Crop Protection 69 (2015) 28–33

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Tolerance of broccoli cultivars to pre-transplanting clomazone

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ARTICLE INFO

Article history:
Received 26 September 2014
Received in revised form
25 November 2014
Accepted 27 November 2014
Available online 20 December 2014

Keywords:
Crop injury
Herbicide tolerance
Cole crops
Weed management

ABSTRACT

Clomazone has been used for weed management in cabbage (*Brassica oleracea* L., Capitata group) production in the U.S.A. for over 20 years; however, the herbicide is not currently registered for other crop groups within *B. oleracea*. The specialty crops pesticide registration program (The IR-4 Project) is pursuing clomazone registration for broccoli (*B. oleracea*, Italica group) and cauliflower (*B. oleracea*, Botrytis group). The objective of this study was to assess the tolerance of a genetically diverse collection of 44 hybrid broccoli cultivars to pre-transplanting clomazone application and identify susceptible cultivars not suitable for clomazone use. A greenhouse experiment demonstrated differences in tolerance among broccoli cultivars when injury ratings and shoot weights were compared. The most tolerant cultivar, Chief, was only slightly injured and its shoot weight was not reduced in comparison to the untreated controls by clomazone incorporated into potting medium at 3.0 mg/kg; whereas, the most susceptible cultivar, Patron, was moderately injured and its shoot weight was reduced by clomazone at 1.5 mg/kg. Injury ratings from field experiments also demonstrated differences between cultivars in response to pre-transplant clomazone application. At two weeks after transplanting into treated soil, the most tolerant cultivars exhibited minor injury at 1.12 kg/ha, and the most susceptible cultivars were moderately injured by 0.28 kg/ha. Injury ratings were much lower at 6 weeks after transplanting than at two weeks. Broccoli head weights were reduced by 0.28 kg/ha for 4 cultivars in 2012 and 1 cultivar in 2013, and stem diameters of 2 cultivars were reduced by this treatment in 2012. The low rate did not affect harvest date for any cultivar, but at 1.12 kg/ha, clomazone delayed head maturation for twelve cultivars in 2012 and 4 cultivars in 2013. These responses were inconsistent between years, and the greater injury observed in 2012 than in 2013 may have been due to the transplanting method which moved treated soil into the root zone. Overall, the results indicate that pre-transplanting application of clomazone at the rate that is approved for cabbage, 0.28 kg/ha on coarse soils, is relatively safe for use on most of the 44 broccoli cultivars evaluated in this study. The risk of crop injury that may occur under unfavorable environmental conditions can be reduced by choosing the most tolerant cultivars.

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1. Introduction

Clomazone has been used for weed management in cabbage (*Brassica oleracea* L.) in the U.S.A. since the early 1990's, but it is not registered for other cole crops within the species. However, in 2013 the U.S. Environmental Protection Agency (Rutgers University, 2014) established a residue tolerance for clomazone in crops grouped in the heading vegetable brassica crop grouping which includes cabbage, broccoli, and cauliflower. This may result in the addition of broccoli and cauliflower to the clomazone registration for brassica vegetables. Research to support this registration was conducted through the IR-4 Project, but recommended uses for clomazone in broccoli have not been published. Clomazone is used on many crops, and maximum allowed application rates for clomazone range between 0.28 and 1.68 kg active ingredient/ha (Anonymous, 2014) and are adjusted for soil type and crop tolerance. Maximum cabbage application rates are 0.28 and 0.56 kg/ha for coarse and fine soils, respectively, and it is likely that these will be the rates for other cole crops.

Clomazone is in the isoxazolidinone herbicide family and is classified as a carotenoid biosynthesis inhibitor (Senseman, 2007). It inhibits chlorophyll and carotenoid synthesis, and seedlings of susceptible species are bleached white, yellow or reddish purple before death (Duke et al., 1985; Duke and Kenyon, 1986). It may cause transient, minor symptoms on tolerant plants that are typically observed as chlorosis along the margins of older leaves.

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http://dx.doi.org/10.1016/j.cropro.2014.11.013
0261-2194/Published by Elsevier Ltd.

Natural variation in clomazone tolerance within crop species is common, and differences in tolerance among cultivars or genotypes have been reported for most crops for which it is registered, including cucumber (*Cucumis sativus* L.), (Al-Khatib et al., 1995; Staub et al., 1991), pumpkin [*Cucurbita maxima* Duchesne, *Cucumis*. *moschata* Duchesne (Poir.), *Cucumis*. *pepo* L.] (Harrison and Keinath, 2003), watermelon (*Citrullus lanatus* L.) (Harrison et al., 2011), sweetpotato [*Ipomoea batatas* L. (Lam.)] (Harrison and Jackson, 2011), broccoli (Harrison and Farnham, 2013), cabbage (Hopen et al., 1993), maize (*Zea mays* L.) (Keifer, 1989), rice (*Oryza sativa* L.) (Mudge et al., 2005; Scherder et al., 2004; Zhang et al., 2004), and beans (*Phaseolus vulgaris* L.) (Sikkema et al., 2006). Hopen et al. (1993) reported that three of thirty six genetically diverse cabbage cultivars were more severely injured by pre-transplanting clomazone application than were the others. One of the most sensitive, Bravo, remains an important commercial fresh market cultivar. The head weights of susceptible cultivars were reduced by the highest rate evaluated, 1.1 kg/ha in one of the two years of the study. They also identified highly tolerant cultivars, including Stonehead, that were not injured by clomazone treatment at up to 1.1 kg/ha. Harrison and Farnham (2013) compared the response of 4 broccoli and 4 cabbage cultivars to pre-transplanting clomazone treatment in greenhouse and field experiments. Although cultivars in both crop groups varied in response to clomazone, none of the broccoli cultivars were injured as severely as the sensitive cabbage cultivar, Bravo. Injury ratings in a field experiment varied significantly among the cultivars; however, head weights were only reduced for Bravo cabbage at 1.1 kg/ha. In an accompanying greenhouse study, significant differences in tolerance among the cultivars were observed when injury ratings and shoot weights were compared after three weeks growth in clomazone treated potting medium.

Table 1
Seed sources for broccoli cultivars used in the study.

Alf Christianson Seed Company (Now owned by Sakata Seed America)	SC-100
Bejo Seeds Inc. 1972 Silver Spur Place Oceano, CA 93445, USA	Alborado, Batavia, Beaumont
Harris Seeds 355 Paul Rd., P.O. Box 24966, Rochester, NY 14624, USA	Bravo
Johnny's Selected Seeds P O Box 299 Waterville, Maine 04903, USA	Bay Meadows, Diplomat
Known-You Seed Company, LTD No.114-6, Zhuliao, Dashu District, Kaohsiung 84043, Taiwan	Chief, Green King, Green Super, Legato
Orsetti Seed Company, Inc. 2300 Technology Parkway, PO Box 2350 Hollister, CA 95024-2350, USA	Denali, Express, Platinum
Osborne Seed Company 2428 Old Hwy 99 South Road Mount Vernon, WA 98273, USA	Castle Dome
Otis S. Twilley Seed Co. 121 Gary Road Hodges, SC 29653, USA	Packman, Premium Crop
Reed's Seeds 3334 NYS Route 215 Cortland, NY 13045, USA	BI 10
Rupp Seeds Inc. 17919 Country Road B Wauseon, OH 43567-9458, USA	Avenger, Concord, Emerald Pride, Greenbelt, Gypsy, Imperial, Marathon, Monaco, Patriot, Triathlon, Windsor
Sakata Seed America 18095 Serene Drive Morgan Hill, CA 95037, USA	Destiny
Seminis Vegetable Seeds, Inc 2700 Camino Del Sol Oxnard, CA 93030, USA	General, Heritage, Liberty, Major, Revolution, Tlaloc, Tradition
Snow Seed Company 21855 Rosehart Way Salinas, California 93908, USA	Legacy, Vantage Point
Stokes Seed PO Box 548 Buffalo NY 14240-0548, USA	Captain, Everest, Ironman, Patron, Stonehead
Tokita Seed Company, LTD 1069 Nakagawa, Minuma-ku Saitama, 330-8532, Japan	Sakura, TRI-8011, TSX-0788
Vesey Seed Company PO Box 9000 Calais, Maine 04619-6102, USA	Green Magic

Over 90% of U. S broccoli is produced in California and Arizona (U.S. Department of Agriculture (2012)). Production and consumption of broccoli has increased in recent years. This along with water shortages experienced by western growers has spurred an increase in production in the eastern U.S. to provide locally grown, fresh broccoli to the large eastern population centers. Considerable research is currently directed towards developing broccoli cultivars and production practices for the eastern U.S. (Cornell University, 2011). Improved, integrated weed management approaches will be needed, because the higher rainfall in the eastern production areas increases weed growth and stimulates frequent weed seed germination. If registered, clomazone may become an important component of broccoli weed management, because it provides residual control of annual grasses and broadleaves that are not effectively controlled by the other herbicides registered for this crop. The objective of this study was to assess the variability of tolerance to pre-transplanting clomazone treatment in a genetically diverse sampling of available broccoli cultivars that is much larger than previously examined (Harrison and Farnham, 2013) and to identify susceptible cultivars that are not suitable for clomazone use.

2. Materials and methods

2.1. Greenhouse experiment

A greenhouse experiment was used to quantify clomazone tolerance of 44 commercial, hybrid broccoli cultivars (Table 1). Four cabbage cultivars (Bravo, SC-100, Stonehead, and Vantage Point) were included as standards with known clomazone responses (Harrison and Farnham, 2013). The greenhouse was located at the U.S. Vegetable Laboratory (USVL), Charleston, SC, USA (32° 48′ N, 80° 3′ W). During the experiments, greenhouse temperatures ranged between 20 and 32 °C, supplemental lighting was not provided, and humidity was increased from ambient with an evaporative cooling system. The potting medium was a 1/1 (v/v) mixture of a commercial peat-vermiculite potting mixture (Metro-Mix 360; Sun Gro Horticultural Distribution, Bellevue, WA, USA) and washed river sand. Powdered limestone and controlled release fertilizer (Osmocote 15-9-12 plus, Scotts, Marysville, OH, USA) were added at 1.1 g/L and the mixture was blended in a portable cement mixer for 5 min. The commercial formulation of clomazone (Command 3ME, FMC Corp., Philadelphia, PA, USA) was incorporated into potting medium by adding the appropriate volume of herbicide to 500 ml of water, spraying the mixture directly onto the potting medium, and incorporating in the concrete mixer for 10 min. Clomazone concentrations were 0, 1.5, and 3.0 mg clomazone active ingredient/kg dry potting medium. The concentrations for the greenhouse experiment were selected based on previous research which demonstrated that these levels caused moderate to severe injury to broccoli cultivars (Harrison and Farnham, 2013). The treated potting mixture was used to fill 350 ml polystyrene cups, and greenhouse-grown seedlings at the two leaf stage were transplanted into the cups. Based on the surface area of the cups