EVALUATION OF A LOW VOLUME AGRO-CHEMICAL APPLICATION SYSTEM FOR CENTER PIVOT IRRIGATION

H. J. Farahani, D. L. Shaner, G. W. Buchleiter, G. A. Bartlett

ABSTRACT. *A low volume agro-chemical application system, called Accu-Pulse Precision Applicator, was recently introduced. Accu-Pulse features an independently operated spray boom attached to a center pivot or a linear move irrigation system. The unique spray applicators have adjustable discharge volumes [from 8 to 31 mL per pulse (0.27 to 1.05 oz)] and enable applications at low rates similar to ground sprayers and much lower than chemigation and pivot-attached sprayer systems. The low rates are achieved by periodic pulsing of the chemical solution through the applicators on a span-by-span basis. A series of tests were conducted to evaluate the engineering performance of the Accu-Pulse system. Entrapped air caused the most discharge variability, affecting isolated applicators on a branch line. In the absence of entrapped air, the discharge variability (CV) was less than 15% for medium to high discharge settings [19 to 31 mL (0.64 to 1.05 oz)] and varied from 13% to 34% at lower settings [below 19 mL (0.64 oz)]. Uniformity of applicator discharge is not synonymous with application uniformity as the wetting coverage tests show. Based on stained water-sensitive papers, much larger droplets were detected under Accu-Pulse than a ground rig sprayer, suggesting a greater potential to reduce spray drift. However, percent wetting coverage was about one-third to one-half smaller under Accu-Pulse than the ground sprayer. For a commercial Accu-Pulse on an eight-tower center pivot, wetting coverage values were in the 40% range as compared to coverage values of about 60% for a ground sprayer. From growers' perspective, the uniformity of applied chemical is an important performance criterion. This study does not address uniformity in chemical application, efficacy, or cost but advances the basic understanding of spray pattern, overlap, wetting coverage, discharge uniformity, droplet size, and pulse time characteristics of the Accu-Pulse system. Additional studies are needed to evaluate and compare the performance and efficacy of Accu-Pulse with other agro-chemical systems.*

Keywords. *Application technology, Irrigation, Center pivot, Chemigation.*

Efficient application of agro-chemicals is a challenge for farmers to maintain an economical production system. Producers in sprinkler-irrigated fields are faced with three main choices in applying agro-chemicals: a ground rig applicator (tractor-mounted sprayers), an airplane, or chemigation. Other agro-chemical application systems, such as pivot-attached sprayers on center pivot irrigation systems, have also been developed and demonstrated (Larsen, 1980; Lyle and Bordovsky, 1986; Taylor, 1986). Chemigation has been successfully used for decades where chemicals are injected in the irrigation water (Threadgill, 1985). Even though chemigation can be very effective and efficient (Chalfant and Young, 1981; Dowler, 1982; Young, 1982; Myers, 1985; Johnson et al., 1986; Lyle et al., 1989; New et al., 1990), there are some limitations (Sumner et al., 2000b). For example, not all chemicals can be applied by chemigation because the typical minimum irrigation volume dilutes their effect (Dowler and Sumner, 1993). In other cases, it may be critical to apply the chemicals even though there is ample soil water to meet crop needs. Sometimes crop stand and weather conditions limit the opportunities to apply the necessary chemicals with ground applicators or airplanes. That is particularly critical when the window of application for effective disease and insect control is small. Conventional applicators also pose other problems such as disposal of left over tank mixtures and human exposure to agro-chemicals during mixing and loading (Sumner et al., 2000b).

A Pivot-Attached Sprayer System (PASS) was developed by Sumner et al. (1997) that used micro-irrigation components to apply 2340 L/ha (250 gal/acre) of solution uniformly to crops grown under a center pivot irrigation system. PASS has advantages over chemigation when chemicals are not labeled for application by chemigation. Also, foliar-applied pesticides that are not effective when applied via chemigation in a large volume of water [above 37400 L/ha (4000 gal/acre)] can be applied with PASS at a much lower volume [1870 to 2806 L/ha (200 to 300 gal/acre)]. Chemigation and PASS were found to be effective methods for applying agro-chemicals when large volumes of water are needed for effective penetration into the crop canopy or for activating pre-emergence herbicides (Sumner et al., 2000a). PASS applications demonstrated a potential for the commercial application of some materials that are not compatible

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with chemigation, such as defoliants, post-emergence herbicides, fungicides, and insecticides.

Agro-chemicals that are mixed in a holding tank and then applied with PASS are considered to be applied by a high volume sprayer transported by an irrigation system. A low volume agro-chemical application system, called Accu-Pulse Precision Applicator (Valmont Industries, Valley, Nebr.), was recently introduced that applies volumes similar to ground sprayers and well below chemigation and PASS. Accu-Pulse features an independently operated spray boom attached to a center pivot (fig. 1) or a linear move irrigation system. Agro-chemicals labeled for application with ground sprayers can be used with Accu-Pulse (Bartlett, 2001). In contrast to chemigation, Accu-Pulse runs independently of the irrigation system and uses a separate water supply, and basically converts center pivots and linear moves into long spray rigs that can spray large fields at low rates. A positive displacement pump injects chemicals directly into the water in the supply line. This provides the potential to minimize risk and the inconvenience of having unused chemical solution at the end of an application.

Accu-Pulse evolved through earlier concepts of pulsing the chemical application to achieve varying low rates of application. Most significant system modifications were made in late 1990s through cooperative field research with the RDO Farms in Park Rapids, Minnesota (Griffel, 2001). Accu-Pulse offers the potential for flexibility in scheduling, application rate, precision, and energy savings in agro-chemical applications. The engineering and agronomic performance of Accu-Pulse under a wide range of field, crop, and climate conditions needs independent testing. This article presents laboratory and field testing results evaluating the engineering performance of the Accu-Pulse system. One of the important performance criteria is the application uniformity of chemical concentration. This study does not address uniformity in applied chemical concentration, efficacy, or cost.

System Description and Characteristics

The Accu-Pulse system (fig. 1) has two separate supply tanks and pumps – one for water and the other for concentrated chemicals (Valmont Industries, Inc., 2001a; 2001b). A centrifugal pump takes water from the water supply tank and pressurizes a 38-mm (1.5-in.) diameter supply line running the entire length of the pivot (and supported by the truss) to a pressure greater than 379 kPa (55 psi). A positive displacement pump injects chemicals directly into the water in the supply line. At the odd-numbered towers of the pivot, the supply line branches to two valve assemblies with each assembly (consisting of three solenoid valves) controlling flow to a 16-mm (0.625-in.) diameter branch line supplying the individual applicators between adjacent towers. The spray applicators are attached to the branch lines and suspended at 1.52-m (5-ft) intervals from a cable strung between towers (shown in fig. 1). The height of the cable can be adjusted from 1 to 2.7 m (3.3 to 8.9 ft) as the crop grows. A programmable logic controller (PLC) opens and closes the three solenoid valves in the necessary sequence to produce the pulses (described later). The PLC monitors the pressure at the end of the branch line and the tower movement and initiates a pulse after a pre-set pulse time and only if the tower is moving. If there is insufficient pressure, a fault is recorded. If more than one fault is recorded in a 30-min period, the system shuts down as a safety precaution.

Figure 1. Accu-Pulse agro-chemical application system mounted on a center pivot.

The Spray Applicator

One of the unique features of the Accu-Pulse system is its spray applicator, also known as accumulator. The applicators are individual units that consist of a nozzle with a spreader at the lower end and an accumulator housing at the upper end (fig. 2). The applicators have a dual function of storing and dispensing of the chemical solution. The applicators have adjustable discharge volumes [from 8 to 31 mL per pulse (0.27 to 1.05 oz)]. Each applicator has an inlet and an outlet port at the sides and a discharge nozzle at the lower end. All applicators installed on a branch line between adjacent towers are considered a set and are pulsed by manipulating the liquid pressure inside that branch line. Pulsing is accomplished by opening and closing the three solenoid valves mounted on the tower and at the upstream end of each branch line. Two of these solenoid valves, called the FILL valves, are connected in series for rapid filling of the branch line and the other is called the FIRE valve. All three valves are controlled by relay switches and the PLC, and they are normally closed (when not energized) to guard against excess chemical discharge caused by improper operation and/or loss of electricity.

The filling, discharging, and refilling cycle of applicators on a branch line is best described using the schematics in figure 3. An integral component of each applicator nozzle is a flap that acts like a valve. By opening the FILL valves, the inlet line is pressurized to about 379 kPa (55 psi) and the opening to the discharging nozzle is sealed by the flap, causing the solution to flow into the accumulator and compressing a spring (see flap position in fig. 3a). As the accumulator is filling, solution also flows through the applicator to the next applicator downstream. This process continues sequentially until all of the applicators on the branch line are filled. After the accumulator is filled with a known volume, the contents are discharged at a specified pulse interval. Pulsing occurs by closing of the FILL valves and opening the FIRE valve to the atmosphere for a fraction of a second which reduces the pressure inside the branch line. This sudden drop in pressure causes the flap to seal the

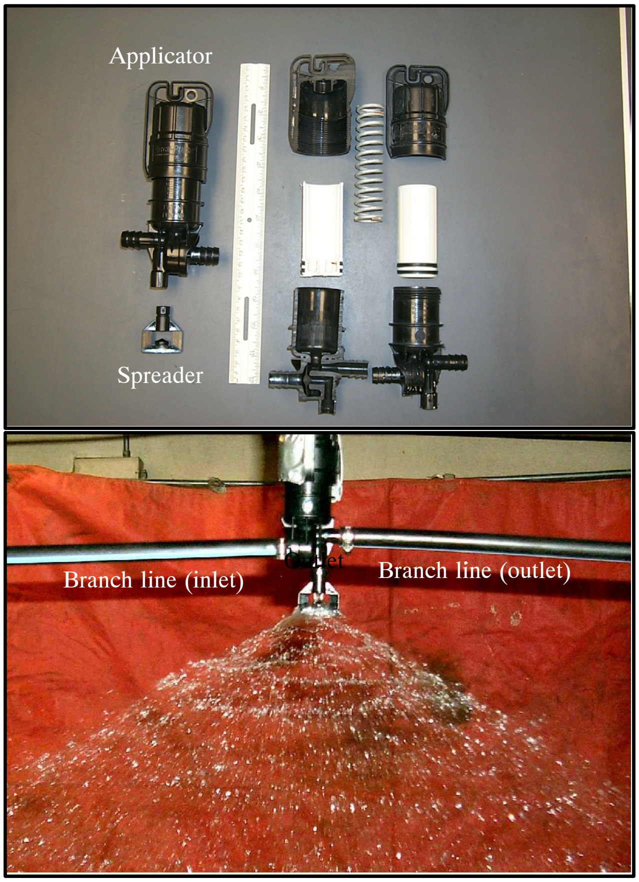


Figure 2. An Accu-Pulse applicator: internal components (top) and spraying on a branch line (bottom).

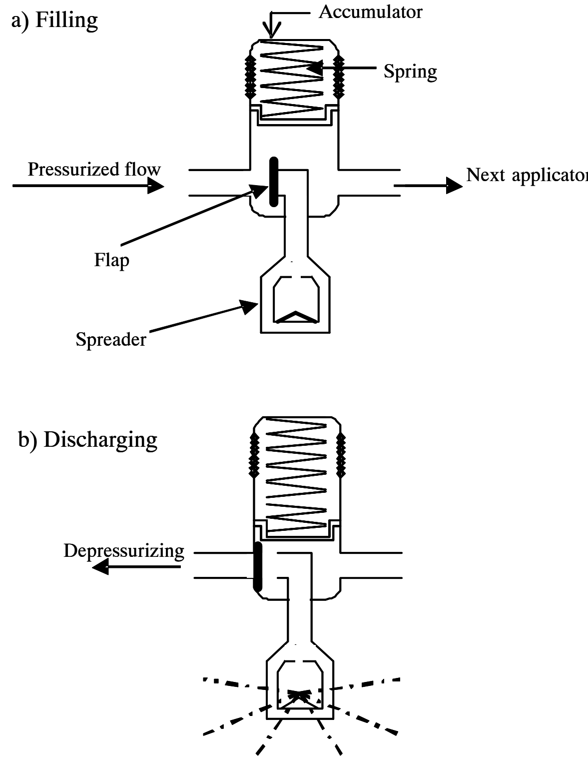


Figure 3. Schematics of an Accu-Pulse applicator showing the accumulator's spring and flap valve positions during filling (a) and discharging (b).

applicator inlet port (see flap position in fig. 3b), allowing the compressed spring to expand, which forces the cylinder downward and discharges the solution onto a convex plate or spreader (fig. 2). The applicators have threaded caps and provide a wide range of settings for volume. The relationship between discharge volume (*V*, mL) and cap setting (*S*) is:

$$V = 7.8 + 1.16 \times S \tag{1}$$

where the cap settings (*S*) range from 0 to 20 and correspond to theoretical discharge volumes per pulse of 8 to 31 mL (0.27 to 1.05 oz), respectively.

Parameters Affecting Performance

Parameters such as discharge uniformity, spray pattern, droplet size, and wetting coverage are of interest to growers but typically are not analyzed quantitatively by most producers or applicators. These parameters affect spray effectiveness. One of the important engineering parameters affecting optimal performance of Accu-Pulse is the pulse time, or the time required to ensure complete draining and refilling of all applicators on a branch line before initiating the next pulse. Another important parameter is the length of time to keep the FIRE valve open (to the atmosphere) to initiate pulsing.

The pulse time is a function of liquid pressure during refilling, the number of applicators on the branch line, and their discharge volume settings. A typical application rate for Accu-Pulse is 234 L/ha (25 gal/acre). The application rate is dependent upon the volume settings of the applicators, the pulsing interval, and speed of travel. Because the applicators are uniformly spaced 1.52 m (5 ft) apart on the branch lines, they are set at increasingly higher flow rates along a center pivot to accommodate the increasing area of coverage as distance increases from the center. For a given center pivot, a computer program is used to determine the pulse intervals and applicator settings for each branch line as a function of drive unit speeds and span lengths along the pivot. The pulse interval may vary from one span to the next, particularly if drive unit speeds are different. One of the important criterions for application effectiveness is the amount of coverage of a plant's canopy or the ground. The higher the number of pulses per unit distance travel is desirable as it is expected to increase coverage per unit area. The pulse interval must, on the one hand, be greater than the minimum time required to refill the branch line, but on the other hand, it should be short enough for adequate spray overlap as the tower moves. The varying applicator discharge settings and pulse intervals combined with the start/stop movements of the towers result in enormous combinations of events during a field application. These many combinations complicate system evaluation, particularly under field conditions.

Methods and Materials

Applicator Spray Pattern

Static catch can tests of applicator spray patterns were conducted in the laboratory to quantify the shape of the pattern at different accumulator volume settings, heights above ground, and operating pressures. A total of 167 catch cans [8.25-cm (3.25-in.) inside diameter and 15 cm (5.91 in.) high] were placed in radial lines [covering a maximum of 2.44 m (8 ft) in radius] under an Accu-Pulse branch line

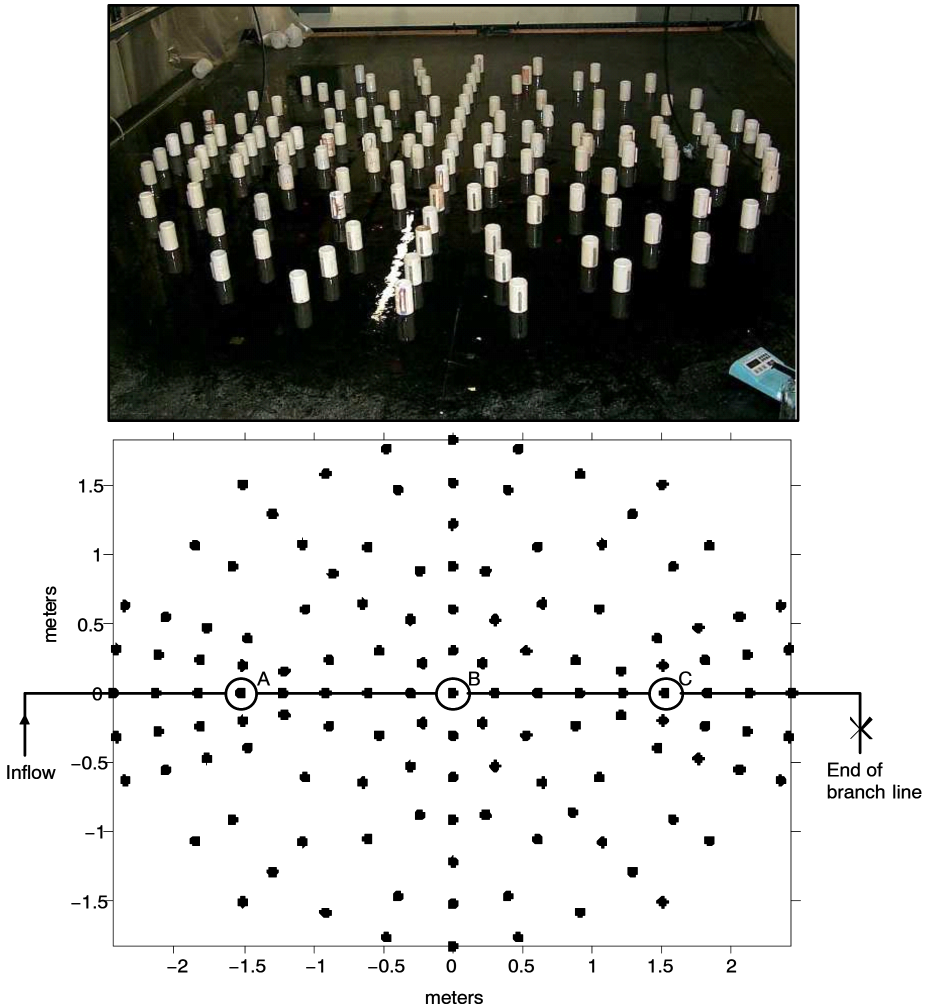


Figure 4. Catch cans in the laboratory (top) and their spatial positions in respect to the Accu-Pulse branch line with three applicators marked as A, B, and C (bottom) (1 m = 3.3 ft).

(fig. 4). The catch can spacing was 0.305 m (1 ft) in the radial direction in either 15- or 30-degree increments in the angular direction. There were three applicators (shown as A, B, and C in fig. 4) at 1.52-m (5-ft) spacing on the branch line. The outer applicators (A & C) were included as buffers and their discharge was directed to a drainpipe to prevent their spray contribution to the catch cans. The volume of water in each catch can was measured with a graduated cylinder after 6000 pulses.

Spray pattern tests were conducted with the spreader at the bottom of the applicator set at 0.61, 0.91, 1.22, 1.52, and 1.83 m (2, 3, 4, 5, and 6 ft) above the catch cans. Catch can data were collected for two applicator cap settings of 5 and 15 [corresponding to discharge volumes of 13.6 and 25.2 mL (0.46 to 0.85 oz) per pulse, respectively] at an operating pressure of 379 kPa (55 psi). The effect of different operating pressures on spray pattern was examined in a second set of tests with the applicator set at 5 and 15 volume settings and pressures of 379 and 482 kPa (55 and 70 psi). In all tests, the branch line pressure was created with a centrifugal pump and pulsing occurred 0.5 s after a pressure transducer at the end of the branch line indicated the desired pressure following a pulse. The spreader was a convex plate with side arms (fig. 2). The side arms interfere with the nozzle discharge and thus were always aligned parallel to the branch line for consistency. The tests were carried out by setting all three applicators at the desired setting, starting the pump (without pulsing), flushing the branch line with water for 5 min to minimize entrapped air bubbles, pulsing 6000 times, and measuring the volume of water in each catch can. The data were analyzed and spray patterns produced using the Surfer Software (V7.0, Golden Software, Inc., Golden, Colo.).

Applicator Wetting Coverage

An important measurement of spray effectiveness is the percent coverage (or wetting) per unit area of a target plant or ground surface as the spray boom passes over. Wetting coverage tests were conducted under an Accu-Pulse installed on a two-tower center pivot located at the Agricultural Engineering Research Center (AERC), Colorado State University (Fort Collins, Colo.) and under a commercial Accu-Pulse installed on an eight-tower center pivot in a field near Yuma, Colorado. For comparison, wetting coverage tests were also conducted under a ground rig sprayer at the AERC site.

The Accu-Pulse system installed on the two-tower pivot at AERC consisted of a branch line that was 51.2 m (168 ft) long and had 33 applicators at 1.52-m (5-ft) spacing. The

33 applicators were set to pulse interval every 23 s, delivering 224 L/ha (24 gal/acre) that matched the application rate of a ground rig sprayer. Preliminary tests showed the length of time to keep the FIRE valve open (to the atmosphere) to initiate pulsing was 0.25 s. The applicator volume (cap) settings ranged from 4 (first applicator) to 18 (last applicator). To capture the spatial variability of percent wetting coverage, a total of 30 collectors (resembling artificial plants) were placed underneath the Accu-Pulse branch line in the orientation shown in figure 5a. This orientation resembles six parallel rows of plants (A through F) that were 0.76 m (30 in.) apart, with five plants (1 through 5) per row. Each collector had three arms set at 120-degree intervals to which water-sensitive papers [76 × 52 mm (3 × 2 in.), Syngenta Crop Protection AG, CH-4002 Basel, Switzerland] were attached. Each collector (fig. 5b) was attached to a 0.9 m (36 in.) long and 13-mm (0.5-in.) diameter aluminum that was rod sharpened at one end. The Accu-Pulse branch line was set at 0.91 m (3 ft) above the collectors' arms, which were 0.61 m (2 ft) above the ground surface. The water-sensitive papers were placed on all collectors' arms just before starting the Accu-Pulse and were immediately collected after the pivot passed over them. The same experiments were conducted under a ground rig sprayer. The ground rig had nozzles spaced 0.51 m (20 in.) apart and 0.43 m (17 in.) above the collectors' arms. The ground rig straddled the center two rows (C & D), with its spray coverage data from the outer two rows (A & F) not used in the analysis due to lack of complete overlap.

Similar wetting coverage tests were also conducted under a commercial Accu-Pulse installed on an eight-tower center

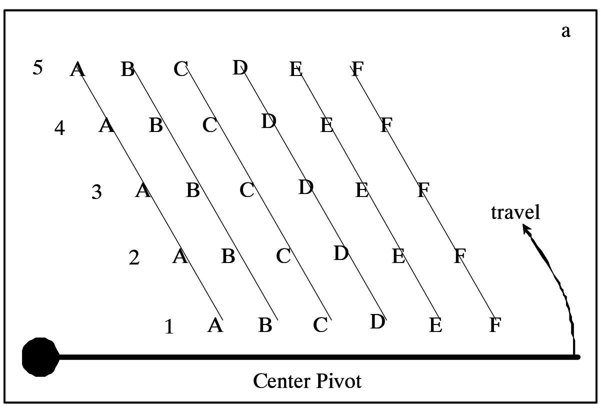


Figure 5. Schematic of a 5 × 6 grid of collectors (marked A through F) placed underneath an Accu-Pulse installed on a center pivot at the AERC site (a), and a collector with its three arms (b).

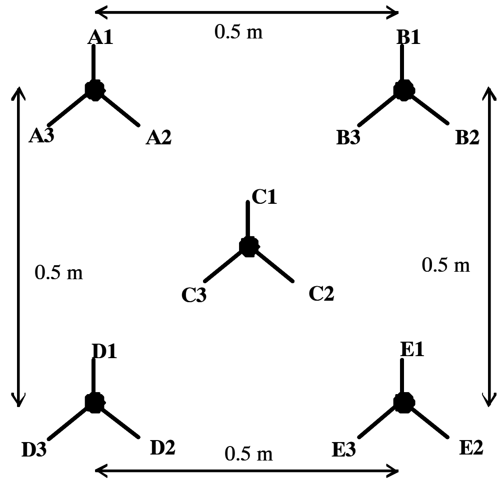


Figure 6. Schematic of the 0.5-m (1.64-ft) grid used at the Yuma site with five collectors (A through E) with three arms per collector.

pivot at Yuma, Colorado, designed to deliver 224 L/ha (24 gal/acre) with a pulse interval of 9 s. The tests were conducted before planting to eliminate crop interference. Three 0.5-m (1.64-ft) grids with each grid composed of five collectors (fig. 6) were placed on a radial line in the field. The three grids were placed between towers one and two, four and five, and seven and eight. This radial setting of the three grids was replicated at a second radial line. The Accu-Pulse passed over the first radial set of grids about 15 min after starting the system and crossed the second radial grids 30 min later. The water-sensitive papers were placed on all the arms of the collectors just before the start of the pivot and were immediately collected after the pivot passed over them.

The placement, collection, scanning, and image processing of depositions on water-sensitive papers are time consuming and labor intensive. Water-sensitive papers from all wetting coverage tests were scanned at 300 dpi to create a digital image, which was processed by image processor software to count the number of pixels that were darker than a user-defined threshold value. Because of low application volumes and minimized overlap of stains, results from water-sensitive papers were useful to compute percent wetting coverage, for instance the ratio of the number of dark pixels to the total pixels per paper.

Applicator Discharge Uniformity Across a Branch Line

A single branch line with 30 applicators spaced at 1.52-m (5-ft) intervals was set up in the laboratory for discharge measurements. The branch line was suspended from three rows of 9-mm (3/8-in.) steel cables approximately 1.22 m (4 ft) above the test floor. The objective was to test the uniformity of discharge for three replications of 50 consecutive pulses for a range of operating pressures of 241, 310, 379, 482, and 620 kPa (35, 45, 55, 65, 70, and 90 psi) and a range of constant applicator settings for all 30 applicators of 0, 5, 10, 15, and 20. The intention was to detect discharge variability across the branch line without complicating the test with varying applicator settings. A valve at the end of the branch line was used to flush the line of possible entrapped air for five min before each test. Prior to each test, 200 pulses were conducted to additionally flush possible trapped air inside the applicators. With the applicators set at the desired setting, a 1-gal plastic jug was hung underneath each applicator nozzle to catch the entire 50-pulse volume of water, which was measured with a graduated cylinder.

Refill Timing of Applicators and Branch Lines

Two refill timing tests were performed in the laboratory using the previously described branch line with 30 applicators. In the first test, the time to completely refill the whole branch line was measured using a pressure gauge and a stopwatch. A pressure gauge was installed at the end of the branch line and the elapsed time from the instant of discharge to the moment the gauge reached the desired operating pressure (signaling end of refilling) was measured. Time to refill was measured with all 30 applicators set at a constant volume setting of 0, 10, or 20 at operating pressures of 379 and 482 kPa (55 and 70 psi), with each test repeated three times.

A better understanding of the timing sequence of events within an applicator and flow characteristics of the branch line during pulsing intervals are needed for hydraulic modeling and design purposes. For that purpose, an applicator was instrumented to allow measurement of compression and expansion of its spring (shown in fig. 3) during pulsing. A 10-mm diameter hole was drilled in the cap of an applicator and a thin metal rod (with a flat foot) was placed through the hole with the foot resting on top of the applicator's piston. The hole had no effect on the applicator's operation or hydraulics. The instrumented applicator was set at a volume setting of zero and replaced the first applicator on the 30-applicator branch line. With all other applicators also set at zero, the branch line was set to pulse every 9 s at an operating pressure of 379 kPa (55 psi). At the instant of discharge, the metal rod rapidly moved downward, coming to a momentary stop before moving upward during refilling. Two time measurements (called time1 and time2) were recorded: time1 = elapsed time from the instant of discharge to start of spring compression marked by the rod just starting to move back upward after coming to a momentary stop (marking the completion of discharge), and time2 = elapsed time from the instant of discharge to the end of spring compression marked by the rod coming to a complete stop after rising (marking the end of refill or simply the minimum required pulse time). The difference between time1 and time2 represents the applicator's refill time (time3) (or the total spring compression time). After completing three reps of the above time measurements for the first applicator on the 30-applicator branch line, the operating pressure was raised to 482 kPa (70 psi) and the test was repeated. With the instrumented applicator still at position one on the branch line, this procedure of measuring time1 and time2 at the two operating pressures was repeated with all 30 applicator settings changed from 0 to 10 or 20. The entire procedure described above was then repeated for each of the odd numbered applicators (i.e. 3, 5, 7, 9, 11 ... 29), as well as applicator 30, by replacing each one sequentially with the instrumented applicator.

Results and Discussions

Effect of Applicator Volume Setting and Height on Spray Pattern

The variability in catch can volumes was very high (percent coefficient of variation, CV, values well above 100), especially at lower heights (table 1). The tests were not replicated but the high spatial variability and the shapes of the spray patterns were consistent across varying applicator volume and height settings and line pressures. Analysis of the catch can data using kriging interpolation showed that the spray pattern was a donut shape with distinct peaks, with two examples shown in figures 7 and 8 for the applicator set at 5 and 15 volume settings and placed at 0.61 and 1.83 m (2 and 6 ft) above the floor, respectively. The outer peaks are the result of flow interference caused by the side arms of the spreader (shown in fig. 2). As highlighted in figures 7 and 8, the spray patterns were more a function of height than applicator volume setting.

The wetted radius of the spray pattern increased with increasing height of the spreader. The wetted radius increased from 1.22 m (4 ft) for the spreader at a height of 0.61 to 2.44 m (2 to 8 ft) at a height of 1.83 m (6 ft) (fig. 9). The wetted radius was always greater than the height of the spreader, providing a minimum of more that 50% overlap between adjacent applicators at all height settings. Also as the height of the spreader increased, the peak of the catch can volume decreased and moved further away from the applicator. For the constant applicator spacing tested herein, results imply that the overlap between adjacent applicators will change as the height of the applicators is adjusted for plant height during the season. For instance, the overlap between adjacent applicators is about 80% when the spreader is at a height of 0.61 m (2 ft) while the overlap increases to 160% as the spreader height is increased to 1.83 (6 ft). For a given volume setting, this varying overlap will affect the

Table 1. Summary of catch can data (167 cans) from underneath an Accu-Pulse spray applicator after 6000 pulses.

Applicator Volume Setting	Applicator Height (m)	Volume in Catch Cans Mean (mL)	CV[a] (%)	Range[b] (mL)
Operating pressure = 379 kPa (55 psi)				
5	0.61	23	247	0–416
5	0.91	18	150	0–108
5	1.22	20	160	0–238
5	1.52	24	126	0–203
5	1.83	18	90	0–73
15	0.61	45	222	0–724
15	0.91	43	180	0–335
15	1.22	40	186	0–508
15	1.52	37	158	0–335
15	1.83	41	112	0–290
Operating pressure = 379 kPa (55 psi)				
5	1.52	19	150	0–164
15	1.52	45	114	0–281
Operating pressure = 482 kPa (70 psi)				
5	1.52	21	160	0–202
15	1.52	45	111	0–280

[a] CV = coefficient of variation.
[b] Range = minimum and maximum values.

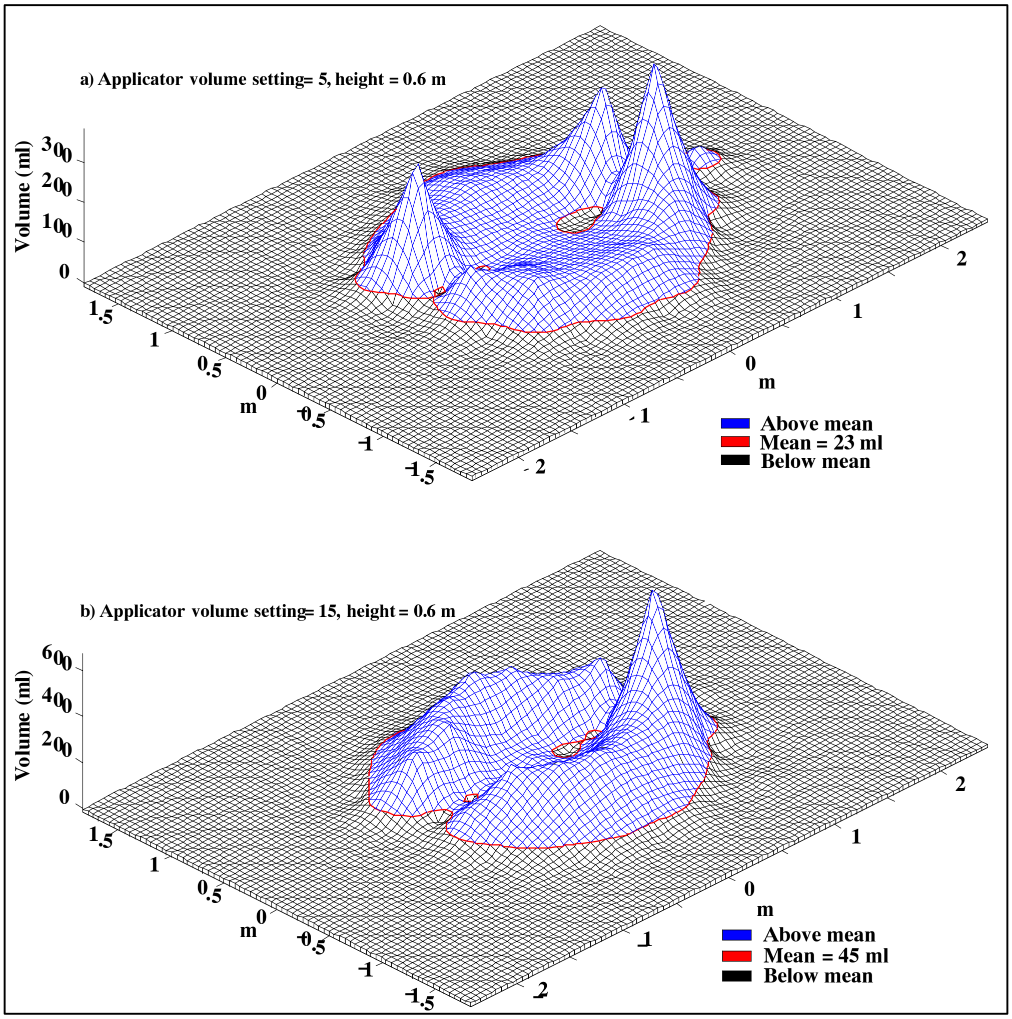


Figure 7. Three-dimensional spray patterns for a single spraying Accu-Pulse applicator at a height of 0.61 m (2 ft) above the catch cans and at volume settings of 5 (a) and 15 (b) (after 6000 pulses).

spatial uniformity of the chemical application. The height of the applicators is adjustable from 1 to 2.7 m (3.3 to 8.68 ft). Over that range, the wetted radius will vary from 1.6 to roughly 3.3 m (5.2 to 10.8 ft), respectively, and the same rate of chemical solution application will be spread across a ground area four times greater when applicators are at a height of 2.7 m rather than a height of 1 m. The expected effect is non-uniformity in chemical coverage on a ground area basis, but because of the interception by the growing plants, the increased overlap with increased height may not be realized because of that interception.

Variability of Percent Wetting Coverage

Accu-Pulse produced larger spray droplets than the ground rig sprayer (fig. 10), suggesting that application via Accu-Pulse may be less subject to drift compared to a ground rig sprayer. However, the wetting coverage was spatially less uniform under Accu-Pulse than the ground rig. At the AERC site, the spatial variability was higher and percent coverage was lower under the Accu-Pulse than the ground rig (fig. 11). Percent coverage was about twice greater and variability (CV) was two-third smaller underneath the spray rig (58% with a CV of 12%) than the Accu-Pulse (31% with a CV of 35%) (table 2). For each system, coverage did not show any obvious directional bias, being similar in the longitudinal (i.e., parallel to the spraying boom) and forward (perpendicular to the spraying boom) directions (table 2).

The method of application affects coverage and the two application systems are distinctly different. The ground rig is a continuous spraying while Accu-Pulse is intermittent. For a pulse interval of 23 s at AERC, at a drive unit speed of 2.2 m/min (7.2 ft/min), and a maximum wetted diameter of 4.3 m (14 ft), pulses occurred every 0.85 m (2.8 ft) of travel, or roughly a maximum of five pulses impinging a given collector. Since each pulse lasts 0.25 s, the Accu-Pulse sprayed a collector an equivalent of 1.2 s while the ground rig [at 107 m/min (350 ft/min)] sprayed a collector for 2.4 s or twice as long as the Accu-Pulse. Typical pulse intervals for Accu-Pulse under commercial center pivots are about nine seconds for high speed and modern towers. A 9-s pulse time for the AERC pivot produces a calculated 13 pulses impinging a given collector, or 2.5 times more pulses than at the 23-s interval. However, a 9-s pulse time would have required redesigning the applicators to lower discharge settings to keep the desired application rate of 224 L/ha (24 gal/acre). The combined effect of increasing the number of pulses per distance traveled while decreasing the discharge per pulse on coverage is not entirely known from this study.

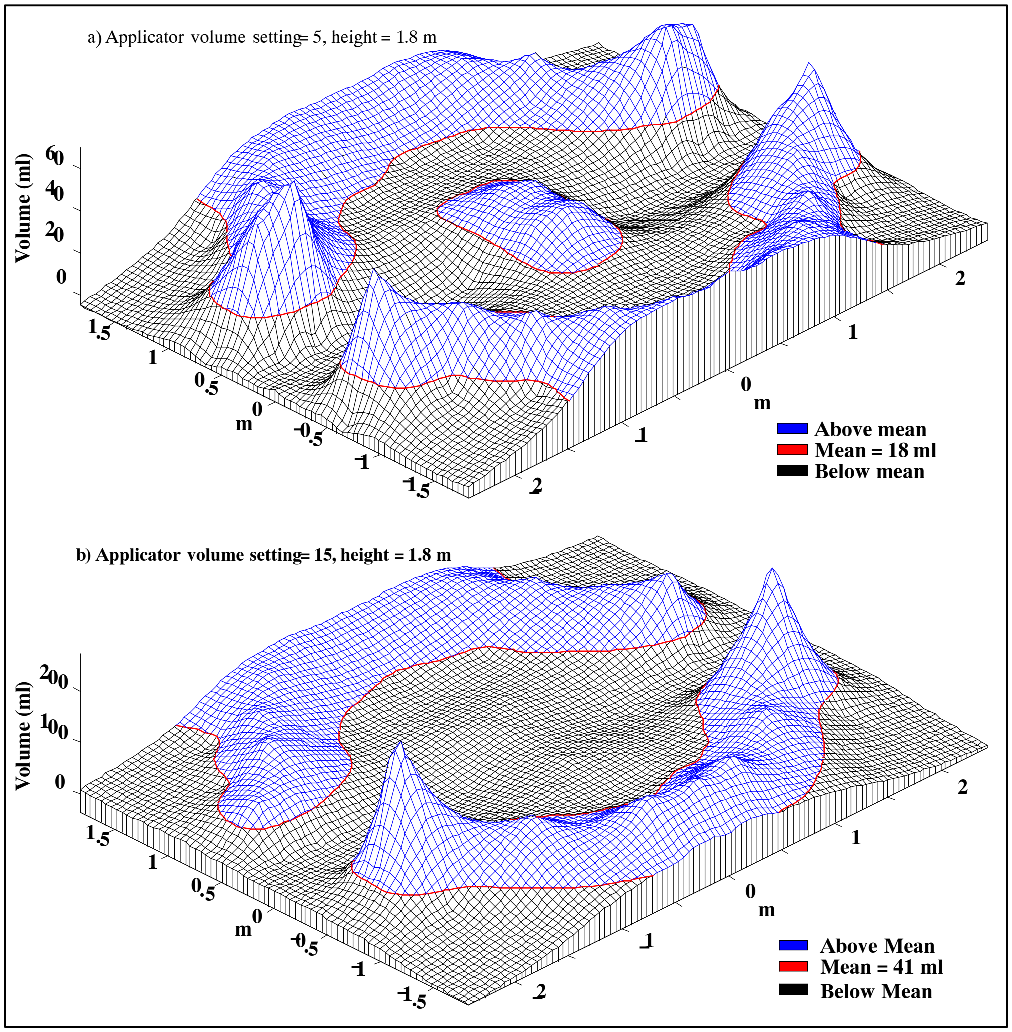


Figure 8. Three−dimensional spray patterns for a single spraying Accu-Pulse applicator at a height of 1.83 m (6 ft) above the catch cans and volume settings of 5 (a) and 15 (b) (after 6000 pulses).

When a similar wetting coverage test was conducted using a commercial Accu-Pulse system at the Yuma site, the coverage values slightly improved and variability decreased as compared to the AERC data, but still remained below the spray rig data. As highlighted in table 3, overall mean coverage values at Yuma were 43%, 40%, and 40% for spans two, five, and eight. It is noted that the Yuma tests were conducted on 25 April 2003 with high winds, during which ground rig, chemigation, or aerial application methods would have most likely been avoided.

Discharge Variability Across a Branch Line

Preliminary tests showed the greatest cause of variability in applicator discharge across a branch line was due to the presence of air in the branch line. The effect was mostly a large difference in discharge from two adjacent nozzles and not across the entire branch line. Any entrapped air in the branch line expands as the line pressure is reduced to initiate pulsing. This phenomenon tends to force liquid solution in the 1.52-m (5-ft) branch line between two applicators to back up into the upstream applicator during discharge. Since there is no flap (or valve) to seal the applicator's outlet port during discharge (see fig. 3), this backflow solution discharges through the nozzle of the upstream applicator, which can increase the applicator's discharge up to two- to three-fold. Flushing the branch line before pulsing reduced, but did not always eliminate, the entrapped air effect.

In the absence of entrapped air, repeatability of discharge volume across the branch line and over time was good (fig. 12). As summarized in table 4, mean discharge volumes per pulse were 9.8, 14.6, 20.6, 25.0, and 29.3 mL (0.33, 0.49, 0.69, 0.83, and 0.98 oz) for the applicator settings of 0, 5, 10, 15, and 20, respectively. These measured values deviate by -25%, 7%, 6%, 1%, and 5% from the theoretical values at the 0, 5, 10, 15, and 20 applicator settings, respectively.

Higher line pressures did not change applicator discharge volume significantly because the spring was adequately compressed at all pressures during refilling (fig. 13). However, as the operating pressure and the applicator setting increased, discharge variability across the branch line decreased. At 379-kPa (55-psi) operating pressure, CV values of 32%, 23%, 15%, 11%, and 14% were found for the 0, 5, 10, 15, and 20 settings (table 4). No clear classification of discharge variability was found for chemical spray nozzles. The discharge variability (CV) of less than 15% was found for medium to high discharge settings [19 to 31 mL (0.64 to 1.05 oz)] and was considered good. At lower settings [below 19 mL (0.64 oz)], variability was fair to poor, ranging

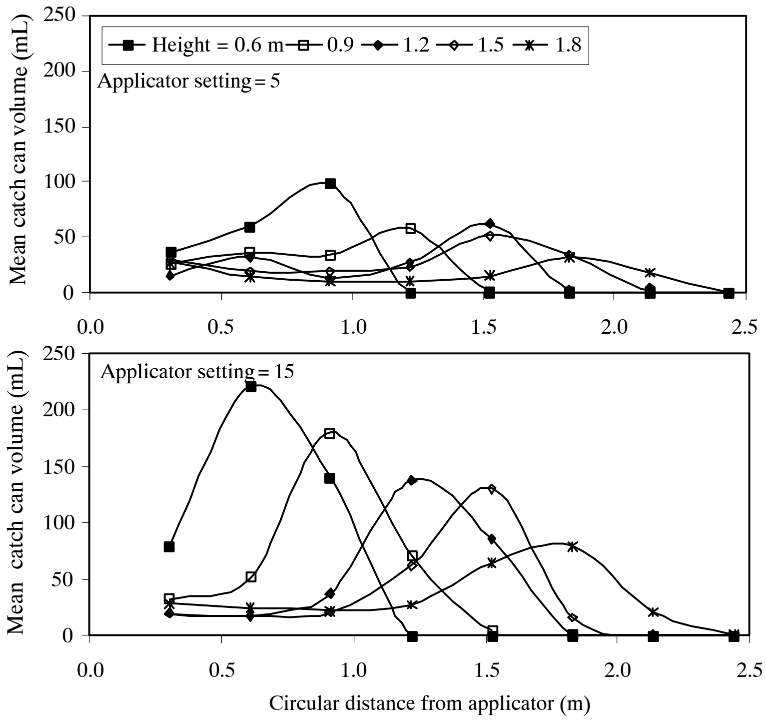
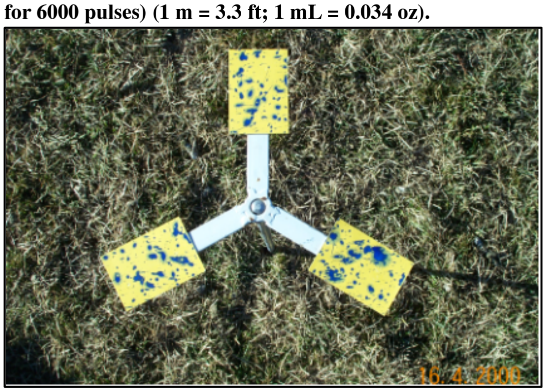
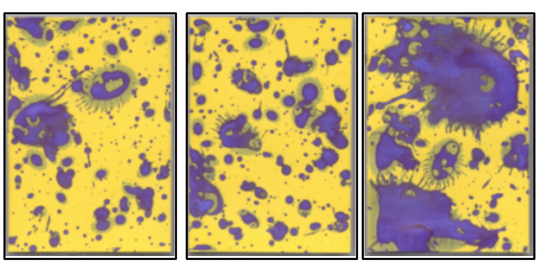


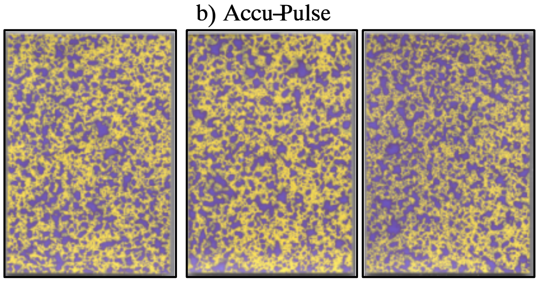
Figure 9. Mean of catch can volumes in a series of circular rings at varying radii from a pulsing applicator at volume settings 5 (top) and 15 (bottom) (data for 6000 pulses) (1 m = 3.3 ft; 1 mL = 0.034 oz).



a) Collector with stained water sensitive papers



b) Accu-Pulse



c) Ground rig sprayer

Figure 10. Stained water-sensitive papers on three arms of a collector placed underneath a spraying Accu-Pulse (a & b) and underneath a ground rig sprayer (c).

from 13% to 34%. The zero volume setting had the highest variability, with CV values ranging from 15% to 34%. The zero setting is usually used for the first few applicators near the pivot that are expected to cover a small percentage of the field.

Table 2. Summary of wetting coverage values for water-sensitive papers on 30 collectors[a] placed underneath a spraying Accu-Pulse and a ground rig sprayer at the AERC site.

	Wetting Coverage for Ground Rig Sprayer		Wetting Coverage for Accu-Pulse	
	Mean (%)	CV[b] (%)	Mean (%)	CV[b] (%)
Across collectors 1 through 5 in the longitudinal direction (i.e., parallel to the spraying boom, fig. 5a)				
1	60	10	35	46
2	54	13	32	34
3	61	11	29	27
4	57	14	30	27
5	61	11	28	39
Across collectors A through F in the forward row direction (i.e., perpendicular to the spraying boom, fig. 5a)				
A	–	–	28	43
B	56	12	33	33
C	57	12	30	40
D	62	10	32	34
E	58	14	34	26
F	–	–	26	35
Across all collectors (fig. 5a)				
Replication 1	58	12	30	33
Replication 2	58	14	32	40
Overall	58	12	31	35

[a] 5 × 6 rows of collectors with three water-sensitive papers per collector.
[b] CV = coefficient of variation.

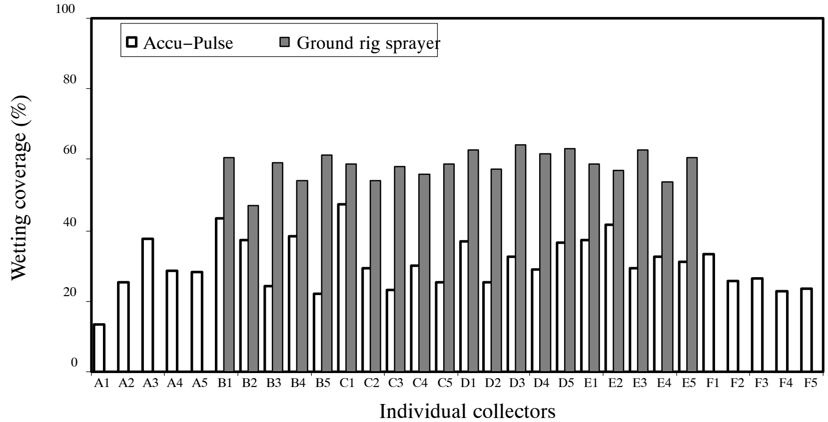


Figure 11. Measured percent wetting coverage for each collector (mean of three water−sensitive papers per collector) from underneath a spraying Accu-Pulse and a ground rig sprayer at the AERC site.

Table 3. Summary of wetting coverage values for water-sensitive papers from three 0.5-m (1.64-ft) grids placed in two Radial lines and underneath spans 2, 5, and 8 with each grid composed of five collectors with three water-sensitive papers per collector placed underneath a commercial Accu-Pulse at Yuma, Colorado.

		Wetting Coverage					
		Mean (%)			CV[a] (%)		
	Collector	Span 2	Span 5	Span 8	Span 2	Span 5	Span 8
Wetting coverage for each collector in each 0.5-m grid							
Radial line 1	A	48	30	37	4	23	14
	B	51	37	36	15	12	12
	C	41	39	34	26	9	6
	D	43	47	37	6	–	15
	E	39	30	39	26	53	28
Radial line 2	A	45	40	48	8	12	5
	B	46	44	50	20	22	27
	C	43	44	44	7	36	11
	D	41	39	39	9	2	14
	E	38	48	40	4	19	4
Wetting coverage across all three 0.5-m grids in each radial line							
Radial line 1	All collectors	44	37	36	15	21	15
Radial line 2	All collectors	43	43	44	10	19	13
Overall	All collectors	43	40	40	12	20	14

[a] CV = coefficient of variation.

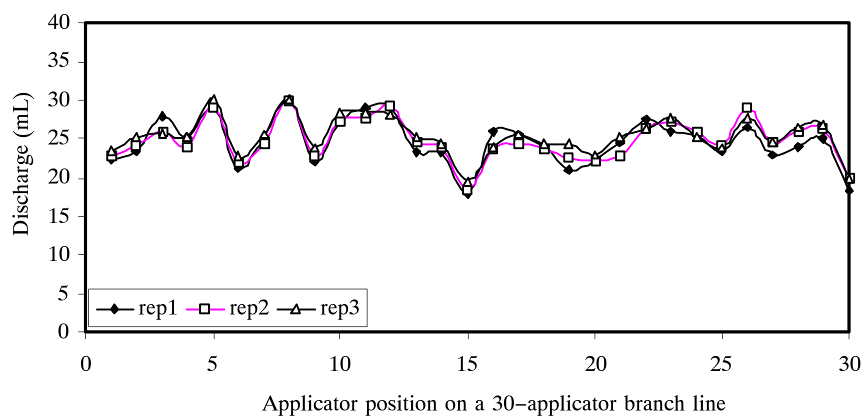


Figure 12. Three replicated measurements of discharge volume per pulse from 30 applicators (volume setting 15) across a branch line (1 mL = 0.034 oz).

Table 4. Summary of applicator discharge per pulse measurements for 30 applicators set at various constant volume settings (0, 5, 10, 15, or 20) on a branch line in the laboratory.

	Mean (mL)					CV[a] (%)					Minimum (mL)					Maximum (mL)				
Applicator volume setting	0	5	10	15	20	0	5	10	15	20	0	5	10	15	20	0	5	10	15	20
Operating press. [kPa (psi)]																				
241 (35)	5.7	15.7	17.8	24.7	26.0	15	20	15	9	14	4.1	8.0	11.0	19.9	18.9	7.7	19.6	23.3	29.0	33.5
310 (45)	10.6	15.1	20.3	26.2	25.4	34	24	12	10	14	4.4	9.8	16.4	19.9	19.9	18.8	24.4	25.5	30.1	32.6
379 (55)	9.4	13.7	20.3	25.0	29.3	25	23	13	11	14	5.7	5.1	15.0	18.7	20.0	16.5	22.5	25.6	30.1	41.0
482 (70)	7.8	13.6	19.9	26.4	25.1	31	14	12	9	10	5.3	11.2	15.8	19.0	19.9	15.6	18.3	25.8	33.0	30.6
620 (90)	9.2	14.2	21.3	26.8	29.5	32	13	9	6	8	6.1	11.3	16.8	23.3	24.5	17.5	18.8	25.5	30.3	36.9
Mean	8.5	14.5	19.9	25.8	27.1															
Theoretical discharge (eq. 1)	7.8	13.6	19.4	25.2	31.0															

[a] CV = coefficient of variation.

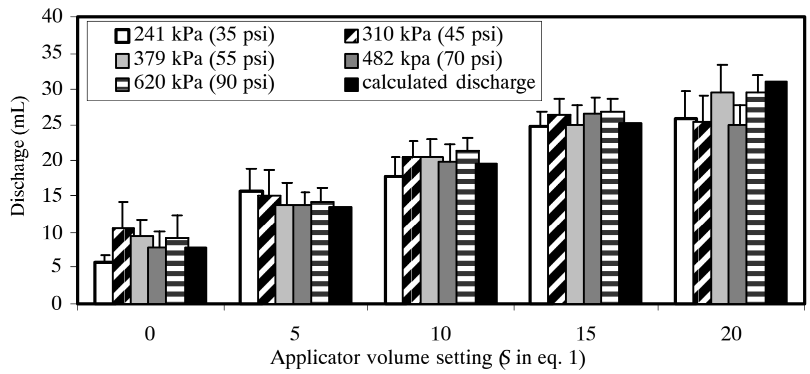


Figure 13. Mean and standard deviation (bars) of discharge volume measurements for 30 applicators on a branch line at various volume settings and branch line operating pressures (calculated discharge values are from eq. 1) (1 mL = 0.034 oz).

Refill Timing for Applicators and Branch Lines

The time required to refill a branch line (and all of its attached applicators) following a pulse is an important parameter affecting system performance. Results show that refill time was a function of the operating pressure as well as the applicator discharge setting, with lower volume settings and higher operating pressures leading to quicker refill times. Mean refill times at 379-kPa (55-psi) operating pressure were 2, 3.6, and 5 s with all 30 applicators on the branch line set at volume settings 0, 10, or 20, respectively. Pulsing faster than these refill times leads to incomplete refilling which could undermine performance. Refill times were reduced by about 0.5 s as pressure increased to 482 kPa (70 psi). This was expected as a higher pressure translates to a higher flow rate during refill. Results suggest that a minimum pulse time of 9 s, as recommended by the manufacturer, is sufficiently long to ensure adequate refilling of applicators prior to the next pulse.

The compression and expansion intervals of applicator's spring during pulsing are a measure of the refill time. Figure 14 presents measured time1 and time2 variables, with the latter representing the lapsed time from the moment of pulsing to the end of the refill process of a given applicator. As shown, the time for sequential refilling of applicators increases as the distance of applicator to the inlet increases. It is noted that time1 (the elapsed time for complete emptying of all applicators) was about 1 s and largely unaffected by applicator volume setting. The timing event measurements are helpful in designing and modeling the flow characteristics and chemical mixing within the branch line and into each applicator.

Conclusions

The unique applicators enable applications at rates much lower than chemigation and pivot-attached sprayers and similar to ground sprayers. Accu-Pulse basically converts center pivots into long spray rigs that can spray large fields. A branch line with 30 applicators spaced at 1.52-m (5-ft) intervals required a fraction of a second to complete pulsing and up to 5 s to complete the refilling process following the pulse. The manufacturer recommends a minimum of 9 s between pulses. For the conditions tested in this study, the 9-s pulse time is found to be adequately long to ensure a complete refilling of applicators. Entrapped air caused significant discharge variability, with most of the effect reflected in large difference in discharge between two adjacent applicators, and not across the entire branch line. In the absence of entrapped air in the branch line, the discharge variability (CV) was less than 15% for medium to high discharge settings [19 to 31 mL (0.64 to 1.05 oz)] and varied from 13% to 34% at smaller settings [below 19 mL (0.64 oz)]. As the operating pressure and the applicator discharge setting increased, discharge variability across the branch line decreased. Flushing the branch line and performing pre-application pulsing reduced the entrapped air effect and is thus recommended.

Uniformity of applicator discharge is not synonymous with application uniformity as the wetting coverage tests show. Based on stained water-sensitive papers, much larger droplet sizes were detected under Accu-Pulse than the ground rig sprayer, suggesting a greater potential to reduce spray drift. However, the spatial variability of coverage was about two to three times larger and percent wetting coverage was about one-third to half smaller under Accu-Pulse than

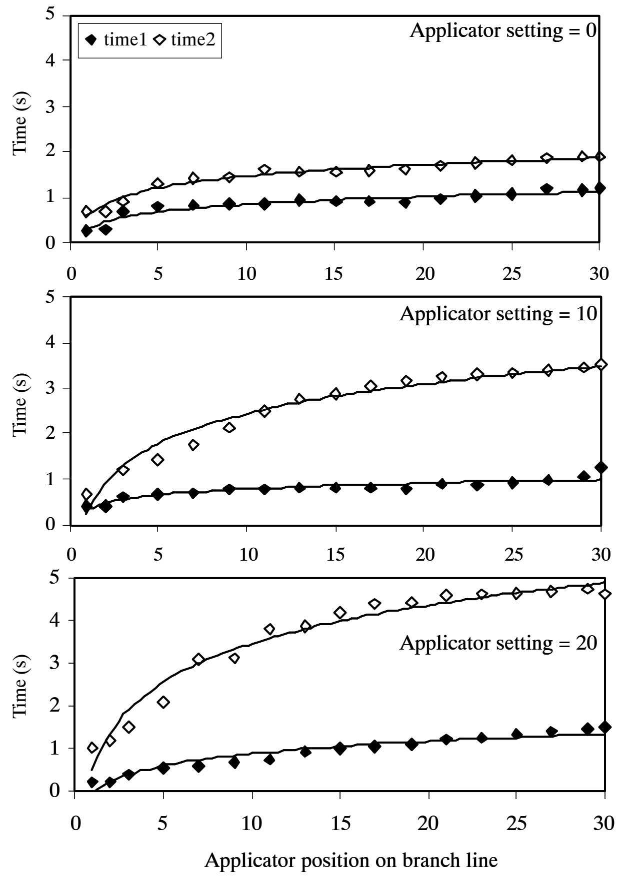


Figure 14. Measured elapsed time to discharge (time1) and to complete refilling (time2) from the instant of pulsing of applicators on a 30-applicator branch line at 0, 10, or 20 volume settings.

the ground sprayer. For instance, mean coverage values for a commercial Accu-Pulse on an eight-tower pivot at Yuma were in low 40% range as compared to coverage values of about 60% for a ground sprayer. What is not known from this study is whether the 40% coverage by Accu-Pulse at Yuma is satisfactory. That must be determined based on agronomic performance or chemical efficacy defined as the percent control relative to a no chemical treatment control.

Some producers are interested in using self-propelled sprinkler systems to apply chemicals effectively, economically, and in a timely fashion without delay due to weather or soil conditions. One important performance criteria is the application uniformity of chemical concentration, particularly for applications at very low rates. This study does not address uniformity in applied chemicals, efficacy, or cost but advances the basic understanding of spray pattern, overlap, wetting coverage, discharge uniformity, droplet size, and pulse time characteristics of Accu-Pulse. A constant rate chemical injection pump is used in Accu-Pulse because it is considerably less expensive than a variable rate pump. This design can potentially create non-uniformity in chemical application over time and space since the rate of chemical injection is constant but the rate of water flow varies depending on the different number of towers moving. Applicators on a branch line operate as a unit and only pulse when the tower is moving. Since individual interior towers move as needed to maintain alignment, the total number of pulsing applicators and thus the flow for filling the applicators is not constant causing the flow in the supply line to be non-uniform. The effect of this potential source of varying concentration on the uniformity of the applied chemical concentration is not known at this time and requires research.

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