NOTES

AUTOMATED GREENHOUSE SPRAY SYSTEM FOR INCREASED SAFETY AND FLEXIBILITY

D. E. Rowe,* S. Malone, and Q. L. Yates

Abstract

Under EPA’s Workers Protection Standard Act of 1992, persons applying pesticide in a greenhouse are usually required to wear protective clothing and a face mask and to breath filtered air. The impervious clothing is usually uncomfortable and may be a health risk via overheating and potential for dehydration. The objective of this research was to devise an automated greenhouse spray system to eliminate hand application. Using off-the-shelf components, pesticides are applied at a predetermined time through mist nozzles suspended in greenhouse bays. The automated spray system reduces pesticide exposure to the applicator and others and thus reduces potential liability for the employer, facilitates better control on application rates, is more repeatable than hand application, reduces costs of hazardous waste disposal, and reduces disruption of other greenhouse operations.

On 15 Apr. 1994, the generic provisions of Environmental Protection Agency’s Worker Protection Standards Act of 1992 (EPA, 1992) became effective. This ambitious and comprehensive set of regulations defined specific procedures and guidelines for handling and application of pesticides with the intent to: “(1) Eliminate or reduce exposure to pesticides; (2) mitigate exposures that occur; and (3) inform employees about the hazards of pesticides.” For most agricultural situations, persons spraying a pesticide are required to wear a protective suit, gloves, and face mask and breath filtered air. Although the handler, the person mixing and applying the pesticide, may be protected from the pesticide, that person may be exposed to very uncomfortable or dangerously high temperatures inside the suit and might risk serious dehydration. Even if the pesticide handler does the spraying at moderately cool ambient temperatures, the temperature inside the suit can still be unpleasantly high after a few minutes of strenuous work.

If an automated system for pesticide application is used in lieu of hand spraying, most of the hazard and discomfort for the handler is eliminated. One system which is available is the Dramm Autofog (Hummert International, Earth City, MO). This unit applies commonly used pesticides using an “automatic aerosol micro-particle generator” and a circulating fan. This specialized unit costs about $5000.00, which may be prohibitively expensive if several units are needed for simultaneous fumigation of different greenhouse areas. The objective of this research was to design an automated spray system that can be modified to fit any greenhouse and constructed of off-the-shelf components to minimize its cost.

Materials and Methods

Major components of the automated spray system are (i) a tank for holding mixed pesticides, (ii) a pressurized air source, (iii) a structure for applying the pesticide over the plants, and (iv) timers with switches to control tank pressurization and operation of machinery in the greenhouse bay. The mechanism was constructed of off-the-shelf parts and no endorsement of the manufacturers or vendors is implied. Other manufacturers’ products can be substituted for those mentioned in this publication and listed in Table 1 when they serve the same purpose. One exception to the substitution is the KCFM Flora Mist nozzle. This unit has proven to be critical to the effectiveness of this system and should not be replaced without substantial testing.

Spray System

The tank used to hold the pesticide mix was a beverage-type made of stainless steel with a capacity of 18.9 L (5 gallons) (Weed Systems, Gainsville, FL) [1] with a safety valve and rated maximum pressure of 1.035 × 10^6 Pa (150 lb in^{-2}). [2] Pressurized air was provided from either a centrally located tank when bays were connected about a head-house or from a portable tank for the more isolated greenhouse. With the centrally located pressurized air tank, air was piped to each greenhouse through a 15.8-mm (5/8 inch) i.d. rigid copper pipe. Static air-line pressure was 3.45 × 10^2 Pa (50 lb in^{-2}). [3] A 12.7-mm (1/2 inch) solenoid valve with coil (Dayton Manufacturing, Chicago, IL) [2] was attached to the end of the pipe in the greenhouse bay to regulate air flow to the spray tank. The air was routed to the spray tank via a 12.7-mm i.d. flexible, chemical-resistant high-pressure hose with maximum rated pressure of 1.38 × 10^2 Pa (200 lb in^{-2}) (Speedaire, Chicago, IL) [3] for the isolated greenhouse bay (7 × 12 m), the pressurized air was from a portable air tank with a capacity with 75.6 L^3 (20 gallons) and a single stage compressor pump with a 120-V motor rated at one horsepower. Pesticides are applied to the plants in a greenhouse bay using a misting system constructed of either galvanized pipe or a flexible hose attached to a rigid frame. For both structures, a flexible high-pressure chemical-resistant hose (12.7-mm i.d.) routes the spray mix from the spray tank to a primary feeder line located overhead in the greenhouse bay (Fig. 1).

The misting structure constructed of galvanized pipe has a primary line with 9.5-mm (3/8 inch) i.d. and branching lines with 6.4-mm (1/4 inch) i.d. Generic stainless steel or brass ball values [4] are installed on branch lines to prevent application of spray to benches when those benches do not have plants. To reduce the frequency of cleaning, an in-line screen filter or line strainer is installed in the primary feeder line [5]. On the branch lines that were suspended above the center of the long axis of each greenhouse bench, Flora-mist nozzles (Hummert International, Earth City, MO) [6] rated to deliver

1 The number in brackets is cross-referenced to the code of parts vendor found in Column 1 of Table 1.

Table 1. Spray system parts and vendor part numbers.

<table>
<thead>
<tr>
<th>Code</th>
<th>Item</th>
<th>Vendor</th>
<th>Part number</th>
<th>Vendors address</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2]</td>
<td>1/2 inch Solenoid brass valve and coil</td>
<td>W.W. Grainger Inc.</td>
<td>3A434 and 6X543</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[3]</td>
<td>Speedaire chemical resistant 1/2 inch ID hose</td>
<td>W.W. Grainger Inc.</td>
<td>5W921</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[4]</td>
<td>In-line brass ball valve</td>
<td>W.W. Grainger Inc.</td>
<td>5X713</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[5]</td>
<td>Line strainer</td>
<td>W.W. Grainger Inc.</td>
<td>2P131</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[6]</td>
<td>KCFM Flora Mist nozzle</td>
<td>Hummitt International</td>
<td>18-4675</td>
<td>5400 Earth City Expressway, Earth City, MO</td>
</tr>
<tr>
<td>[7]</td>
<td>Speedaire chemical resistant 3/8 and 1/4 inch ID hoses</td>
<td>W.W. Grainger Inc.</td>
<td>5W020 and 5W019</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[8]</td>
<td>Brass “T”s” and elbows, hose barbs and ferrules</td>
<td>W.W. Grainger Inc.</td>
<td>3P868, 2A734, 2A734, 6X409, 3P882</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[9]</td>
<td>Intermatic 7-Day Timer model T2005</td>
<td>W.W. Grainger Inc.</td>
<td>2A210</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
<tr>
<td>[10]</td>
<td>Potter &amp; Brumfield 8-pin relay, model KRPA-11AG-120</td>
<td>W.W. Grainger Inc.</td>
<td>3A993</td>
<td>333 Knightsbridge Parkway, Lincolnshire, IL</td>
</tr>
</tbody>
</table>

0.032 m³ h⁻¹ at 2.76 × 10⁵ Pa (8.5 gal h⁻¹ at 40 lb in⁻²) were installed in an inverted position every 0.91 m.

The alternative misting structure uses a chemical-resistant flexible hose throughout the primary (9.5-mm i.d.) and branch (6.4-mm i.d.) lines [7]. The hoses were clamped to a frame made of 12.7-mm-i.d. thin-walled electrical conduit suspended from the greenhouse ceiling. The mist nozzles were attached to brass ‘T’s’ [8] and spliced into the flexible hose using hose barbs [8] and at the distal end of every branch, a brass elbow [8] and a hose barb. When a flexible hose was used to connect the branch line and primary line, the branch lines could be raised and lowered on pulleys to desired height above each bench.

The automatic operation of the spraying system was controlled with a 7-d timer clock (Intermatic, Saint Louis, MO) [9] wired to eight-pin relays (Potter and Brumfield, Chicago, IL) [10]. The greenhouse bay was wired so that when the relays were energized by the 7-d timer, the electrical current

Pesticide Spray System

Fig. 1. Schematic showing major components of stationary automated spray system installed in a greenhouse bay.
like structure 1.2 m wide and 1.6 m high with horizontal steps at 20-cm vertical intervals. The steps were covered with water-sensitive paper pieces 52 by 76 mm (Tee Jet, Spraying System Co., Wheaton, IL). When water droplets impacted the water-sensitive paper, its color changed from yellow to blue. The ladder was positioned to measure spray below and to the side of the mist nozzle. This ladder-like structure was positioned perpendicular to the axis of the branch line with the top corner of the ladder near a nozzle (Fig. 2). The water sensitive paper was placed on the steps, labeled by position, and exposed to the normal 3-min spray sequence. The papers were then immediately removed, dried, and used to estimate coverage and droplet size by microscopic counting of drops per square centimeter. The system was tested three times in each of two 12 by 15 m bays; one bay had 35 mist nozzles and the other had 44 mist nozzles. The spatial density of the mist droplets was determined for 100, 80, and 50% of saturation. The volume of droplets was based on median diameter size of droplets estimated using the standard count scales included with the kit (Field Application Support PP 4.323, Ciba-Geigy Limited, Switzerland).

**Discussion**

Experience with 15 automated spray systems for >2 yr has shown the system to be effective on pest control. Whereas before, the cost in effort, time, and the discomfort of spraying a bay were weighed against the level of damage caused by buildup of a pest, now pest buildup is not tolerated because the costs and inconvenience of spraying have been greatly reduced. Considered in this decision is the desirability to effect spraying after normal work hours and reduce interruption to other greenhouse labor, to reduce the potential for exposure of workers in adjacent bays to fumes leaked from the sprayed bay, and to reduce heat stress on the plants. In the summer, spraying in the late evening avoids radiant heating of the house and allows the bay to be closed for 2 h without exposing the plants to injurious heat stress. In the winter, night spraying allows the greenhouse crew to use all of the daylight hours for work.

For the automated spray system the amount of active ingredient is fine-tuned for each greenhouse bay and is applied with a repeatability not expected with use of hand spraying by different employees or even with the same employee.

**Spray Coverage**

A few drops at the beginning and ending of the spray cycle were large, but the median diameter of droplets was very small (<200 µm). This size droplet is qualitatively characterized by Ross and Lembi (1985) as mist to fine spray. The criteria for saturation was >200 droplets cm⁻². At this density, many droplets are overlapping and the paper is blue-purple in color. The criteria for 80 and 50% coverages were droplet counts of 160 and 100 cm⁻², respectively. In the two greenhouse bay tests, the Flora-mist nozzle had a saturating spray up to a horizontal distance of 1.2 m in absence of plant materials (Fig. 2). The guidelines included with the water-sensitive paper recommended a minimum coverage of 20 to 30 droplets cm⁻² for insecticides and 50 to 70 droplets cm⁻² for fungicides. Thus by this test, most of the spraying can be considered as oversaturation. In the tested bays, with nozzles 0.91 m on centers and 1.2 to 1.6 m above benches.
that were 1.1 to 1.8 m wide, every position on the bench was sprayed by more than one nozzle, an important consideration because the nozzles can be plugged. The quantity of pesticide, which was suspended in the air as a fog, settled on all surfaces if vents were kept closed and the air was not circulated.

Unlike the Dramm Autofog, the automated spray system is not portable. Major costs were the air pressure system, the mixing tank, and the wiring for the controls, but the Flora-mist nozzle was very inexpensive at <$2.00. One cost-cutting option is to use manual switches outside the spray area for turning off the air handlers and vents and for executing the spray event. The described spray system, which may have been over-built in some respects, has an estimated unit cost between 15 and 25% of the Dramm Autofog.

Conclusions
The automated greenhouse spray system was developed to eliminate the inconvenience and health risks of hand-spraying. The realized effects have been several: reductions in costs for disposal of excess spray as hazardous waste and disposal of protective suits, less disruption to other greenhouse labor operations, more flexibility in choice of spraying times, elimination of hazard to others in greenhouses near the sprayed bay, more predictable spray applications, reduced exposure and handling of spray material by employees with concurrent reduction in employer’s liability, reduced reluctance to spray and better control of pests, and elimination of some of the variability found with hand-spraying.

Acknowledgments
We express our appreciation to Ms. Anna Mleczko for the excellent drawing of the spray system in the greenhouse bay.

References

Abbreviation: LAI, leaf area index.

Comparison of Three Leaf Area Index Meters in a Corn Canopy

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Abstract
Measurement of leaf area index (LAI) is critical to understanding many aspects of crop development, growth, and management. Availability of portable meters to estimate LAI non-destructively has greatly increased our ability to determine this parameter during the cropping season. However, with several devices on the market, each with an independent set of protocols for gathering accurate estimates of LAI, it is necessary for scientists to have comparisons of these meters under field conditions before selecting one for purchase and use. The objective of our study was to compare the LAI estimates by three meters (AccuPAR, LAI-2000, and SunScan) to LAI measured by destructive sampling. Leaf area index of two corn (Zea mays L.) hybrids, grown on a Pachic Haplustoll, was measured at the R2 stage by the four methods before and after successive thinning of plant stands. Destructively sampled LAI ranged from 4.59 to 1.25 for the initial stand to the most severe thinning. Hybrids did not differ in LAI. All meters underestimated LAI compared with destructive sampling. When all data from all rings of the LAI-2000 meter were included in the calculations, LAI-2000 estimates of LAI differed from those of the other two meters. However, when data from Ring 5 was removed from the calculations, estimates of LAI for the LAI-2000 improved and were indistinguishable from the other meters. The relationship between LAI estimated destructively and by each of the meters was described by a unique linear equation for each hybrid. Results of this study, and experience with use of the meters, suggest that users should consider protocols for operating each meter before deciding which device best suits their application.

Notes
1 Mention of commercial products in this paper is solely to provide specific information for the reader. It does not constitute endorsement by the USDA’s Agricultural Research Service or University of Nebraska’s Agricultural Research Division over other products.