Research Reports

Differences in Tolerance of Broccoli and Cabbage Cultivars to Clomazone Herbicide

Howard F. Harrison, Jr.[1] and Mark W. Farnham

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Summary. **Clomazone herbicide is registered for cabbage (*Brassica oleracea* Capitata group) in the United States but not for other crop groups within the species. Greenhouse and field experiments were designed to compare the tolerance of broccoli (*B. oleracea* Italica group) and cabbage cultivars to clomazone to assess its potential for weed management in broccoli. Four broccoli cultivars (Captain, Green Magic, Legacy, and Patron) and four cabbage cultivars (Bravo, SC 100, Stone Head, and Vantage Point) were evaluated in all experiments. In a greenhouse experiment where seedlings were transplanted into potting medium containing clomazone at 0, 1.0, 2.0, and 4.0 parts per million (ppm), 'Bravo' cabbage was most susceptible. Its injury ratings and shoot weight reduction at 1.0 ppm were similar to ratings and shoot weight reduction for the other cabbage cultivars at 4.0 ppm. Among the broccoli cultivars, Patron was highly susceptible, exhibiting injury and shoot weight reduction similar to Bravo. Green Magic was the most tolerant broccoli cultivar, and it exhibited injury and growth reduction similar to the tolerant cabbage cultivars. In a field experiment where clomazone was applied pre-transplanting at 0.25, 0.5, and 1.0 lb/acre, 0.25 lb/acre caused moderate chlorosis to the susceptible cultivars, Bravo and Patron. At 0.50 and 1.0 lb/acre, most cultivars exhibited chlorosis at 2 weeks after transplanting (WAT); however, tolerant cultivars recovered and injury was often not observed at 6 WAT. At 1.0 lb/acre, chlorosis persisted until maturity on 'Bravo' and 'Patron' foliage. Clomazone did not reduce mean broccoli head weight or the percentage of plants producing market-size heads. Mean cabbage head weight for 'Bravo' was reduced by clomazone at 1.0 lb/acre. This study indicates that the variability in clomazone tolerance among broccoli cultivars may be similar to that among cabbage cultivars and suggests that the herbicide can be used safely on tolerant broccoli cultivars at rates that are recommended for cabbage.**

Since the 1970s, over 90% of U.S. broccoli has been produced in California and Arizona (U.S. Department of Agriculture, 2012). Production and consumption of broccoli has increased in recent years, and increased demand has spurred interest in increasing production in the eastern United States to supply the large eastern population centers. Considerable research is currently directed toward developing cultivars and cultural practices suitable for production regions of the eastern United States (Cornell University, 2011). Effective integrated weed management is essential to the success of eastern broccoli production. Weed management in eastern production may require measures additional to those used in California and Arizona because of differences in weed species common in the regions and higher rainfall in the east that increases weed growth and stimulates frequent weed seed germination.

Clomazone is registered for weed management in direct seeded and transplanted cabbage production in the United States, except in California where the herbicide is banned (FMC Corp., 2005). However, it is not registered for the other cole crops [broccoli, brussels sprouts (*Brassica oleracea* Gemmifera group), cauliflower (*B. oleracea* Botrytis group), collards (*B. oleracea* Acephala group), kale (*B. oleracea* Acephala group), and others] that are in the same species. Cultivars within a cole crop type are frequently called a crop group. Clomazone is an important component for weed management in cabbage and several other vegetable crops because it provides residual control of several important annual grass and broadleaf weeds. The recommended use rates for clomazone for all crops range from 0.15 to 1.5 lb/acre and are based on soil type and crop tolerance. The higher rates of clomazone recommended for highly tolerant crops control more weed species and provide longer lasting control than the low rates recommended for less tolerant crops. The recommended use rates for transplanted cabbage are 0.25 and 0.5 lb/acre for coarse and fine soils, respectively; clomazone can also be used on direct seeded cabbage at up to 0.5 lb/acre.

Hopen et al. (1993) evaluated the response of 36 genetically diverse cabbage cultivars to clomazone applied before transplanting. Most of the cultivars were tolerant of clomazone, chlorosis was minor and short lived, and yields were not reduced. Three cabbage cultivars that exhibited higher levels of chlorosis, including the important hybrid cultivar, Bravo, also had yields reduced by 1.0 lb/acre clomazone in one of the two years of the study. Natural variation in clomazone tolerance among cultivars or genotypes within crop species has also been reported for bean [*Phaseolus vulgaris* (Sikkema et al., 2006)], corn [*Zea mays* (Keifer., 1989)], cucumber [*Cucumis sativus* (Al-Khatib et al., 1995; Staub et al., 1991)], pumpkin [*Cucurbita maxima*, *C. moschata*,

C. pepo (Harrison and Keinath, 2003)], rice [*Oryza sativa* (Mudge et al., 2005; Scherder et al., 2004; Zhang et al., 2004)], sweetpotato [*Ipomoea batatas* (Harrison and Jackson, 2011)], and watermelon [*Citrullus lanatus* (Harrison et al., 2011)]. The objective of this study was to evaluate the clomazone tolerance of broccoli cultivars in comparison with cabbage cultivars using greenhouse and field experiments to assess the potential for safely using clomazone for weed management in broccoli.

Materials and methods

Greenhouse experiment. Four hybrid broccoli cultivars (Captain, Green Magic, Legacy, and Patron) and four hybrid cabbage cultivars (Bravo, SC 100, Stonehead, and Vantage Point) were chosen for this study based on differences in tolerance observed in a preliminary screening experiment or previously reported research (Hopen et al., 1993). All hybrid seed were purchased from commercial sources. A greenhouse experiment was designed to assess the effect of clomazone on early growth. The greenhouse was located at the U.S. Vegetable Laboratory, Charleston, SC. Temperatures ranged between 20 and 32 °C, supplemental lighting was not provided, and humidity was increased from ambient by an evaporative cooling system. The greenhouse potting mixture was a 1/1 (v/v) blend of a commercial potting mixture (Metro-Mix 360; Sun Gro Horticultural Distribution, Bellevue, WA) and washed river sand. Powdered limestone and controlled-release fertilizer (Osmocote 15–9–12 plus; Scotts, Marysville, OH) at 1.1 g·L^{-1} potting medium were added, and the mixture was blended in a portable cement mixer for 5 min. Clomazone (Command 3 ME; FMC Corp., Philadelphia, PA) was incorporated into the potting medium by adding the appropriate volume of the commercial formulation to 500 mL of water, spraying directly onto the potting mixture in a cement mixer using a handheld sprayer, followed by mixing for 10 min. Clomazone concentrations were 0, 1.0, 2.0, and 4.0 ppm (weight clomazone/dry weight of potting medium). The clomazone-treated potting mixture was used to fill 12-fl oz polystyrene cups. Greenhouse grown seedlings at the two-leaf stage were transplanted into the polystyrene cups containing clomazone-treated potting medium. After 2 weeks, each plant was rated for clomazone injury on a 0 to 10 scale where 0 = no chlorosis, 3 = ≈30% of leaf area chlorotic, 7 = ≈70% of leaf area chlorotic, and 10 = shoots completely chlorotic or plant dead. At 18 d after transplanting, shoots were excised at the soil surface, placed in a forced-air drying oven at 50 °C for 96 h, and dry weight measurements were collected. The experiment was arranged in a randomized complete block design with five replicates where plants within a block were grouped on a greenhouse bench section, and it was repeated. Experiments 1 and 2 were initiated on 13 May and 13 June 2011, respectively. Shoot weights varied among the cultivars; thus, shoot weights for clomazone-treated plants were converted to percent of control weight, so cultivars could be compared. Preliminary analysis of variance for rating and shoot weight data indicated that interactions between experiments and treatments were significant; thus, the data for the two repeats of the experiment were analyzed separately.

Table 1. Injury ratings for four broccoli and four cabbage cultivars in response to clomazone in potting medium in the greenhouse.

		Clomazone concn (ppm)[z]			
		1.0	2.0	4.0	
Cultivar	Crop	Injury rating (0 – 10 scale)[x]			$LSD_{0.05}$[y]
		Expt. 1			
Captain	Broccoli	3.4	5.2	8.4	1.6
Green Magic	Broccoli	1.8	4.0	6.4	1.0
Legacy	Broccoli	2.4	4.0	7.4	0.6
Patron	Broccoli	5.6	6.2	8.8	1.4
Bravo	Cabbage	7.6	8.2	8.6	NS
SC 100	Cabbage	0	2.4	7.8	1.6
Stone Head	Cabbage	0	1.4	6.4	0.8
Vantage Point	Cabbage	0.2	0.8	6.0	0.8
$LSD_{0.05}$[w]		0.8	1.2	1.0	
		Expt. 2			
Captain	Broccoli	2.2	5.2	8.4	1.2
Green Magic	Broccoli	0	2.8	5.4	1.0
Legacy	Broccoli	1.2	3.8	6.4	1.3
Patron	Broccoli	2.8	7.0	8.6	0.9
Bravo	Cabbage	5.4	8.0	8.4	0.8
SC 100	Cabbage	0	1.6	5.0	1.0
Stone Head	Cabbage	0	2.6	4.6	1.6
Vantage Point	Cabbage	0.2	1.0	3.2	0.7
$LSD_{0.05}$[w]		0.8	1.0	1.3	

[z]1 ppm = 1 mg·kg^{-1}.
[y]Fisher's protected least significant difference at $\alpha = 0.05$ for comparing concentration means within cultivars.
[x]0 = no chlorosis and 10 = plants completely chlorotic or dead; all untreated control plants exhibited no chlorosis and were rated zero.
[w]$LSD_{0.05}$ for comparing cultivar means within concentrations.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
9.3540	gal/acre	L·ha^{-1}	0.1069
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha^{-1}	0.8922
28.3495	oz	g	0.0353
7.4892	oz/gal	g·L^{-1}	0.1335
1	ppm	mg·kg^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32
(°F ÷ 1.8) + 255.37	°F	K	(K – 255.37) × 1.8

U.S. Vegetable Laboratory, U.S. Department of Agriculture, Agriculture Research Service, 2700 Savannah Highway, Charleston, SC 29407

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[1]Corresponding author. E-mail: howard.harrison@ars.usda.gov.

Cultivar means within clomazone rates and clomazone rate means within cultivars were compared using Fisher's protected least significant differences test at $\alpha = 0.05$.

FIELD EXPERIMENT. Field experiments were conducted in Spring and Fall 2011 to assess clomazone tolerance of the four broccoli and four cabbage cultivars in standard eastern production environments. The soil type was Yonges fine silty sand (Typic Endoaqualfs). The soil pH was 6.4 and soil organic matter was below 0.5%. The soil tested high for phosphorous and potassium; thus, the only fertilization was sidedress applications of calcium nitrate 2 and 6 WAT at 300 lb/acre. Broccoli was grown using standard cultural practices. The soil was shaped into beds (6 inches high and 16 inches wide) spaced 40 inches apart. The entire area of the experiment was treated with napropamide herbicide at 2.0 lb/acre to reduce the labor required for hand weeding. Napropamide was applied within 48 h of transplanting using a power take-off driven sprayer calibrated to deliver 22.3 gal/acre. Clomazone was broadcast over clomazone-treated plots in 12.0 gal/acre with a carbon dioxide pressurized plot sprayer ≈24 h before transplanting and watered in with ≈1 inch of sprinkler irrigation. About 5-week-old greenhouse grown seedlings were mechanically transplanted on the beds spaced 1 ft between plants. Transplanting dates were 18 Mar. and 15 Sept. 2011. The experiment was arranged in a split plot design with four replicates. Main plot treatments included clomazone at 0, 0.25, and 0.5 lb/acre for the spring-planted experiment and 0, 0.25, 0.5, and 1.0 lb/acre for the fall-planted experiment. Subplot treatments were the cultivars, with 20 seedlings transplanted into each subplot. During the growing season, weeds were managed with cultivation and hand weeding, and overhead irrigation was provided as needed to prevent moisture stress. Plots were rated for clomazone injury at 2 and 6 WAT using the scale described for the greenhouse experiment. Broccoli heads were harvested by hand when they reached market size of ≈4 inches head width, and cabbage heads were harvested when the first mature heads of a cultivar reached the cracking stage. Injury ratings, head weight, and percentage of plants producing market-size heads were subjected to analysis of variance and mean injury ratings within cultivars and clomazone treatments and yield means within cultivars were compared using Fisher's protected least significant differences test at $\alpha = 0.05$.

Results

GREENHOUSE EXPERIMENT. Injury ratings from both experiments (Table 1) demonstrated that there are marked differences in the tolerance of commercial cultivars to clomazone in both broccoli and cabbage crop groups. Within both, there were differences among cultivars in injury rating for each concentration in both experiments. The most susceptible cultivars, Bravo and Patron, exhibited injury levels at 1.0 ppm similar to ratings for the most tolerant cultivars, Green Magic and Vantage Point, at 4.0 ppm. Although there were interactions between treatments and experiments, the relative tolerance of cultivars based on injury ratings or shoot weight reduction was similar in both experiments. Shoot weights of untreated plants varied among cultivars (Table 2); however, when converted to percent of control, cultivar relative shoot weights were different at each concentration in both experiments. Shoot weights of the most susceptible cabbage cultivar, Bravo, at 1.0 ppm clomazone were less than 50% of the control shoot weights in both experiments. The susceptible broccoli cultivar, Patron, was reduced over 50% by 1.0 ppm only in Expt. 1. Shoot weights of the most tolerant cultivars, Green Magic broccoli and Stonehead and Vantage Point cabbage were reduced less than 50% by clomazone at 4.0 ppm. Injury ratings closely corresponded to shoot weight reduction for all cultivars indicating that both criteria are useful for assessing clomazone tolerance.

FIELD EXPERIMENT. Clomazone injury ratings in the field (Tables 3 and 4) were generally lower than the ratings observed in the greenhouse experiment (Table 1). At 2 WAT, the recommended rate for cabbage in coarse soils, 0.25 lb/acre, moderately injured 'Bravo' and 'Patron' and slightly injured 'Captain' in the spring experiment. At 6 WAT, the highest injury rating at 0.25 lb/acre was 1.5 for 'Patron'. In the fall experiment, the

Table 2. Shoot dry weights of four broccoli and four cabbage cultivars in response to clomazone in potting medium in the greenhouse.

			Clomazone concn (ppm)[z]			
		Control	1.0	2.0	4.0	
		Shoot dry wt				
Cultivar	Crop	(g)[z]	(% of control)			$LSD_{0.05}$[y]
		Expt. 1				
Captain	Broccoli	1.7	69	64	27	16
Green Magic	Broccoli	1.7	101	85	53	28
Legacy	Broccoli	1.6	75	67	28	24
Patron	Broccoli	2.1	46	31	18	8
Bravo	Cabbage	1.8	40	36	33	NS
SC 100	Cabbage	1.7	73	83	31	39
Stone Head	Cabbage	1.7	96	104	66	NS
Vantage Point	Cabbage	1.8	112	114	73	24
$LSD_{0.05}$[x]		NS	32	24	18	
		Expt. 2				
Captain	Broccoli	1.7	84	62	55	15
Green Magic	Broccoli	2.1	103	82	58	23
Legacy	Broccoli	1.6	97	65	51	31
Patron	Broccoli	1.7	86	49	31	18
Bravo	Cabbage	2.4	48	33	25	8
SC 100	Cabbage	1.9	87	76	55	NS
Stone Head	Cabbage	2.2	85	96	72	19
Vantage Point	Cabbage	1.8	90	114	100	NS
$LSD_{0.05}$[x]		0.5	28	16	16	

[z]1 ppm = 1 mg·kg^{-1}, 1 g = 0.0353 oz.
[y]Fisher's protected least significant difference at $\alpha = 0.05$ for comparing concentration means within cultivars; NS = Nonsignificant; F test indicated that means were not different at $P \leq 0.05$.
[x]$LSD_{0.05}$ for comparing cultivar means within concentrations.

susceptible cultivars were only slightly injured by 0.25 lb/acre at 2 WAT and no injury was observed at 6 WAT. Only minor injury was observed for all cultivars except 'Bravo' and 'Patron' at 0.50 lb/acre, and for most of the tolerant cultivars, no injury was observed at 6 WAT. The 1.0-lb/acre rate caused greater injury than the other rates with 'Patron' at 2 and 6 WAT, 'Bravo' at 6 WAT, and 'Captain' at 2 WAT. At this rate, chlorosis was observed on 'Bravo' and 'Patron' foliage at crop maturity. The high rate was included in the fall experiment to cause severe injury to the susceptible cultivars to better demonstrate differences in tolerance among cultivars. However, overall injury ratings in the spring-planted experiment were higher than in the fall; thus, injury levels with 1.0 lb/acre in the fall were not much higher than ratings at 0.5 lb/acre in the spring. Lower injury in the fall may have resulted from higher air and soil temperatures that promoted rapid growth and recovery from clomazone injury. Similarly, greenhouse average injury ratings for Expt. 1 planted in May were slightly higher at 4.7 than for Expt. 2 planted in June at 3.9 (Table 1).

Few differences were observed with cabbage yield component data (Table 5). The percentage of plants producing market-size heads was lower than the control for 'SC 100' at 0.5 lb/acre in spring and fall experiments. Percentages of 'Vantage Point' plants producing market-size heads were higher in both clomazone-treated plots than in the control plots in the spring experiment. Mean head weight was lower than the control for 'Bravo' at 1.0 lb/acre in the fall experiment, and 'SC 100' head weights at 0.25 lb/acre were higher than head weights at 0.5 lb/acre in the spring experiment. The application of clomazone caused no differences in the percentage of plants producing heads or in mean head weight for broccoli (Table 6).

Table 3. Injury ratings for four cabbage cultivars taken 2 and 6 weeks after transplanting (WAT) into field plots treated with different rates of clomazone in Spring and Fall 2011.

			Clomazone rate (lb/acre)[z]			
			0.25	0.50	1.00	
Cultivar	Season	WAT	Injury rating (0 to 10 scale)[x]			$LSD_{0.05}$[y]
Bravo	Spring	2	3.3	4.0	—	2.0
SC100		2	0.0	0.0	—	NS
Stonehead		2	0.0	0.3	—	NS
Vantage Point		2	0.0	0.0	—	NS
		$LSD_{0.05}$[w]	0.4	1.6	—	
Bravo	Spring	6	1.3	4.3	—	0.9
SC100		6	0.0	0.3	—	NS
Stonehead		6	0.0	0.0	—	NS
Vantage Point		6	0.0	0.3	—	NS
		$LSD_{0.05}$[w]	0.7	0.4	—	
Bravo	Fall	2	1.3	2.8	5.0	0.8
SC100		2	0.0	0.5	0.4	NS
Stonehead		2	0.0	0.0	0.0	NS
Vantage Point		2	0.0	0.0	0.0	NS
		$LSD_{0.05}$[w]	0.4	0.9	0.8	
Bravo	Fall	6	0.0	1.3	3.5	1.6
SC100		6	0.0	0.0	0.2	NS
Stonehead		6	0.0	0.0	0.0	NS
Vantage Point		6	0.0	0.0	0.0	NS
		$LSD_{0.05}$[w]	NS	NS	1.4	

[z]1 lb/acre = 1.1209 kg·ha^{-1}.
[y]Fisher's protected least significant difference at $\alpha = 0.05$ for comparing mean injury ratings among the different clomazone application rates; NS = Nonsignificant; F test indicated that means were not different at $P \leq 0.05$.
[x]0 = no chlorosis and 10 = plants completely chlorotic or dead.
[w]$LSD_{0.05}$ for comparing mean injury ratings among the different hybrids at a given clomazone application rate.

Discussion

The greenhouse experiment demonstrated similarity between visual clomazone injury and early growth reduction in broccoli and cabbage, and cultivar differences in clomazone tolerance were detected using visual rating and growth data. The most tolerant broccoli cultivar, Green Magic, was similar in clomazone response to tolerant cabbage cultivars, and it showed greater tolerance than the susceptible cabbage cultivar, Bravo. 'Captain' and 'Patron' broccoli were less tolerant than 'Green Magic', but both had lower injury ratings or shoot weight reduction than 'Bravo' cabbage in some instances. The cultivar differences in clomazone tolerance observed in this system correspond to those observed in our field experiment and those reported by Hopen et al. (1993). Based on the surface area of the cups and the weight of potting medium they contain, the 1.0 ppm concentration is equivalent to a surface application of 0.35 lb/acre. However, greenhouse and field rates may not be directly comparable, because field surface application incorporated by sprinkler irrigation would not result in uniform clomazone concentrations in the rooting zone like the greenhouse procedure, and the adsorptive capacity of the greenhouse medium probably differs from that of the field soil. Since greenhouse and field results correspond closely, the greenhouse method is useful as a rapid and inexpensive assay to test cultivars and germplasm lines for clomazone tolerance. The greenhouse assay also allows testing at very high rates that are useful for identifying highly tolerant cultivars. Using very high rates in the field is undesirable because of the potential for clomazone to persist in the soil and injure subsequent crops (FMC Corp., 2005).

The responses of 'Bravo' and 'Stonehead' cabbages in our field experiments were similar to those reported by Hopen et al. (1993). In their experiments, 'Stonehead' was highly tolerant to clomazone, whereas 'Bravo' was among three cultivars of the 36 tested whose yields were reduced by clomazone at 1.0 lb/acre. They also reported that most cultivars showed minor early chlorosis caused by clomazone at 2 WAT, which was often not observed at 6 WAT. Little clomazone research in cole crops has been published. Scott et al. (1995) evaluated

Table 4. Injury ratings for four broccoli cultivars taken 2 and 6 weeks after transplanting (WAT) into field plots treated with different rates of clomazone in Spring and Fall 2011.

			Clomazone rate (lb/acre)[z]			
			0.25	0.50	1.00	
Cultivar	Season	WAT	Injury rating (0 to 10 scale)[x]			$LSD_{0.05}$[y]
Captain	Spring	2	1.0	1.5	—	0.6
Green Magic		2	0.0	0.2	—	NS
Legacy		2	0.0	1.0	—	NS
Patron		2	2.3	4.0	—	0.5
		$LSD_{0.05}$[w]	0.4	0.5	—	
Captain	Spring	6	0.4	1.5	—	0.8
Green Magic		6	0.0	0.0	—	NS
Legacy		6	0.0	0.4	—	NS
Patron		6	1.5	2.3	—	0.6
		$LSD_{0.05}$[w]	0.5	0.7	—	
Captain	Fall	2	0.0	0.5	1.8	0.9
Green Magic		2	0.0	0.0	0.4	NS
Legacy		2	0.0	0.4	1.1	0.7
Patron		2	0.3	1.8	4.3	0.9
		$LSD_{0.05}$[w]	NS	0.5	1.1	
Captain	Fall	6	0.0	0.0	0.5	NS
Green Magic		6	0.0	0.0	0.0	NS
Legacy		6	0.0	0.0	0.0	NS
Patron		6	0.0	0.8	3.3	1.8
		$LSD_{0.05}$[w]	NS	0.4	1.4	

[z]1 lb/acre = 1.1209 kg·ha^{-1}.
[y]Fisher's protected least significant difference at $\alpha = 0.05$ for comparing mean injury ratings among the different clomazone application rates; NS = Nonsignificant; F test indicated that means were not different at $P \leq 0.05$.
[x]0 = no chlorosis and 10 = plants completely chlorotic or dead.
[w]$LSD_{0.05}$ for comparing mean injury ratings among the different hybrids at a given clomazone application rate.

Table 5. Mean head weight and percent market-size heads harvested at maturity from cabbage plants of four cultivars grown in field plots treated with different rates of clomazone herbicide in Spring and Fall 2011.

		Clomazone rate (lb/acre)[z]				
Cultivar	Season	0.0	0.25	0.50	1.00	$LSD_{0.05}$[y]
		Mean head wt (kg)[z]				
Bravo	Spring	1.58	1.65	1.39	N/A	NS
	Fall	1.57	1.36	1.34	1.17	0.26
SC100	Spring	0.41	0.44	0.36	N/A	0.05
	Fall	0.49	0.55	0.50	0.51	NS
Stonehead	Spring	1.32	1.21	1.22	N/A	NS
	Fall	0.94	0.93	0.97	1.10	NS
Vantage Point	Spring	1.46	1.47	1.32	N/A	NS
	Fall	1.20	1.22	1.14	1.39	NS
		Market-size heads (%)				
Bravo	Spring	91.0	91.0	81.5	N/A	NS
	Fall	92.1	87.9	89.6	83.4	NS
SC100	Spring	91.6	91.0	85.6	N/A	4.4
	Fall	91.0	94.3	85.1	89.5	5.6
Stonehead	Spring	98.8	94.8	96.4	N/A	NS
	Fall	92.2	95.8	94.1	96.6	NS
Vantage Point	Spring	88.0	96.2	96.6	N/A	7.1
	Fall	88.1	83.2	84.2	88.9	NS

[z]1 lb/acre = 1.1209 kg·ha^{-1}, 1 kg = 2.2046 lb.
[y]Fisher's protected least significant difference at $\alpha = 0.05$ for comparing clomazone rate means within cultivars and seasons; NS = Nonsignificant; F test indicated that means were not different at $P \leq 0.05$.

pretransplanting incorporated clomazone application for weed management in several cole crops, including broccoli, cauliflower, green cabbage, and red cabbage, and the related crop, pak choi (*Brassica rapa*). They concluded that green cabbage and pak choi were most sensitive to clomazone; however, only one cultivar of each crop group was included in their study. Laboratory studies (Scott and Weston, 1992) demonstrated that the I_{50} values (50% inhibition concentrations) for chlorophyll production by clomazone were 16, 11, 3, and 11 μM, and I_{50} values for inhibition of carotenoid production were 20, 10, 4, and 8 μM clomazone for broccoli, cauliflower, and green and red cabbage, respectively. This range (about 4- to 5-fold difference in the rates tolerated) is similar to differences in tolerance within broccoli and cabbage crop groups in our experiments and that of Hopen et al. (1993). The green cabbage cultivar, Bravo, used by Scott and Weston (1992) and Scott et al. (1995) has proven to be sensitive to clomazone in comparison with other green cabbage cultivars in this study and by Hopen et al. (1993). Scott et al. (1995) concluded that preplant-incorporated application of clomazone may not be safe for use in cole crops because of the risk of crop injury, and their observation probably contributed to the label precaution that roots of transplanted cabbage should be below the herbicide-treated zone to reduce injury, and mechanical incorporation is not recommended (FMC Corp., 2005).

Injury ratings indicate that the range in clomazone tolerance among the broccoli cultivars in this experiment was similar to that of the cabbage cultivars. The lack of a clomazone effect on 'Patron' broccoli head weight in comparison with 'Bravo' cabbage may be due to the much smaller size of broccoli heads in comparison with cabbage. Broccoli plants with growth reduction as a result of clomazone injury may be able to produce full-sized heads more readily than can be produced by clomazone injured cabbage plants. In the greenhouse, clomazone reduced shoot weight of broccoli and cabbage plants that had injury similar to that observed for 'Bravo' and 'Patron' at the high rates in the field. A reduction of early growth in response to moderate clomazone injury probably occurs under

Table 6. Mean head weight and percent market-size heads harvested at maturity from broccoli plants of four cultivars grown in field plots treated with different rates of clomazone herbicide in Spring and Fall 2011.

Cultivar	Season	Clomazone rate (lb/acre)[z] 0.0	0.25	0.50	1.00	$LSD_{0.05}$[y]
		Mean head wt (kg)[z]				
Captain	Spring	0.19	0.20	0.19	N/A	NS
	Fall	0.19	0.19	0.20	0.20	NS
Green Magic	Spring	0.27	0.24	0.27	N/A	NS
	Fall	0.27	0.27	0.27	0.28	NS
Legacy	Spring	0.31	0.33	0.29	N/A	NS
	Fall	0.32	0.33	0.35	0.34	NS
Patron	Spring	0.30	0.32	0.31	N/A	NS
	Fall	0.24	0.24	0.24	0.24	NS
		Market-size heads (%)				
Captain	Spring	91.2	93.0	94.0	N/A	NS
	Fall	95.3	98.8	95.2	95.2	NS
Green Magic	Spring	95.0	92.8	93.1	N/A	NS
	Fall	94.0	93.0	96.6	91.0	NS
Legacy	Spring	74.4	62.5	68.0	N/A	NS
	Fall	96.6	91.4	93.8	92.0	NS
Patron	Spring	86.1	80.5	80.7	N/A	NS
	Fall	97.3	97.5	95.6	95.2	NS

[z]1 lb/acre = 1.1209 kg·ha^{-1}, 1 kg = 2.2046 lb.
[y]Fisher's protected least significant difference for comparing clomazone rate means within cultivars and seasons; NS = Nonsignificant; F test indicated that means were not different at $P \leq 0.05$.

field conditions, but moderate injury may not cause reduced yield.

Overall, our results indicate that clomazone tolerance in broccoli may be sufficient to allow safe use of the herbicide at the recommended rate for cabbage, 0.25 lb/acre for coarse soils. Further research is needed to evaluate broccoli response in different soils and environments before clomazone can be recommended for broccoli. This research is warranted because clomazone provides persistent control of annual grasses and some broadleaf weeds and controls several important broadleaf weeds that are not controlled by the other preemergence herbicides registered for broccoli. The most tolerant broccoli and cabbage cultivars appear to tolerate rates higher than the recommended rate for cabbage; however, susceptible cultivars may be moderately injured at the recommended rates. The large differences in clomazone tolerance observed among cultivars suggest that conventional plant breeding approaches could be used to develop highly tolerant cole crop cultivars.

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