Chemical Control of Foliar Diseases of Peanuts, Peppers, and Onions as Affected by Spray Nozzle Types, Nozzle Orientations, Spray Intervals, and Adjuvants

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ABSTRACT

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The efficacy of disease-control chemicals applied at low spray pressure (2.1 kg/cm^2) was the same if sprayed through hollow-cone or flat-fan nozzles for control of peanut leaf spot, bacterial spot of pepper, and blast or purple blotch of onions, four diseases that represent different pathogen and crop canopy types. Control of bacterial spot of pepper was best when maneb plus zinc sulfate was added to a copper hydroxide spray that was applied twice rather than once each week. Control of blast and purple blotch on onions was best when a spreader-sticker was added to the mancozeb spray, which was applied through two nozzles over the center of each row with one oriented forward (45°) and the other backward (45°). When nozzle numbers per row were reduced from three to one for pepper but the sprays were directed primarily to the young, upper leaves, which are most susceptible to bacterial spot, disease control was not strongly compromised. When nozzle numbers were reduced from three to one for peanut and the sprays were directed to the center of row-canopy exclusively, peanut leaf spot control was improved slightly in that zone. A slight increase in peanut leaf spot occurred in the row-middle zone (vine growth between row centers) that received no sprays, but yield was not compromised. In contrast, when nozzle numbers per row were reduced from two to one (oriented downward) and no adjuvant was added to the spray mix, control of onion blast and purple blotch was inferior to that obtained with treatments where two nozzles per row were used in conjunction with the adjuvant.

Additional key words: *Allium cepa, Alternaria porri, Arachis hypogaea, Botrytis* sp., *Capsicum annuum, Cercospora arachidicola, Cercosporidium personatum, Xanthomonas campestris* pv. *vesicatoria*

In 1963, Wilson et al (15) found no notable differences between flat-fan (FFN) and hollow-cone nozzles (HCN) for disease and insect control on tomatoes, potatoes, cabbage, eggplants, and sugar beets. Yet, it is assumed that better disease and insect control is achieved if sprays are delivered through HCN rather than FFN (1,8,13). The rotating discharge of spray from the HCN is thought to impinge more efficiently on leaves with various orientations (8). Not only are pesticide applicators taught that HCN are superior to FFN (1) but questions on tests for pesticide applicator certification address this subject.

One standard question extension and commercial representatives ask a grower who has incurred poor disease control is what nozzle type he used. Also, growers are sometimes told to use high spray pressures, which require HCN. If low spray pressures could be used effectively with FFN, less expensive sprayers could be used in many situations and spray drift could be reduced both by the lower spray pressure and the characteristics of the spray from FFN. The degree of importance that should be ascribed to nozzle type needs clarification.

Studies were conducted on peanuts, peppers, and onions to determine if different spray nozzle types used at low spray pressure were as influential in foliar disease control as other variables such as nozzle orientation, spray interval, and adjuvants that could have different influences on control of specific plant diseases. The five diseases studied on the three crops represent different canopy types and both fungal and bacterial diseases.

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MATERIALS AND METHODS

Crop culture and field test design. A randomized complete block design was used for each test. Cultural methods were typical for each crop, except in the pepper test, where a postemergence application of the herbicide sethoxydim plus crop oil was used to suppress grass weeds. Chemical treatments in all tests were applied with a CO_2-pressurized backpack sprayer at a pressure of 2.1 kg/cm^2. Because different nozzle sizes have different discharge capacities, spray volume and desired rates per unit area were held constant between treatments within tests by adjusting ground speed.

Peanut (*Arachis hypogaea* L.). Peanut tests consisted of four replicates with the cultivar Florunner planted in four-row plots 6.1 m long and 0.9 m apart, with spray treatments and assessments conducted on the center two rows. The unsprayed outside rows provided a major source of inocula (5) for both early leaf spot, caused by *Cercospora arachidicola* Hori, and late leaf spot, caused by *Cercosporidium personatum* (Berk. & Curt.) Deighton. Leaf spot assessments were made by counting spots on 10 leaves randomly collected from the canopy zone that was about halfway between the ground and the top of the canopy along the row-centers. Where assessments were made in the row-middles (vine growth between row-centers), the same procedure was used, but the depth of the canopy in those areas was naturally shallow compared with the row-center canopy even though the ground was covered by the vines. Later, leaflets absent per 10 leaves became the criterion used to measure treatment influence because unsprayed or less effective treatments resulted in defoliation to the degree that leaf spot counts became unreliable (5,10). Nozzle treatments were assessed for two levels of disease by using two rates of chlorothalonil (Bravo 500), 2.48 and 1.24 L/ha.

All spray treatments in the peanut tests were applied in 374 L of water per hectare. Comparisons between nozzle types were made using HCN tip-core sizes D2-25 and D4-13 versus FFN sizes 8002 and 8003 (Spraying Systems Co., Wheaton, IL). Three nozzles per row were mounted on a horizontal boom with the center nozzle discharging downward. The outer nozzles were spaced 45.7 cm from the center and mounted on swivels to adjust for horizontal vine growth between row-centers. During early plant growth, spray from all three nozzles was directed at foliage along the row-center, but by midseason, the foliage along the row-center was receiving one-third of the total. The single-nozzle-per-row treatment with an 8003 FFN was applied at the same fungicide rate and spray concentration as the equivalent three-nozzle-per-row treatment, except the fungicide was deposited as a band 30.5–45.7 cm wide along the row-center.

In both the 1982 and 1983 peanut tests, sprays were applied at 2-wk intervals beginning 39 days after planting. Five and seven applications were made for the 1982 and 1983 tests, respectively.

Pepper (*Capsicum annuum* L.). The pepper tests consisted of four replicates; each plot was a single 5.5-m row on a raised bed with row-centers 1.2 m apart. Forty-day-old, individually containerized (Todd Trays) pepper transplants of the susceptible cultivar Yolo L were set on 10 June 1983, a time when commercial growers would normally be harvesting in the area. This time was chosen to conduct the test because temperatures and rainfall would normally enhance disease spread and progress for bacterial spot, caused by *Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye (*X. c.* pv. *vesicatoria*). Overhead irrigation was applied occasionally to enhance the epidemic.

Three days before setting the transplants, a portion (1 cm^2) of the first or second true leaf of each plant was infiltrated with a composite of three copper-resistant strains (XV E-3, XV 81-23, and XV 82-7) of *X. c.* pv. *vesicatoria* with a hypodermic syringe. Sources of inocula were pure cultures grown in nutrient broth and incubated at 30 C. Cells in the log phase of growth were centrifuged from the cultures and suspended in sufficient sterile tap water to attain an optical density of 0.3 at 600 nm in a Spectronic 20 spectrophotometer, which results in about 10^8 cells per milliliter. The final composite inoculum was made by placing 1 ml of the standardized cell concentration of each strain into a common 100 ml of sterile tap water.

All treatments were sprayed with a mixture of copper hydroxide (Kocide 101 77WP) at 3.36 kg/ha and maneb plus zinc sulfate (Manzate D 80WP) at 1.68 kg/ha in 468 L of water per hectare, except for the unsprayed treatment and another where the copper product was applied alone. All chemical treatments except the one-spray-per-week treatment were applied every 3–4 days. A single, downward-discharging HCN (D4-45) placed above the row-center was used for one treatment. The remaining chemical treatments were delivered with three nozzles per row, with one nozzle in the same position as the single-nozzle-per-row treatment and the other two spaced equidistant to the side and below the center nozzle. The three-nozzle treatments consisted of D4-45 disk-core HCN, except for the FFN treatment with 8003 nozzles. For the first eight spray dates, the side nozzles were 23 cm from the center and 15 cm below the center nozzle, and for the last five spray dates, these distances were increased to 30.5 and 25.4 cm, respectively. To facilitate spray deposition on the larger plants, each side nozzle was mounted on swivels that could be adjusted according to plant width. The percentages of leaves with any symptoms of bacterial spot were assessed with the Barratt-Horsfall method (11).

Onion (*Allium cepa* L.). The onion test consisted of five replicates; each plot was a row of transplanted sets of the cultivar Granex FI PRR on raised beds 0.92 m apart and 9.2 m long. Fungicide applications began 2 wk after transplanting, and spray intervals varied from 5 to 9 days. This variation resulted primarily from attempts to spray just before the arrival of a weather front. Seven sprays of mancozeb (Dithane M-45 80WP) at 2.24 kg diluted in 281 L of water per hectare were applied for each fungicide treatment. For select treatments, a spreader-sticker adjuvant (Triton B-1956) was added to the spray at 0.5 L/ha. Nozzle treatments included D4-25 HCN and 8003 FFN types. The HCN and FFN types were compared with and without the adjuvant where each row was sprayed with two nozzles above the row-center. Both nozzles were mounted on the same double swivel on 45° angles from the horizontal, with one aimed forward and the other backward. One treatment was sprayed without an adjuvant with a single, downward-discharging HCN centered over the row.

Disease assessments were made for both onion blast, caused by *Botrytis* sp., and purple blotch, caused by *Alternaria porri* (Ellis) Ciferri, because both diseases occurred on the leaves during the test. Percentages of leaf surface with each disease in each plot were assessed over a 22-day period beginning 34 days after the first application date.

Statistical analyses for all tests were done with the new Duncan's multiple range test, using square-root transformations for data sets in which zeros or low numbers occurred. Also, the *t* test was used for select comparisons within the 1983 peanut test.

RESULTS

Peanut. In 1982, peanut leaf spot and subsequent defoliation were high in the unsprayed treatment (Table 1). Leaf spot assessments were made 75 days after planting when no defoliation had occurred except for three leaflets, all being within plots of the unsprayed treatment. Treatments receiving chlorothalonil at 1.24 L/ha had a higher leaf spot rating than those treated at 2.48 L/ha. No notable differences occurred between nozzle types or between nozzle sizes among types at either fungicide rate. Identifiable disease foci caused enough variation in leaf spot counts between plots to preclude statistical differences between the two fungicide rates. Defoliation at later dates was a better parameter in this test to separate the effects of the two fungicide rates. At 107 days after planting (Table 1), defoliation was greater than 90% (37 of 40 leaves per sample) for the unsprayed treatment. In contrast, defoliation among treatments ranged from 34 to 51% and from 2.5 to 13% for the half and full rates of chlorothalonil, respectively. No statistical differences were found between nozzle types or between nozzle sizes among types within the low or high fungicide rates even though the ranges of defoliation were distinctly high and low, respectively.

Peanut leaf spot and associated defoliation were delayed in 1983 compared with 1982 although planting dates were similar (22 and 21 May, respectively). At 109 days after planting in 1983 (Table 2), leaf spot severity was similar to that at 75 days in the 1982 test (Table 1). Fungicide rates influenced leaf spot severity at both 123 and 137 days after planting in 1983 (Table 2). Leaf spot severities were not statistically different between nozzle types within fungicide

Table 1. Effects of spray nozzle types and two rates of chlorothalonil on peanut leaf spot control in 1982[w]

			Days after planting and assessment[y]		
			Leaf spots/ 10 leaves	Leaflets absent/10 leaves	
Nozzle type[x]	Nozzle tip no.	Chlorothalonil rate (L/ha)	75 days	95 days	107 days
None	None	None	552 a	25.8 a	37.0 a
Hollow-cone	D2-25	2.48	17 b	0.5 be	5.3 b
Hollow-cone	D4-13	2.48	7 b	0.5 be	1.3 b
Flat-fan	8002	2.48	10 b	0.0 b	2.8 b
Flat fan	8003	2.48	15 b	0.0 b	1.0 b
Flat-fan	8003	1.24	19 b	4.3 c	20.3 a
Flat-fan	8002	1.24	34 b	1.5 de[z]	15.5 ab
Hollow-cone	D4-13	1.24	28 b	2.5 c	13.5 ab
Hollow-cone	D2-25	1.24	27 b	3.5 c	16.0 a

[w] All chlorothalonil treatments began 39 days after planting and were applied in 374 L of water per hectare at 2.1 kg/cm^2 of tank pressure.

[x] Three nozzles per row were used, with one over the row-center and the other two each mounted on swivels 45.7 cm from the center.

[y] Assessments were made in the middle of the peanut canopy along the row-center. Within columns, means followed by different letters are significantly different ($P = 0.05$) according to Duncan's new multiple range test.

[z] No statistical differences among means at half rate ($P = 0.01$).

Table 2. Effects of spray nozzle types, nozzle number per row, and two rates of chlorothalonil on peanut leaf spot control in 1983[v]

Nozzle type (no./row)[w]	Nozzle tip no.	Chlorothalonil rate (L/ha)	Days after planting and assessment[x]: Leaf spots/10 leaves: 109 Days	123 Days	137 Days	Leaflets absent/10 leaves: 123 Days	137 Days	Yield[y] (kg/ha)
None	None	None	585.0 a	...[z]	...[z]	28.8 a	38.0 a	3,319 a
Hollow-cone (3)	D2-25	2.48	5.0 b	11.5 a	4.8 a	0.0 b	1.3 b	4,665 b
Flat-fan (3)	8003	2.48	2.3 b	8.3 a	19.8 a	0.3 b	0.8 b	5,041 b
Flat-fan (1)	8003	2.48	4.8 b	4.3 a	4.0 a	0.0 b	0.8 b	4,853 b
Flat-fan (3)	8003	1.24	10.0 b	50.8 b	107.0 b	0.5 b	2.3 b	4,721 b
Hollow-cone (3)	D2-25	1.24	8.0 b	61.8 b	94.3 b	0.5 b	2.5 b	4,564 b

[v] All chlorothalonil treatments began 39 days after planting and were applied in 374 L of water per hectare at 2.1 kg/cm^2 of tank pressure.
[w] Where three nozzles per row were used, one was over the row-center and the other two were each mounted on swivels 45.7 cm from the center.
[x] Assessments were made in middle of the peanut canopy along the row-center. Within columns, means followed by different letters are significantly different ($P = 0.05$ for leaflets absent/10 leaves and yield; $P = 0.01$ for leaf spots/10 leaves) according to Duncan's new multiple range test.
[y] At 9% moisture content.
[z] Defoliation too severe for counts to be made.

rates. Of particular interest was the consistent suppression, albeit small, in leaf spot severity for the single FFN treatment where the fungicide was applied in a horizontal band along row-center, which is where peanut leaf spot is usually most severe. Defoliation in excess of 90% (38 of 40 leaves per sample) did not occur in the unsprayed treatment until the peanuts were 137 days old. Defoliation means at the same time for the low and high fungicide rates ranged from 5.8 to 6.3 and from 2 to 3.3%, respectively. Defoliation was delayed and less severe in 1983 compared with 1982; however, the ranges of defoliation for the two fungicide rates in 1983 were small and without overlap. None of nozzle treatments were statistically different from each other for yield, but all were statistically different from the unsprayed treatment. The two FFN treatments with the high fungicide rate had the least defoliation at 137 days and the highest yields.

By 82 days after planting in the 1983 test, the row-middle zone was completely covered by vines and all treatments had received three of their seven designated sprays. Defoliation in the row-middle zone within the unsprayed treatment was 32 and 65%, respectively, at 123 and 137 days after planting. For the broadcast and banded treatments with FFN at the high fungicide rate, defoliation in the row-middle zone was 0 and 1.25%, respectively, at 123 days after planting and 0% for both treatments at 137 days after planting. Leaf spot counts per 10 leaves were 5 and 9.8 ($P = 0.05$) at 123 days and 9 and 33 ($P = 0.01$) at 137 days after planting for these treatments, respectively (*t* test).

Pepper. HCN and FFN were equally effective in control of bacterial spot of pepper when maneb plus zinc sulfate was added to the copper sprays that were applied twice per week through three nozzles per row (Table 3). These two treatments were the most effective at all disease assessment dates. Where a single HCN per row was used in conjunction with maneb plus zinc sulfate and a twice-per-week spray schedule, control was reduced slightly. Control was reduced considerably when sprays were applied once per week or if maneb plus zinc sulfate was not added to the copper fungicide. All sprayed treatments had significantly less disease than the unsprayed treatment except at the first assessment date for the once-per-week spray treatment and at the last assessment date for the treatment without maneb plus zinc sulfate.

Table 3. Effects of nozzle types, nozzle number per row, spray intervals, and maneb plus zinc sulfate on the efficacy of copper hydroxide for bacterial spot control of pepper in 1983[v]

Nozzle type (no./row)	Nozzle tip no.	Maneb + zinc sulfate added[w]	No. of sprays/wk	Barratt-Horsfall rating[x]: 15 July	22 July	29 July
None	None	No	0	7.3 a	7.3 a	7.5 a
Hollow-cone (3)[y]	D4-45	No	2	4.5 b	5.5 b	6.3 ab
Hollow-cone (3)	D4-45	Yes	1	5.8 a	5.5 b	5.5 bc
Hollow-cone (1)[z]	D4-45	Yes	2	2.3 c	2.5 c	4.0 cd
Hollow-cone (3)	D4-45	Yes	2	1.5 c	2.3 c	3.3 d
Flat-fan (3)	8003	Yes	2	1.8 c	2.5 c	3.3 d

[v] All copper hydroxide treatments were applied at 3.36 kg/ha in 460 L of water per hectare at 2.1 kg/cm^2 of tank pressure beginning 31 days before the first disease assessment date.
[w] Applied at 1.7 kg/ha.
[x] Within columns, means followed by different letters are significantly different ($P = 0.01$) according to Duncan's new mutiple range test (11).
[y] One nozzle above row-center and the other two equidistant to the side and below center nozzle.
[z] One nozzle above row-center.

Table 4. Effects of nozzle types, nozzle orientation, and a spray adjuvant on control of blast and purple blotch of onions when used in conjunction with mancozeb in 1984[u]

Nozzle type (no./row)	Nozzle tip no.	Adjuvant added[v]	Percent disease on leaves: Blast[w]: 17 April	25 April	Purple blotch[x]: 2 May	9 May
None	None	No	19.0 a	32.0 a	33.0 a	47.0 a
Hollow-cone (1)[y]	D4-25	No	12.0 b	11.5 b	17.7 bc	31.0 b
Hollow-cone (2)[z]	D4-25	No	10.0 b	10.9 b	16.7 bc	32.5 b
Hollow-cone (2)	D4-25	Yes	2.6 c	3.4 c	14.0 bc	24.5 bc
Flat-fan (2)	8003	No	9.0 b	10.0 b	13.3 bc	32.0 bc
Flat-fan (2)	8003	Yes	3.2 c	4.0 c	10.7 c	17.0 c

[u] All mancozeb treatments were applied at 2.24 kg/ha in 281 L of water per hectare at 2.1 kg/cm of tank pressure beginning 34 days before the first disease assessment date.
[v] Spreader-sticker applied at 0.5 L/ha.
[w] Within columns, means followed by different letters are significantly different ($P = 0.01$) according to Duncan's new multiple range test.
[x] Within columns, means followed by different letters are significantly different ($P = 0.05$) according to Duncan's new multiple range test.
[y] Over the row-center and discharging downward.
[z] Over the row-center in opposition at 45° from horizontal.

Onion. Nozzle type did not influence control of blast or purple blotch of onions when compared in the presence or absence of a spreader-sticker adjuvant in the mancozeb spray (Table 4). The use of the adjuvant with mancozeb consistently and often significantly improved control of both diseases. Control of either disease with two nozzles per row was not significantly improved compared with a single nozzle per row except with the use of the adjuvant.

DISCUSSION

HCN and FFN were equally effective for the control of peanut leaf spot (primarily late leaf spot), bacterial spot of pepper, and blast and purple blotch of onions. The delivery of identical rates of chemicals within a test through nozzles with different flow-rate capacities was achieved by strict adherence to speed calibrations. In contrast, spray intervals, adjuvants, chemical rates, and nozzle orientations significantly influenced control.

FFN are not designed for use at higher spray pressures as are HCN (4,13). The notion that HCN are better for plant disease control may have originated with those who promoted the use of high spray pressures. The actual origin of this concept is unknown. The design characteristics of the two nozzle types are not always affiliated with pest type by the manufacturers (4). Regardless, the use of high spray pressures is not a prerequisite for effective plant disease control (6,14,15). Considering our results and those of Wilson et al (15), the notion that the swirling spray from a HCN is better than FFN for disease control lacks evidence. Where either nozzle type is used at low spray pressures, the grower should benefit from reduced production costs and less spray drift, at least for those pest-host combinations in our tests and those of Wilson et al (15), because FFN may produce larger droplets (8,15).

Variables other than nozzle type were distinctly influential in altering control of the two fungal diseases on both peanuts and onions and bacterial spot on peppers. Mancozeb increases the amount of soluble copper when the two materials are tank-mixed; this enhances control of bacterial spot where copper-tolerant strains exist (7). Our data indicate a similar adjuvant property for maneb. The use of a traditional spreader-sticker in the onion test also demonstrated its importance for both blast and purple blotch control, regardless of nozzle type.

Spraying fungicides with one overhead nozzle per row on peanuts, peppers, and onions significantly suppressed disease on all assessment dates compared with the unsprayed controls. Furthermore, in no instance did these single-nozzle treatments cause a significant decrease in disease control compared with equivalent multiple-nozzle treatments. These results are supported by the spray technique used by Shoemaker and Lorbeer (12) for onion blast control and are similar to the results of Tomkins et al (14) for bean rust. Unfortunately, our work lacked a treatment where a single nozzle per row was coupled with the adjuvant, and that of Shoemaker and Lorbeer lacked a single-nozzle-per-row treatment without an adjuvant. The forward- and backward-oriented, dual-nozzle-per-row arrangement used in our tests resulted in excellent spray deposition on all sides of the onion leaves from top to bottom, whereas the single-nozzle-per-row treatment did not appear to do so. Miller (9) demonstrated an increasing susceptibility to purple blotch of both emerging and fully developed onion leaves as the onion plant matures. Therefore, with onions, complete coverage of the foliage is important, particularly with older plants.

The use of a single nozzle per row on peanuts and peppers was effective because strategic canopy zones were sprayed. Plaut and Berger (10) demonstrated the greater intensity of peanut leaf spot in the lower-central portion of the peanut canopy on this same cultivar. As pepper leaves age, they are less susceptible to bacterial spot (R. E. Stall, *unpublished*). Brandes (3) was concerned with the lack of information on sprays targeted onto "primary infection courts" (herein referred to as strategic canopy zones). Although our studies support this use-pattern somewhat, the hasty promotion of such a practice on peanuts would ignore our data demonstrating nearly a fourfold increase of peanut leaf spot on terminal vine leaves for the banded treatment. Although this treatment did not significantly reduce yield and it was the only treatment where leaf spot was stabilized within the center canopy, leaf spot did increase significantly within the outer canopy zone, where CO_2 fixation is greatest (2). Larger-scale tests are needed to determine if this small but significant increase in leaf spot is an artifact associated with the testing procedure itself (5). Likewise, with bacterial spot of pepper, only a slight increase in bacterial spot occurred in this test when nozzle numbers were reduced from three to one, but it is conceivable that this treatment may not have performed as well in other weather conditions.

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