W 1280

USING SMART APPLY VARIABLE-RATE TECHNOLOGY TO IMPROVE AIR-ASSISTED "AIR-BLAST" SPRAYER PESTICIDE APPLICATION EFFICIENCY IN NURSERIES AND ORCHARD CROPS

Karl McKim, Extension Assistant, Department of Plant Sciences, University of Tennessee
Dave Lockwood, Professor and Extension Specialist, Department of Plant Sciences, University of Tennessee
Amy Fulcher, Professor and Extension Specialist, Department of Plant Sciences, University of Tennessee
Heping Zhu, Agricultural Engineer, US Department of Agriculture, Agriculture Research Service, Application Technology Research Unit

When purchasing ornamental plants, consumers seek healthy, unblemished plants and have near zero-tolerance for those with insect, mite or disease damage. To provide plants free of pests and their damage, most nursery producers spray pesticides. Pest management of nursery crops is particularly challenging for a number of reasons. The number of different crop species, their associated pests, and the wide range of crop sizes and shapes in a nursery necessitate a deep level of pest knowledge and operator ability to tailor use of a sprayer for the target crop and pest. The perennial nature of nursery crops allows pests to overwinter on crops or debris, ready to infest the crop again the following season. Nursery producers often plant in multi-row blocks that can make it difficult to reach the interior rows due to the physical interference of exterior rows. Producers may apply more product than is needed to exterior rows in an effort to ensure the pesticide application penetrates to interior rows. Fruit growers face unique hurdles in successful pest control. As plants progress from dormancy to bud break, bloom, harvest and post-harvest stages, canopies become more dense and larger. Different cultivar/rootstock combinations result in different size trees. Growers may have orchards on the same farm utilizing training systems ranging from freestanding semi-dwarf to supported full-dwarf tree-wall systems - each of which will present unique challenges in successful pest control. Air-assisted, i.e., "air-blast" sprayers are often used to apply pesticides to shrubs and trees during production. Recent innovations in spray technology have led to the development of an intelligent variable-rate spray system that is now commercially available. The purpose of this publication is to educate extension agents, orchidists, and nursery crop producers about air-assisted sprayers, how variable-rate technology works, and advantages of variable-rate technology over conventional air-blast sprayers.

DEVELOPMENT OF AIR-ASSISTED SPRAYERS

Air-assisted sprayers became widely adopted in the 1950s after successful use for controlling citrus pests. Demand for air-blast sprayers was driven by a war-time labor shortage and simultaneous increase in demand for high-quality fruit. Growers at the time were primarily treating crops using mist sprayers and hand-operated spray guns that required two and three workers, respectively, to operate. Air-blast sprayers provided a labor-efficient alternative, requiring just one worker to accomplish the same task. One study found the first air-blast sprayers could cover an orchard 2 to 2.5 times faster than spray guns and in the same amount of time as mist sprayers with more uniform coverage. Early iterations of these sprayers used aircraft propellors to spray pesticide dusts. Modern air-blast sprayers deliver liquid pesticide mixtures into the airstream, propelling droplets into the crop. These orchard style air-assisted sprayers are currently the most common type of sprayer nursery producers use to apply pesticides to crops.

As little as 30% of the spray solution applied by an air-assisted sprayer lands on the intended target, ***a 30% pesticide application efficiency.***

A SHOTGUN APPROACH: INEFFICIENCY OF TRADITIONAL AIR-ASSISTED SPRAYERS

While air-blast sprayers are a labor-efficient method for delivering pesticides to tree crops, they are inefficient in their delivery of pesticides, resulting in significant waste due to off-target pesticide movement.

Fig. 1. *Air-blast sprayers emit a large spray cloud that can lead to off-target movement of pesticides. Orchard (left), nursery (right). Photo credit: A. Fulcher, H. Zhu*

Air-assisted sprayers are non-targeted, emitting a constant spray of pesticide from every open nozzle while the sprayer is operating (Fig. 1). Spray may not be uniformly distributed on an individual plant or different plants within a block. Pesticide is discharged not only in the space between trees but also in gaps within a tree's canopy. Additionally, unless the operator turns off the sprayer, it continues to discharge the spray solution when turning to go down the adjacent row.

Drift – *The movement of pesticide dust or droplets through the air at the time of application or soon after, to any site other than the area intended. – United States Environmental Protection Agency (US EPA)*

Non-target – *Any plant, animal, organism , or object other than the intended crop to which the pesticide is applied.*

Off-target – *Movement of a pesticide to an unintended object or area.*

Air-assisted sprayers can cause off-target movement of pesticides onto non-target locations both within and outside of the production area. Ground deposits can move into soil and groundwater while airborne particles can drift outside of the intended spray area onto soil, surface water, natural vegetation, or non-target organisms.

Off-target losses are economically and environmentally wasteful, as pesticide deposition in natural, non-crop areas cannot improve crop health, but rather it poses a risk to ecosystem health and function.

Off-target movement of pesticides can also increase the likelihood of exposure and associated health risks to both workers and non-workers who may come into contact with them outside of intended spray areas. Therefore, reducing off-target movement can lessen waste leading to **financial savings, improved environmental stewardship and reduced pesticide exposure for nursery and orchid workers.**

Traditional air-blast sprayers do not account for a range of crop dimensions including individual tree size nor changing tree characteristics over the growing season. Growers have limited options to adjust these sprayers to the many different crop species and sizes, shapes, and densities in production at one time. The main option is to close or angle individual nozzles by hand as blocks with different crop characteristics are sprayed. While this can be done on most if not all sprayers, it requires the operator to stop the sprayer and exit the cab of the tractor each time block characteristics change. This costs time and increases the risk of exposing the operator to pesticides. Operators also can manually change the disc and core combination, pump pressure or travel speed to try to account for differences in crop characteristics. Some nursery producers spray a volume high enough to ensure adequate coverage on their largest or densest trees. These volumes are too high for smaller trees as well as trees with little foliage early in the season, resulting in off-target loss and wasted pesticide as all surfaces are coated indiscriminately. This problem can be further compounded as some pesticide labels instruct applicators to spray until the spray solution drips off the leaves, which requires a spray volume that increases with tree size and canopy density.

PRECISION VARIABLE-RATE TECHNOLOGY

The USDA ARS in partnership with universities including the University of Tennessee, developed a suite of technologies for use with air-blast sprayers capable of sensing plant characteristics and accurately delivering dynamically calculated spray rates to crops across multiple rows of plants. This variable-rate system can be installed on new or existing sprayers. It was licensed to Smart Apply Inc. in 2018, which has since been acquired by John Deere (Fig. 2), and includes:

- **Light detection and ranging (LiDAR) sensor** senses target characteristics (size, shape and density) in real time.
- **Tablet** enables the operator to view and modify spray settings such as the fluid ounces per cubic foot of crop volume detected by the LiDAR sensor.
- **Global positioning system (GPS)** relays tractor position and groundspeed data to the on-board tablet. These data are used in conjunction with data from the LiDAR sensor to synchronize release of a calculated spray volume.
- **Computer algorithm** calculates the appropriate spray rate to be independently emitted by each nozzle using data collected by the LiDAR and GPS.
- **Pulse width modulated (PWM)** solenoid valves actuate independently in real time to control the calculated spray rate through its associated nozzle to its designated segment of the crop. Spray rates and coverage zones are dynamic and unique to each nozzle. A nozzle does not spray if a target is not detected in its zone.
- **Sprayer controller** communicates with the computer algorithm to control PWM valves for nozzles to discharge desired amounts of liquid.

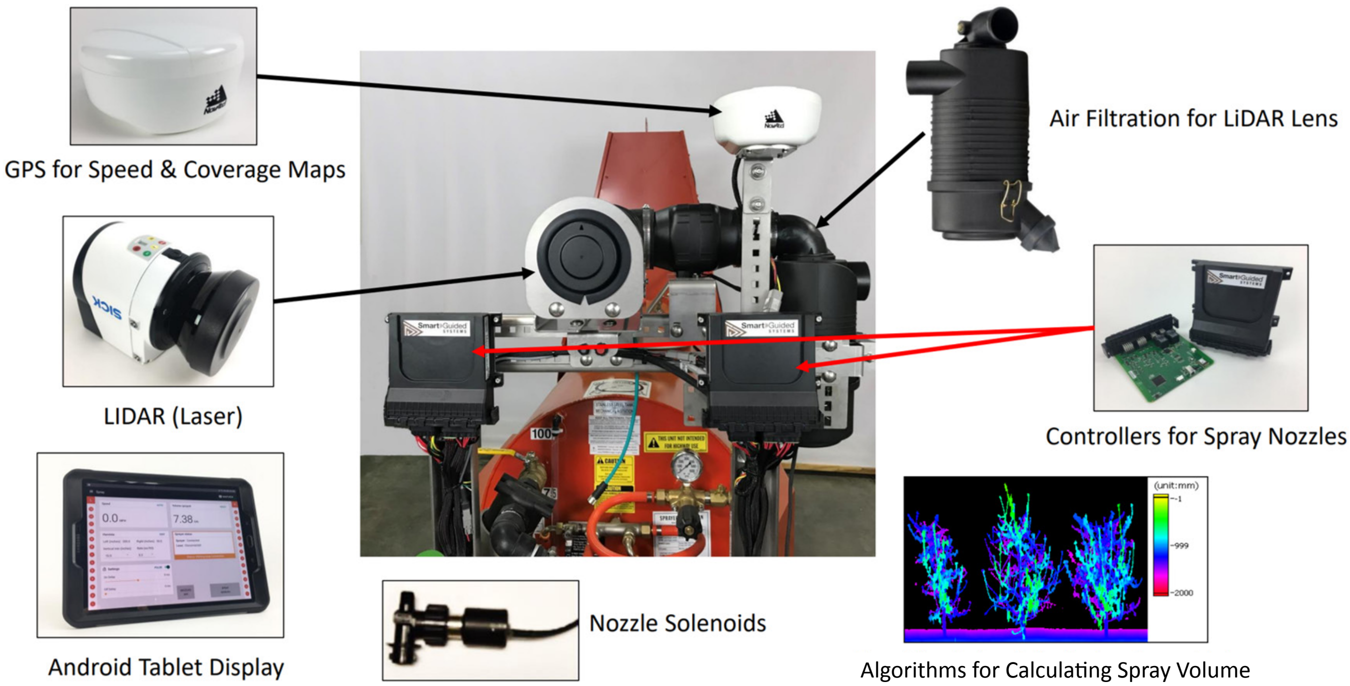


Fig. 2. *An air-blast sprayer equipped with Smart Apply intelligent spray control system. The components including a LiDAR sensor, Android tablet, GPS, and PWM valves allow the system to detect crop characteristics within production blocks and deliver a calculated, targeted spray volume. Photo credit: H. Zhu and S. Booher.*

The system measures tree canopy foliage volume and then multiplies the foliage volume by a base spray rate to calculate spray volume needed for nozzles to discharge. The base spray rate is the spray volume needed to cover one cubic foot of foliage volume. This calculation is similar to the Tree Row Volume calculation that has long been used by orchard operators to determine the gallons per acre (GPA) that they should apply.

PERFORMANCE AND CANOPY PEST CONTROL FROM VARIABLE-RATE SPRAY TECHNOLOGY

Sprayers equipped with USDA-developed variable-rate technology apply a reduced volume of pesticide, consistently around 50 percent less and have greater pesticide application efficiency and related advantages compared to conventional air-blast sprayers (Table 1).

Table 1. Variable-Rate Performance Compared to Conventional, Constant-Rate Air-Assisted Sprayer.

Sprayer Type	Reduces Spray Volume	Provides Sufficient Spray Coverage and Deposit Density	Adjusts to Crop Presence, Size and Volume	Reduces Off-Target Movements to Air and Ground	Reduces Time, Fuel and Water Required
Intelligent, Variable-Rate	X	X	X	X	X
Conventional, Constant-Rate		X			

The sprayer adjusts chemical use to the crop volume in real-time and is more accurate; actuating specific nozzles independently so that it sprays only the crop, not gaps between trees, gaps within tree canopies or the space above or below the canopy (Fig. 3).

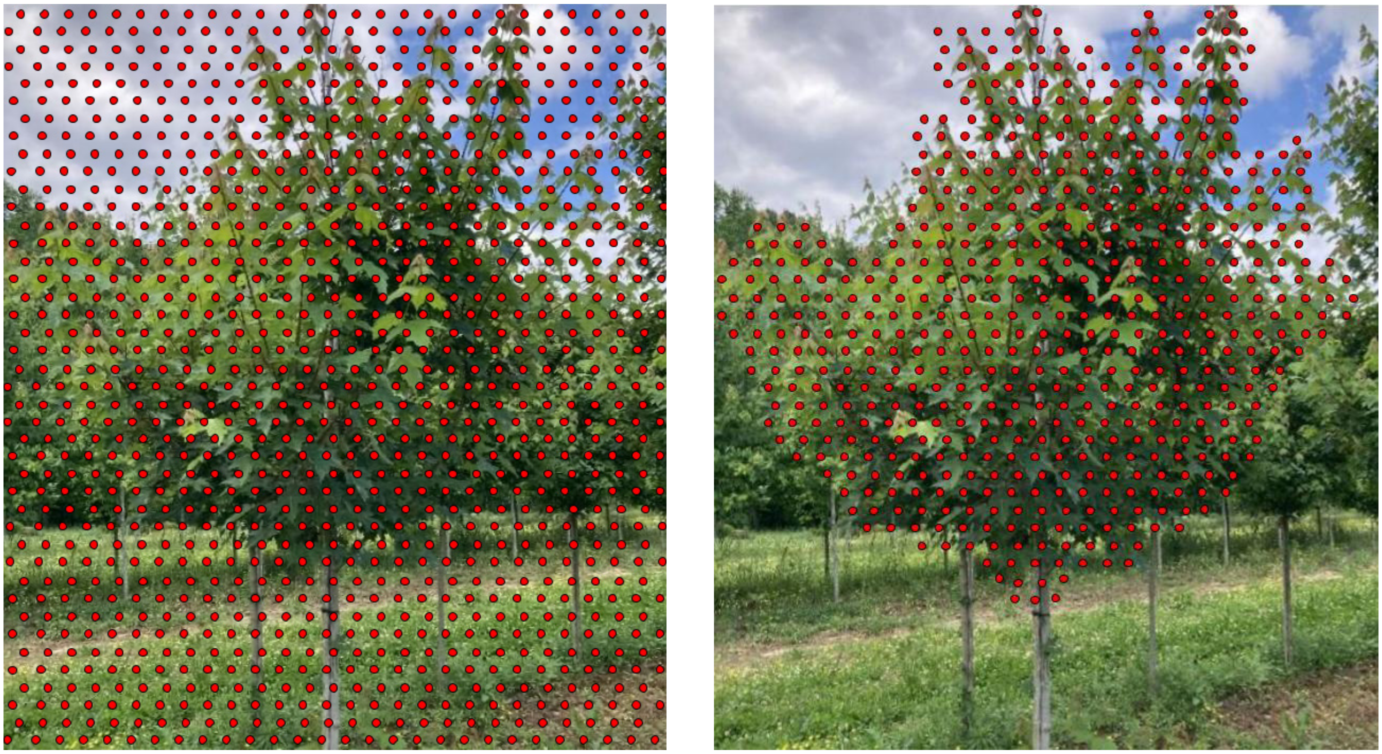


Fig. 3. *Illustration of the spray cloud (red dots) from conventional, constant-rate (left) and intelligent, variable-rate (right) spray applications. Photo credit: A. Fulcher, graphic design K. McKim.*

If the maximum and minimum height selected allows only the trunk to be detected, the system will spray the tree trunks rather than canopies. Trunk applications are discussed in Part 2 of this publication. Additionally, this variable-rate technology adjusts spray based on foliage density such that less-dense foliage receives less spray than more-dense foliage. This feature allows the technology to easily adjust to changing crop canopy characteristics during a growing season, applying a greater volume as the plants grow in height or width or become denser (Fig. 4; adapted from Nackley et al. 2021).

Full bloom (April)	Fruit drop (May)	Advanced ripening (August)
Canopy Density: 49% GPA applied: 21.6	Canopy Density: 75% GPA applied: 24.5	Canopy Density: 69% GPA applied: 25.1

Fig 4. *Spray trials were conducted when apple trees were at full bloom (April), fruit drop (May), and advanced ripening (August). Canopy density was estimated by determining the percent of sunlight blocked by the canopy. Using the sprayer in constant-rate mode applied approximately 80 GPA on each date. Photo credit: A. Fulcher and L. Fessler*

The spray volume is reduced by greatly reducing application to non-target areas and thereby reducing waste – even within the production block (Fig. 5). The amount that is applied to crops is not compromised. **In numerous studies conducted in several states over a decade on a multitude of crops and pest types, pest control was achieved at the same market-acceptable level when using this technology as when a traditional constant-rate spray was applied**.

Fig. 5. *Illustration of variable-rate (left) and constant-rate (right) non-target ground applications from within a multi-row block of pot-in-pot block of oaks when spraying the canopy to prevent foliar diseases. Graphically represented deposits are the average of all cards from the interior row, ground location.*

The variable-rate sprayer can also reduce off-target aerial drift and off-target ground applications outside of the production area as the nozzles are only actuated by the crop's presence rather than being constantly on (Fig. 6).

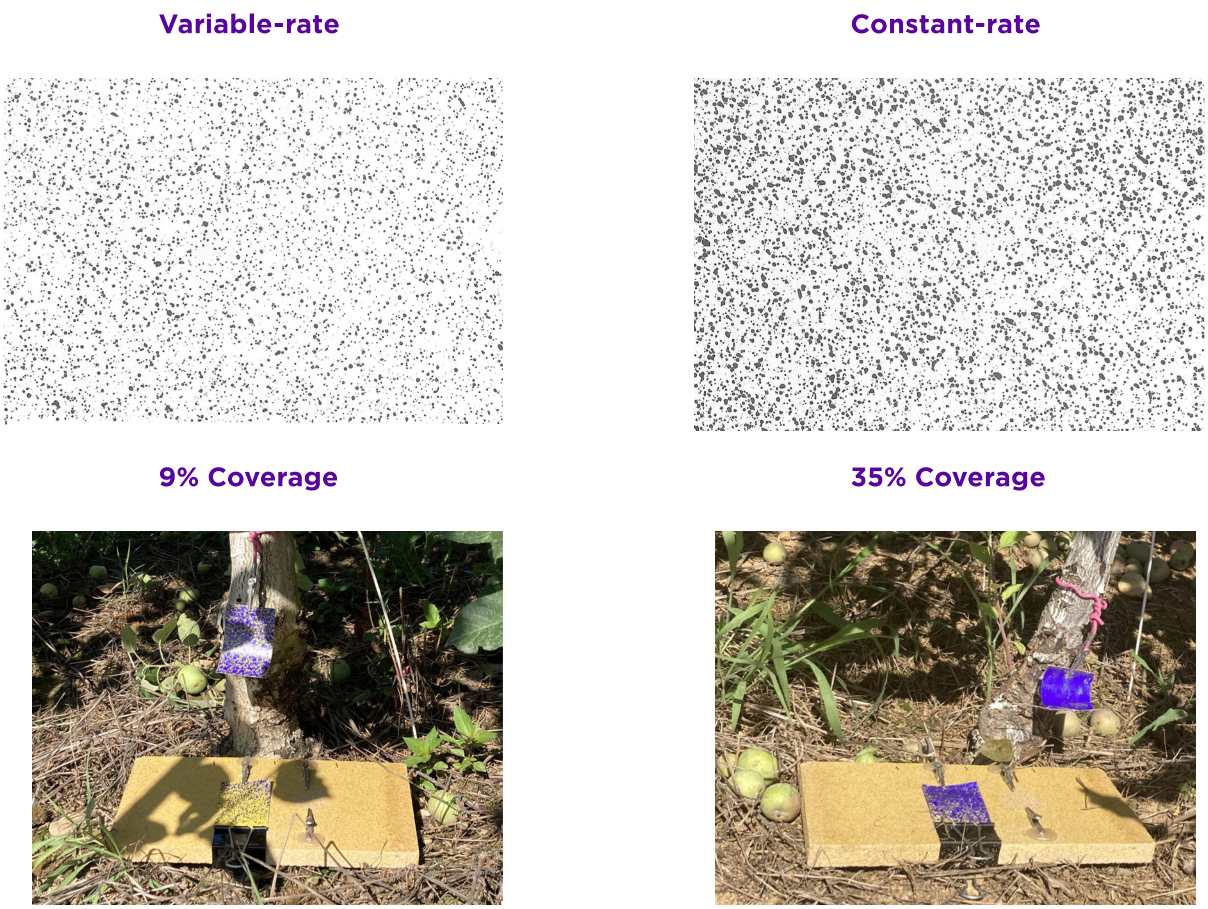


Fig. 6. *Above: Non-target airborne spray drift from variable-rate (left) and constant-rate (right) applications made in April to the canopy of Red Rome apple trees trained to a central leader and grown in a single row.*

Below: Non-target drift to the ground from variable-rate (left) and constant-rate (right) applications made in June to the canopy of Fuji apple trees trained to a tall spindle trellis and grown in a single row. Water sensitive cards turn from yellow to purple from contact with spray solution. More yellow = less pesticide; more purple = more pesticide. Percent coverage listed is the average of all replicate cards in a given location; representative images were selected. Photo credit: A. Fulcher

Because nozzles are actuated less, there is less opportunity for off-target movement. Additionally, because each nozzle is spraying a segment of detected crop, spray droplets are intercepted by the target crop. By spraying on average about 50 percent less volume of spray solution per acre, the variable-rate sprayer not only reduces the cost of pesticides but also reduces water use and spray operator time associated with mixing pesticides and filling the spray tank. This technology reduces fuel use and limits the overall environmental impact of a grower's pest management program. An economic analysis of the benefits of this technology for a 200-acre field nursery estimated a 50 percent reduction in pesticides used, leading to an annual pesticide savings of $70,000. The technology also reduced both the hours of labor associated with pesticide applications as well as fuel costs by 32 percent each (Manandhar 2018). Collectively, these reduced annual pesticide application costs by $406-504 per acre, depending on nursery size. The economic benefit from ecological services that are maintained due to reduced off-target pesticide movement is not included in this calculation but further increases the advantages of using this technology.

Many studies conducted in Tennessee show that variable-rate technology controls a variety of commonly occurring foliar insect pests and diseases at levels similar to those of constant-rate sprayers (Fig. 7). These studies were performed in multi-row block pot-in-pot nurseries and field nurseries, and apple orchards growing apple trees in single rows trained to central leader system and tall spindle trellis.

Spray Less, Pay Less

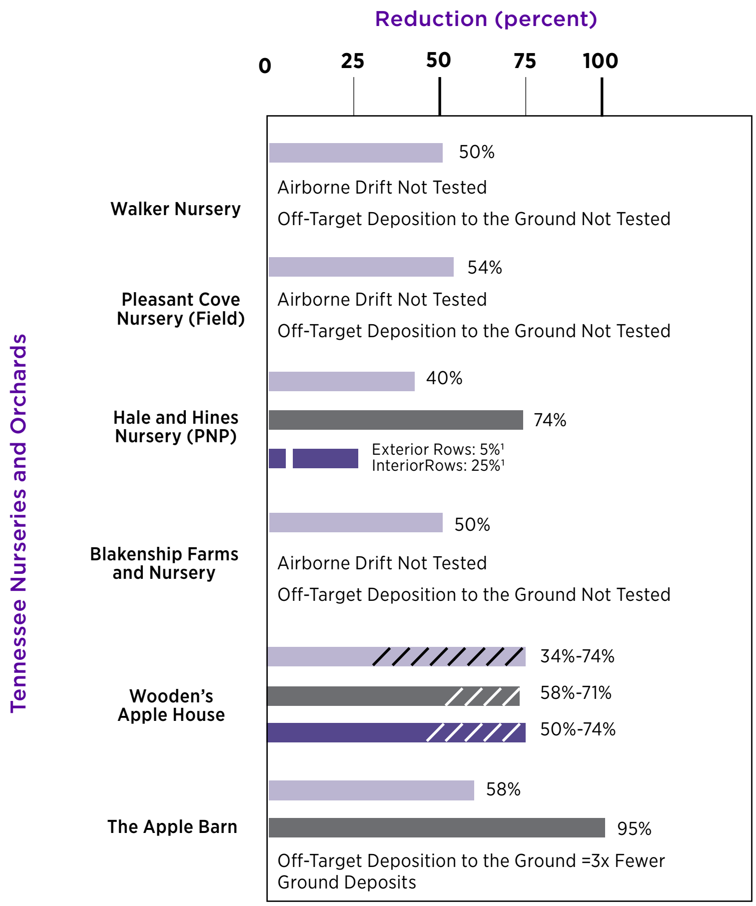
Reoccurring Savings, Year after Year

220 hours save annually during pesticide application due to less time refilling

$406-504 per acre saved annually due to spraying less per acre and refilling less frequently

Fig. 7. *Performance of variable-rate technology in Tennessee nurseries and orchards when compared to traditional constant-rate applications.*

For pesticide volume, airborne drift, and off-target ground deposition, differences between variable-rate and constant-rate were statistically significant except where noted. Insect and disease control from variable-rate applications was comparable to that of constant-rate applications and at market-acceptable levels.



[1] Variable-rate values are not significantly different from constant-rate.

Legend

- Reduction in Pesticide Volume Applied
- Reduction in Airborne Drift
- Reduction in Off-Target Deposition to the Ground
- // Percent Range

Tennessee Nurseries and Orchards	Insects and Diseases Effectively Controlled
Walker Nursery	Powdery mildew
Pleasant Cove Nursery (Field)	Powdery mildew
Hale and Hines Nursery (PNP)	Cylindrosporium leaf spot, tar spot, Japanese beetles
Blakenship Farms and Nursery	Tar spot, anthracnose
Wooden's Apple House	Bitter and white rot
The Apple Barn	Leaf spot, fruit rot

OPTIMIZING THE TECHNOLOGY

Commercially available variable-rate technology includes the following features as well as additional features not described here:

Ability to refine the target crop size using the tablet touch screen: The operator can adjust the minimum and maximum height of the crop detected using the touch screen, eliminating the need to manually adjust nozzles for varying crop characteristics, or the more common practice of not adjusting at all. This allows growers to set the laser to only see the canopy, and eliminate the trunk or tall weeds from actuating the nozzles. The operator can also set the width that the laser senses, which allows the grower to spray the outer row only of a multi-row block. This feature can be helpful when spraying blocks with multiple crop species that have different pest control needs in each row.

On-off work status: Operators can prevent individual nozzles from spraying using the touch screen and no longer need to exit the tractor to physically close nozzles, reducing the risk of pesticide exposure.

Base spray rate: Fluid ounces of spray solution per cubic foot of crop foliage volume can be changed in the cab using the tablet.

Data recording and cloud-based storage: The system records important data such as date and time, chemical applied, overall spray volume and calculates pesticide savings. All data is uploaded in real-time to a secure, cloud-based storage system.

Pesticides other than wettable powders are recommended for this technology: Wettable powders may clog the solenoids that control each nozzle if the tank is not agitated properly during use or spray lines are not thoroughly rinsed after applications. Water used to fill the tank should be debris-free and the sprayer filters should be cleaned with a reasonable frequency.

CONCLUSIONS AND FUTURE DIRECTIONS

Intelligent spray technology is perhaps the most significant innovation in spray technology since the introduction of the air-blast sprayer. Research conducted nationally including in collaboration with Tennessee producers has demonstrated the system's ability to control foliar pests and diseases to market-acceptable levels, the same level as conventional air-blast sprayers, while applying significantly less pesticide, usually a 50 percent or greater reduction. These sprayers can provide financial savings on pesticide, labor, fuel and water while reducing the environmental impacts and risks to worker health and safety caused by widespread off-target drift and residue left on non-target surfaces. Although foliar pests and diseases are a major concern for nursery operators, those which affect the trunks of trees are of equal, or in some cases, greater concern. Projects are ongoing as part of the USDA Specialty Crops Research Initiative "Flatheaded Borer Management in Specialty Tree Crops" to optimize intelligent spray technology for trunk applications to help control trunk boring pests, which will be covered in Part 2 of this publication.

FREQUENTLY ASKED QUESTIONS

How much does it cost?
Please contact Smart Apply – John Deere for this information.

Can I install this technology on any sprayer?
The technology has been installed on hundreds of sprayers of a wide range of styles and ages including 40+ year old air-blast sprayer in our trials, those conducted by the USDA, and by Smart Apply. So far, the sprayer has not been a limitation. However, we recommend that you contact Smart Apply to verify that your sprayer is suitable and before purchasing a new sprayer for use with the technology.

The technology can also be installed on GUSS (Global Unmanned Spray System) for autonomous navigation and added labor savings and worker safety.

Does less spray mean the pesticide solution is more diluted?
No, the spray solution is mixed to the same concentration per labelled instructions. Less of the prepared solution is discharged because of the sensing capabilities of the sprayer, which prevents it from spraying empty spaces in the field.

Does it sense tree stakes? What about weeds?
The technology can detect objects as narrow as a stake or a blade of grass. It cannot distinguish between a crop plant, weeds, a stake, person, or any other object. It senses within the vertical and horizontal parameters that were specified by the operator using the touch screen. To obtain the greatest benefits, control weeds. Maintain your nursery or orchard floor with low vegetation and/or set the vertical height minimum to a distance that targets your crop and adjust, as needed. Please remember weeds compete with your trees for water and nutrients and may serve as alternate hosts for certain pests.

How can I get assistance to invest in this technology?
Growers interested in variable-rate technology can pursue Tennessee Ag Enhancement Program (TAEP) funding for cost share. Nursery producers can take the Tennessee Master Nursery Producer (TMNP) Program or the Advanced TMNP to meet the educational requirements. To learn more about the TAEP program select: https://www.tn.gov/agriculture/farms/taep.html.
To learn more about the TMNP and Advanced TMNP select: www.tnmasternursery.com.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge USDA ARS SCA 58-5082-9-012 for financial support. The authors also express their gratitude to Blankenship Farms and Nursery, Hale and Hines Nursery, Oren Wooden's Apple House, Pleasant Cove Nursery, The Apple Barn, and Walker Nursery. Their partnership made the research described within this publication possible. Appreciation is expressed to Lauren Fessler and Steve Booher for images used in this publication and to Adam Clark, Grace Pietsch, Wesley Wright, and the many undergraduate students who conducted research on the intelligent sprayer. Reviewers Becky Bowling, Midula Gireesh, Walker Harrell, and Tyson Raper are appreciated for their careful review, which greatly improved this publication.

ADDITIONAL RESOURCES AND REFERENCES

https://sprayers101.com

Brann JL. 1956. Apparatus for application of insecticides. Annual Review of Entomology. 1:241-260. https://doi.org/10.1146/annurev.en.01.010156.001325.

Fessler L, Xiaocun S, Wright WC, Zhu H, Fulcher A. 2023. Intelligent, variable-rate spray technology reduces total pesticide output while controlling foliar disease of Shumard oak. J Environ Hort. 41(3):109-120. https://doi.org/10.24266/0738-2898-41.3.109.

Fox, RD, Derksen RC, Zhu H, Brazee RD, Svensson SA. 2008. A history of air-blast sprayer development and future prospects. Transactions of the ASABE. 51(2):405–410. https://doi.org/10.13031/2013.24375.

Manandhar A, Shah A. 2018. Techno-economic analysis of using a conventional sprayer retrofitted with intelligent control functions for pesticide application in nursery crops. ASABE Annual International Meeting 2018, July 29- August 1, Detroit, MI. (Oral). https://doi.org/10.1007/s11119-020-09712-8.

Manandhar A, Zhu H, Ozkan E, Shah A. 2020. Techno-economic impacts of using a laser-guided variable-rate spraying system to retrofit conventional constant-rate sprayers. Precision Agric. 21:1156-1171. https://doi.org/10.1007/s11119-020-09712-8.

Nackley L, Warneke B, Fessler L, Pscheidt JW, Lockwood D, Wright W, Sun X, Fulcher A. 2021. Variable-rate spray technology optimizes pesticide application by adjusting for seasonal shifts in deciduous perennial crops. HortTechnology. 31(4):479-489. https://doi.org/10.21273/HORTTECH04794-21.

Walgenbach J, Parker M, Kon T, Vilani S, Mitchem W, Lockwood D. 2023. 2023 Integrated Orchard Management Guide for Commercial Apples in the Southeast. NC State Extension AG-472.

Zhu H, Derksen R, Guler H, Krause CR, Ozkan E. 2006. Foliar deposition and off-target loss with different spray techniques in nursery applications. Transactions of the ASABE. 49(2):325-334. https://doi.org/10.13031/2013.20400.

Zhu H, Zondag R, Derksen R, Reding ME. 2008. Influence of spray volume on spray deposition and coverage within nursery trees. J Environ Hort. 26(1):51-57. https://doi.org/10.24266/0738-2898-26.1.51.

INSTITUTE OF
AGRICULTURE
THE UNIVERSITY OF TENNESSEE

UTIA.TENNESSEE.EDU

Real. Life. Solutions.™

W 1280 09/24 25-0241 Programs in agriculture and natural resources, 4-H youth development, family and consumer sciences, and resource development. University of Tennessee Institute of Agriculture, U.S. Department of Agriculture and county governments cooperating. UT Extension provides equal opportunities in programs and employment.