

# Research Updates

## Yield of Bell Peppers as Impacted by the Combination of Bacterial Spot and a Single Hail Storm: Will Copper Sprays Help?

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**Summary.** The impact of a single hail storm injury in combination with bacterial spot caused by *Xanthomonas campestris* pv. *vesicatoria* was assessed on three commercial pepper (*Capsicum annuum*) cultivars—King Arthur, Jupiter, and Rebell. In addition, the effectiveness of copper plus maneb sprays on hail-damaged plants to suppress bacterial spot was evaluated. A hail storm of ≈5-min duration severely damaged and defoliated the pepper plants. Severe bacterial spot was ob-

served 10 days later on all plants. Disease ratings taken 2 weeks after the hail storm were significantly greater than ratings before the storm. Unsprayed plots of all three cultivars had the greatest disease and the least yield. Plots sprayed weekly (7-day schedule) had a significantly greater yield and less disease compared to unsprayed and biweekly sprayed (14-day schedule) plots for all three cultivars. The combination of hail damage and bacterial spot resulted in a 6-fold reduction in yield in the absence of copper plus maneb sprays and a 2-fold reduction with weekly sprays when compared to the previous season with no hail injury, but similar levels of bacterial spot disease. Disease ratings were less and yields were greater for 'King Arthur', than for 'Jupiter' and 'Rebell'. A judicious copper plus maneb spray program can suppress bacterial spot and help recovery of a young pepper crop when hail damage occurs.

Bacterial spot of bell pepper caused by *Xanthomonas campestris* pv. *vesicatoria* is an economically important disease in many pepper-producing regions of the country. The disease may cause severe damage during warm, rainy weather (Tegegn, 1985). Present disease management strategies rely on the use of apparently disease and pathogen-free seed or transplants (Ritchie and Dittapongpitch, 1991) and application of copper on a regular basis (McCarter, 1992). Use of copper is complicated by the occurrence of strains of the pathogen having decreased sensitivity to copper (Adaskaveg and Hine, 1985; Marco and Stall, 1983; Ritchie and Dittapongpitch, 1991). Several cultivars resistant to different races of the pathogen are currently available.

Recently, wind and wind-gener-

ated sand injury have been reported to be important factors in the increase of the disease on bell pepper fruits and leaves (Pohronenzny et al., 1992, 1993). However, these reports are based mainly on experiments conducted in laboratories and greenhouses. Hail injury is a type of severe wounding event that affects many horticultural crops. The effects of simulated hail injury on the yield of potatoes (Wille and Kleinkopf, 1992) and peas (Miller and Muehlbauer, 1984) was dependent on the amount of damage and the growth stage at which the hail injury occurred. Hail damage also has been reported to predispose pea plants to infection by bacterial blight and brown spot (Lawyer, 1984). We report the effects of a single hail storm on the development of bacterial spot on peppers and the efficacy of copper plus maneb sprays in reducing disease severity.

### Materials and methods

The tests were conducted at the Sandhills Research Station, Jackson Springs, N.C. Soil was a Candor sand with 1% to 2% organic matter, pH 6.4. General cultivation and tillage practices recommended for pepper production were followed (Sanders et al., 1988). Weekly (once every 7 days) and biweekly (once every 14 days) sprays of copper hydroxide plus maneb (Kocide DF, 2.5 lb/acre + Maneb Plus Zinc F4, 1.5 qt/acre) and unsprayed controls were evaluated. Pepper cultivars in the experiments were: 'Jupiter', an open-pollinated cultivar susceptible to all known races of the pathogen; 'King Arthur', resistant to race 2; and 'Rebell', resistant to races 1 and 2. 'King Arthur' and 'Rebell' are hybrid peppers. Plants were grown for 10 weeks in Styrofoam trays having 200 one-inch (2.5-cm) cells (plug) and transplanted to raised beds in a completely randomized block design on 27 Apr. Each treatment consisted of nine rows on 38-inch (97-cm) centers with nine plants/row spaced 14 inches (36 cm) apart with three replications per treatment. Sprays were applied using a backpack Solo mist sprayer (type 412) calibrated to deliver 50 gal/acre (465 liters·ha<sup>-1</sup>). Chemical rates were calculated on a per-acre basis, considering each row to be 2 ft (61 cm) wide and each plot 10.5 ft (3.2 m) long. Spray treatments were started on 12 May and continued weekly until 17 Aug., for a total of 14 weekly

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and eight biweekly applications. After the first spray application, three inoculated plants, each with a different race of the pathogen, were placed in the center of each plot. These plants had been inoculated with a mixture of two strains of race 1 (copper-resistant), race 2 (copper- and streptomycin-resistant), or race 3 (copper-sensitive) on 5 May and maintained in the greenhouse with occasional misting of the foliage. Overhead irrigation (0.25 inch/acre per h) was applied to the crop as needed to maintain optimum plant growth, normally twice weekly (1 inch/week). Bacterial spot severity ratings on each plant were recorded weekly during the growing season using a 0–9 scale, where: 0 = no diseased leaves observed, 1 = at least one lesion/plant, but <1% leaf area diseased; 2 = 1% to 10%; 3 = 11% to 20%; 4 = 21% to 35%; 5 = 36% to 50%; 6 = 51% to 65%; 7 = 66% to 80%; 8 = 81% to 99%; 9 = 100% leaves diseased and complete defoliation. Results were analyzed using the least square means procedure. Results of a similar 1992 experiment, in which 'Jupiter' was not damaged by hail (Ritchie and Bennett, 1993), were used for comparison.

## Results and discussion

During the later part of May and first few days of June, bacterial spot progressed slowly, with the mean maximum ratings of about one. On 5 June, as initial fruit set was occurring, a hail storm [0.87 inches rain (2.2 cm)] ≈5 min in duration severely damaged leaves and stems and caused severe defoliation of most plants. Severe bacterial spot was observed 10 days after the hail storm. At this time, it was decided to continue the experiment to determine the effects hail injury would have on bacterial spot severity and yield. Fifty-three percent of the plants in the unsprayed plots and 13% in the weekly and biweekly sprayed plots showed several lesions before the hail storm. However, 2 weeks after the hail storm, all plants showed disease. Bacterial spot severity reached a peak during the third week of June, after which a gradual decline in disease was observed until mid-July. During this decline, the weather was hot and dry with little rainfall. A second peak in disease severity was observed during the last week of July, after which the disease gradually declined until the end of the season in August (Fig. 1). Similar disease progress curves were observed for

Disease rating (0-9)

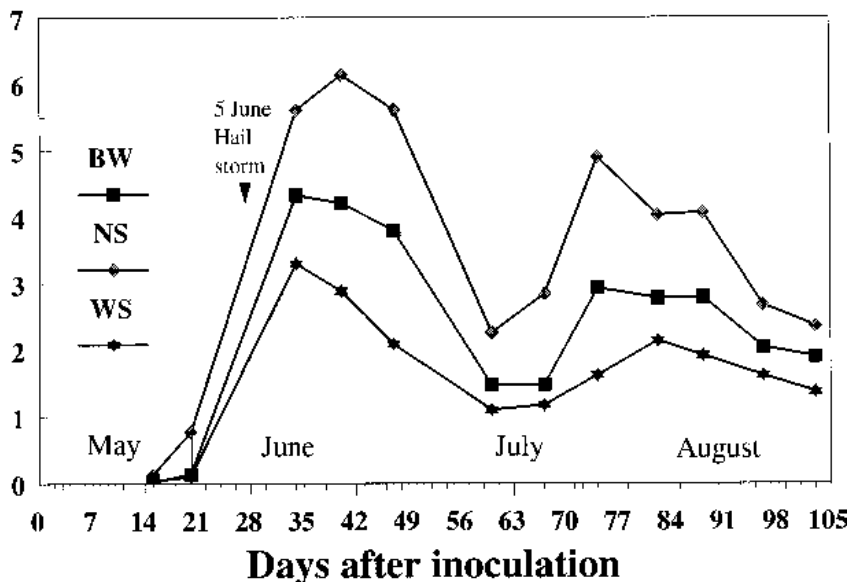


Fig. 1. Effect of hail and three copper plus maneb spray treatment schedules on bacterial spot ratings taken periodically after inoculation on 12 May on the pepper cultivar Jupiter. NS = no spray, BW = biweekly sprays, and WS = weekly sprays. Disease ratings were based on a 0–9 scale, where: 0 = no diseased leaves, 4 = 21% to 35%, 7 = 65% to 80%, 9 = 100% diseased leaves and complete defoliation.

all three cultivars. The disease severity ratings taken after the hail storm were significantly greater than the ratings before the hail storm (Table 1). Maximum disease was observed in the unsprayed plots, followed by the biweekly and the weekly sprayed plots (Fig. 1). Similar results also were obtained when the areas under the disease progress curves (AUDPC) were analyzed for the different spray treatments (Table 2). Even though the hail injury predisposed pepper plants to increased bacterial spot regardless of cultivar or spray treatment, the weekly sprayed plots had the least disease and the greatest yield, followed by the biweekly sprays (Table 2). Assays for the presence of the different pathogen strains indicated that both copper-resistant and copper-sensitive strains were

present. Race 3 was the most predominant strain across all the cultivars and spray treatments, despite being sensitive to copper. The lack of resistance to race 3 of the pathogen was a factor in the epidemic.

The impact of the hail injury and bacterial spot on fruit yield of 'Jupiter' was determined by comparing the 1993 data with the data of 'Jupiter' from a 1992 experiment (Ritchie and Bennett, 1993) conducted at a site contiguous to the 1993 site (Fig. 2). The planting and inoculation dates during the two years were very similar. The peak bacterial spot severity ratings in 1992 on the unsprayed plots of 'Jupiter' taken on 3 July were similar to the peak ratings in 1993 taken on 17 June; however, in 1992, the plants were not damaged by hail. In 1992, the

Table 1. Effect of a single hail injury and copper plus maneb spray treatment schedules on bacterial spot disease ratings<sup>a</sup> before and after a hail storm on three pepper cultivars in 1993.

Cultivar	Before hail (3 June)			After hail (17 June)		
	No spray	Biweekly sprays	Weekly sprays	No spray	Biweekly sprays	Weekly sprays
Jupiter	0.8 aB <sup>y</sup>	0.1 bA	0.1 bA	5.6 aAB	4.3 bA	3.3 cA
King Arthur	1.1 aA	0.1 bA	0.2 bA	5.2 aB	3.8 bB	3.0 cA
Rebell	1.1 aAB	0.2 bA	0.2 bA	6.0 aA	4.1 bAB	3.0 cA

<sup>a</sup>Disease ratings were based on a 0–9 scale, where: 0 = no diseased leaves, 4 = 21% to 35%, 7 = 65% to 80%, 9 = 100% diseased leaves and complete defoliation caused by *Xanthomonas campestris* pv. *vesicatoria*.

<sup>y</sup>Means followed by the same letter (lowercase in rows) for each cultivar within the disease rating groups are not significantly different ( $P \leq 0.05$ ), and means followed by the same letter (uppercase) in columns are not significantly different ( $P \leq 0.05$ ). Disease ratings within each treatment group after hail were significantly greater than before hail ( $P \leq 0.0001$ ).

Table 2. Area under disease progress curves (AUDPC) and total yield for different copper plus maneb spray treatment schedules on three pepper cultivars in 1993

Cultivar	AUDPC			Total yield (bu/acre) <sup>z</sup>		
	No spray	Biweekly sprays	Weekly sprays	No spray	Biweekly sprays	Weekly sprays
Jupiter	325 aA <sup>y</sup>	218 bA	151 cB	77 cA	220 bB	493 aB
King Arthur	258 aB	170 bB	129 cA	156 cA	483 bA	802 aA
Rebell	304 aA	209 bA	138 cA	99 cA	256 bB	774 aA

<sup>z</sup>Total yield based on the sum of three harvests. Yield lb/plot can be estimated using the following formula: (yield bu/acre)/(7.1).

<sup>y</sup>Means followed by the same letter (lowercase in rows) for each cultivar within the AUDPC ( $P \leq 0.0001$ ) or yield ( $P \leq 0.05$ ) groups are not significantly different, and means followed by the same letter (uppercase in columns) are not significantly different ( $P = 0.05$ ).

unsprayed plot yielded 496 bu/acre, compared to 77 bu/acre in 1993. Injury from the single hail storm and the early peak of bacterial spot caused a 6-fold reduction in yield in the unsprayed plots in 1993. The mean disease severity rating in the weekly sprayed plots during 1992 was <1, and the yield averaged 850 bu/acre, indicating the effectiveness of the copper plus maneb sprays and lack of hail injury (Ritchie and Bennett, 1993). In contrast, during the 1993 season, the peak disease severity ratings was 3.3 on hail-injured plants (Fig. 2), and the yields were ≈2-fold less (490 bu/acre). Injury associated with a hail storm significantly increased the levels and economic impact of bacterial spot. The use of regular copper sprays can mitigate these losses. In 1993, the hail storm occurred at initial fruit set, 38 days after transplanting, when the plants were still young and recovery was still possible. However, simulated hail damage studies on peas (Miller

and Muehlbauer, 1984) and potatoes (Wille and Kleinkopf, 1992) indicated that yield reduction is correlated with the amount of injury and the growth stage at which it occurs. In North Carolina, the average cost/acre needed to obtain sustained yields of 300 bu/acre of peppers is about \$1337, which also includes the cost of 10 copper plus maneb applications. It is difficult to enter fruit from the hail-damaged field into the fresh-market chain because of the additional costs involved in running the fruits on a grading line. However, fruit may be sold for processing, where at least \$3/bu could be recovered. In the case of the weekly sprayed plots, a marginal profit of \$111/acre for 'Jupiter' could have been realized. A profit of \$1069/acre for 'King Arthur' would have been possible, compared to a moderate loss in the biweekly sprayed plots and a total loss in the unsprayed plots. Based on the results of these experiments, copper sprays can help a producer recover a

portion of the losses associated with hail-induced bacterial spot epidemics.

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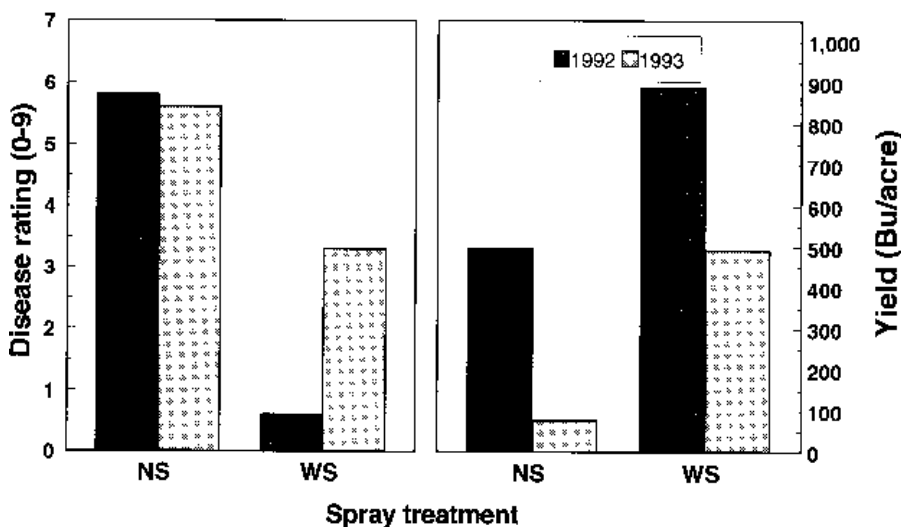


Fig. 2. Comparison of bacterial spot ratings and total yield (bu/acre) for 'Jupiter' during the years with (1993) without (1992) hail storm injury. NS = no spray and WS = weekly sprays. Disease ratings were based on a 0-9 scale, where: 0 = no diseased leaves, 4 = 21% to 35%, 7 = 65% to 80%, 9 = 100% diseased leaves and complete defoliation..