverage is high, artificially lowering the deposit density assessment.

Deposition: the total volume of spray present per cm^2 on the WSP. This can be difficult to accurately determine using two dimensions. Deposition is best measured with #60 stainless steel mesh targets (You et al. 2019) and a tracer in the spray solution.

There are a few programs that can be used to analyze WSP including DepositScan (Zhu et al. 2011), which has been used worldwide, having been downloaded more than 5,000 times in 65 countries. DepositScan measures coverage, deposit density and deposition from high resolution (600 DPI) scans of WSP in less than half a minute. Droplet size, deposit density and deposition accuracy can be limited when coverage exceeds 20 percent (Zhu et al. 2011), but relative comparisons can still be made. There are also several smartphone applications like SnapCard and DropLeaf that accurately measure coverage but are not capable of quantifying droplet size, deposit density or deposition (Brandoli et al. 2021; Ferguson et al. 2016).

Growers can use the results to determine what adjustments they need to make to their tractor or sprayer to more effectively treat their crops. For example, if coverage is equal to or greater than 30 percent in canopies, growers may be able to reduce spray rates and volumes by adjusting their travel speed, pressure, closing some nozzles or selecting different discs and cores. Growers may determine that the trunk and ground are needlessly being sprayed when the canopy is the intended target, and, by closing lower nozzles, they can achieve suitable canopy coverage while also reducing the volume sprayed. Reducing pesticide output saves money on pesticide purchases and reduces the operation's environmental impact. Reducing the per acre application volume also reduces the frequency with which the tank must be refilled. Refilling the tank is normally a bottleneck in nursery pesticide applications, so reducing how often this takes place can make pesticide applications more labor-efficient while also conserving water.

Addressing Card 'Greening'

Ambient humidity and excessive moisture on WSP can cause 'greening,' unsprayed yellow areas of WSP turn green (Fig. 5). The green hue appears dark gray when scanned in grayscale, which can lead to inaccurate analysis even when using the threshold tool. Image editing software can be used to remove much of the background green from color scans of the WSP.

Both decreasing the level of green using the RGB channel and fine tuning the levels of exposure, contrast, highlights and shadows can eliminate much of the green hue. Subsequently, converting these edited color images to grayscale results in more contrast between sprayed areas and the WSP background, allowing for more accurate analysis with DepositScan software.

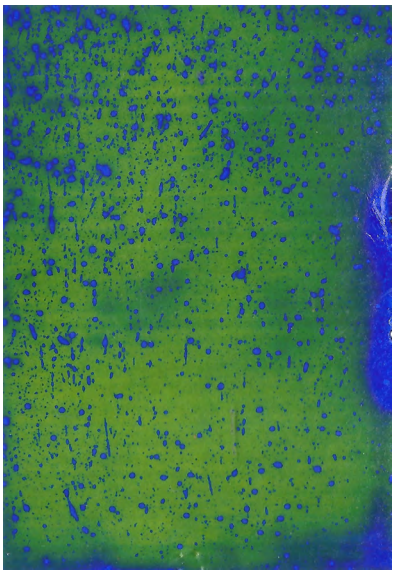

Figure A: *A WSP card with heavy "greening"*

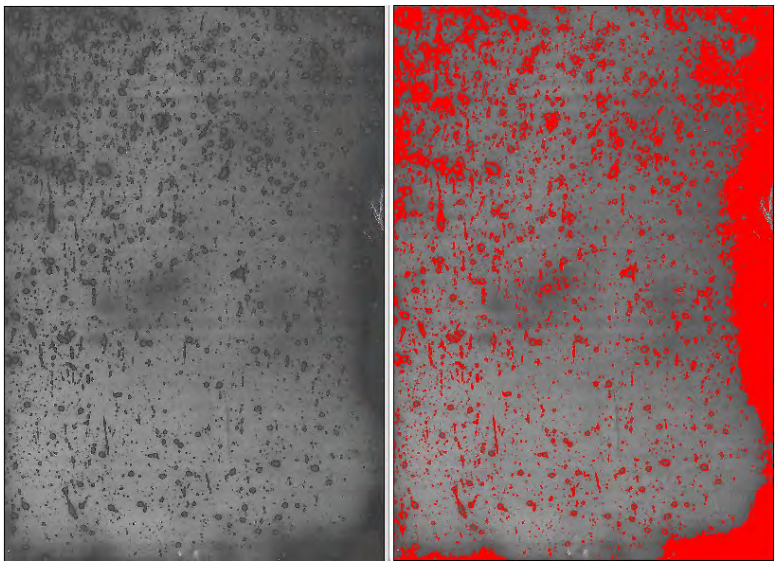

Figure C: *21.80% coverage, 3059 total deposits counted, 81.1 deposits/cm2*

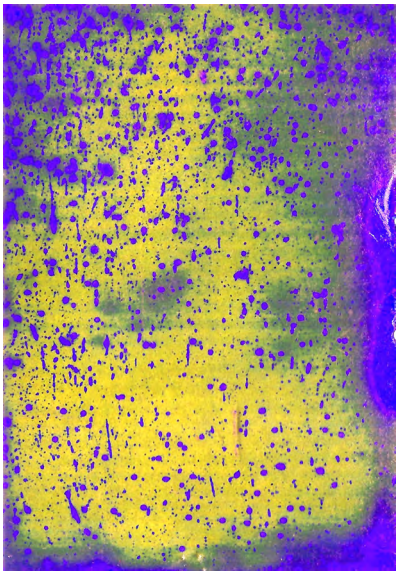

Figure B: *An edited card with reduced levels of green*

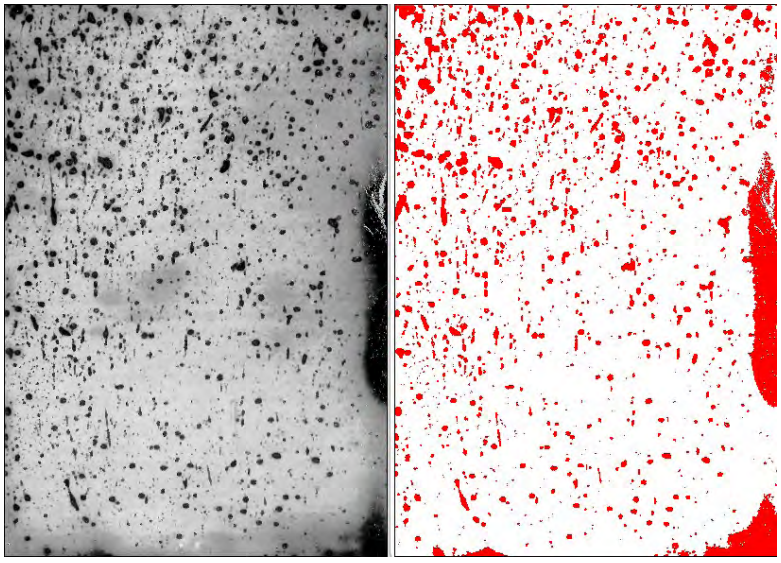

Figure D: *2.90% coverage, 1879 total deposits counted,49.4 deposits/cm²*

Figure 5: *A. WSP card exposed to high humidity exhibits heavy "greening." B. The same WSP card after editing the image to remove the green. C. Coverage and deposit density from cards that were subject to high humidity and turned green. D. The same cards as shown in "C" after using image editing software to reduce background greening.*

Conclusion

WSP is an affordable and accessible tool for scientists undertaking research to investigate spray application characteristics and for growers wishing to "fine-tune" their spray applications. WSP can be easily deployed in locations throughout production blocks or experimental plots and can be used to quantify coverage, deposit density and deposition. Producers and Extension professionals who are advising producers can determine whether their spray is sufficiently penetrating rows of trees, providing adequate coverage on crops or landing in non-target areas both inside and outside of production blocks. This information is important, as reducing pesticide output and losses due to off-target pesticide movement provides both economic and environmental benefits to growers. Growers looking to further reduce pesticide output and increase pesticide application efficiency may choose to utilize an "intelligent" air-blast sprayer equipped with variable-rate technology such as the Smart-Apply™, which senses crop characteristics in real-time and adjusts the spray output accordingly. This "intelligent" sprayer emits spray only when plants are detected and can reduce output between 30 percent and 80 percent depending on production system, crop structure and targeted pests while also reducing losses into the air and onto the ground (Chen et al. 2020; Nackley et al. 2021). More information about variable-rate technology is available in the resources section.

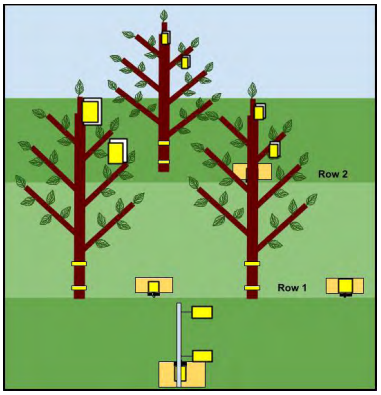

Figure 6*: WSP, indicated by yellow rectangles, can be placed in tree canopies and on trunks throughout a block to determine how well spray is penetrating a block or covering the intended location of a crop plant. It can also be affixed to structures or placed on the ground outside of blocks to assess off-target movement and drift.*

Quick Reference: Five steps to spray analysis

Set a Goal

Determine the target pest and key crops to be treated. Identify key crop locations on which to assess the spray application. For example, when applying dormant oil for many scale pests, the trunk is the target. When spraying foliage for insects and diseases, the most recent canopy growth is typically the target.

Distribute

Just prior to spraying, place WSP at pre-determined locations throughout the production block (Fig. 6). The backs can be labeled with a pencil to identify in what rows or at what location within the plant they are placed. Consider placing WSP cards back-to-back in the canopy if all rows within the block are not planted with the same crop and placing WSP cards on boards on the ground and in areas adjacent to blocks to detect drift.

Spray

Spray the block with water using the same travel speed, pump pressure and nozzles tips as when spraying the intended pesticide. Also adjust nozzles to be on or off based on the crop characteristics. WSP changes color from yellow to blue when contacted by liquid.

Table 1. Recommended minimum droplet densities for coarse and medium low volume sprays (Syngenta 2002).

Numbers of droplets per cm²	Type of spray
20-30	Insecticides
20-30	Herbicides (pre-emergence)
30-40	Contact herbicides (post-emergence)
50-70	Fungicides

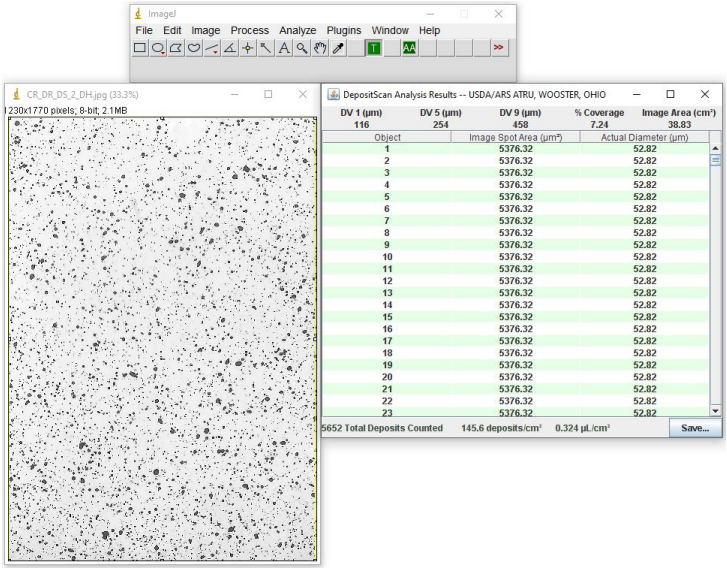

Figure 7*: DepositScan can be used to analyze 600 DPI greyscale images of WSP.*

Collect

Allow WSP to dry. Wear gloves and collect WSP in an organized manner, in particular if WSP was not labeled.

Analyze

Analyze WSP visually or by using WSP analysis software.

- Visual Analysis
  - Visually inspect WSP using the Syngenta guide and droplet counter. Interpret these results and make the necessary changes to spray settings such as nozzle angle, disc and core combinations, spray rate and tractor speed.
  - Table 1 can be used to determine if spray distribution is satisfactory for each type of pesticide sprayed. Droplet density in the target area should not be less than the indicated values.

- Digital Analysis
  - Scan WSP in grayscale as 600 DPI image files.
  - Crop images to contain only the WSP to be analyzed.
  - Analyze WSP images using computer software such as DepositScan (Fig. 7).
  - Interpret results to determine necessary adjustments to spray settings such as nozzle angle, disc and core combinations, spray rate and tractor speed.

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Additional Resources

Water Sensitive Paper for Assessing Spray Coverage: sprayers101.com/wsp-coverage/

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