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Postemergence Liverwort Control in Container-Grown Nursery Crops[1]

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Abstract

Four experiments were conducted in Aurora, OR, and Auburn, AL, to evaluate effectiveness of herbicides for postemergence liverwort control. A sprayable herbicide, quinoclamine (Gentry 25-WP), was applied at rates between 1.8 and 7.6 kg ai/ha (1.6 and 6.8 lb ai/A), with or without a surfactant, and in spray volumes of 1019 or 2037 liters/ha (109 or 218 gal/A). Across all experiments, postemergence liverwort control was good (>90%) at the lowest rate when liverwort infestation was light (liverwort covered ≤25% of the substrate surface with no sporocarps). When liverwort infestation was high (liverwort covered ≥60% of the substrate surface with some sporocarps present), or in conditions favorable to liverwort growth, control improved by using higher rates or including a surfactant. At the highest labeled rate (7.6 kg ai/ha (6.8 lb ai/A)), postemergence liverwort control up to 14 days after applications was 96 to 100% across all four experiments. Long-term liverwort control through 42 to 56 days after application varied depending on the location and time year, with control decreasing as environmental conditions allowed for increased liverwort vigor. Sodium carbonate peroxyhydrate (TerraCyte) provided poor to moderate control, and was largely dependent on liverwort vigor. Flumioxazin (BroadStar) provided unacceptable postemergence control across all experiments.

Index words: quinoclamine, Quinoclamine, TerraCyte, BroadStar, *Marchantia polymorpha*.

Herbicides used in this study: Gentry (quinoclamine), 2-amino-3-chloro-1,4-naphthoquinone; TerraCyte (34% sodium carbonate peroxyhydrate); GreenClean (50% sodium carbonate peroxyhydrate); BroadStar (flumioxazin), 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione; Ronstar G (oxadiazon), 2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ-1, 3, 4-oxadiazolin-5-one.

Species used in this study: liverwort (*Marchantia polymorpha*).

Significance to the Nursery Industry

Liverwort (*Marchantia polymorpha*) is a common weed in propagation and container-grown nursery crops throughout the United States. Quinoclamine is a new herbicide currently under consideration by the Environmental Protection Agency for labeling as a postemergence herbicide on liverworts and mosses in greenhouse and nursery production. Data herein demonstrates that quinoclamine provides effective postemergence liverwort control. Control is improved when applied to light infestations in which liverwort is growing in a single layer covering ≤25% of the container surface and without sporocarps (spore-bearing structures that emerge from the liverwort surface). As liverwort infestations expand, they often cover the entire container surface, grow in multiple layers on top of each other, and develop sporocarps. Multiple layers and the presence of sporocarps reduces efficacy of quinoclamine. Cool temperatures (18 to 22C (64 to 72F)), low UV light levels and abundant precipitation improve liverwort vigor, making them less susceptible to quinoclamine and other herbicides. Quinoclamine applied at 1.9 kg ai/ha (1.7 lb ai/A) provides effective liverwort control when infestations are light or when environmental conditions reduce liverwort vigor (high temperatures and UV light). Quinoclamine at 3.8 to 7.6 kg ai/ha (3.4 to 6.8 lb ai/A) is necessary when infestations become more severe or when environmental conditions favor liverwort growth. A regular scouting program should be used to monitor liverwort population levels for timing of follow-up applications.

Introduction

In the most general sense, the term liverwort refers to any plant in the Class Hepaticae, of which there are approximately 9000 species (3). However, among nursery producers and weed scientists, the term liverwort is used specifically in reference to *Marchantia polymorpha*. *M. polymorpha*, and rarely crescent-cup liverwort (*Lunularia cruciata*), are the only economically important Hepatic weeds in container production (personal observation). To be consistent with the common industry usage of the term, liverwort hereinafter refers solely to *M. polymorpha*.

Liverworts have leaf-like structures called thalli that grow prostrate along the substrate surface. With severe infestations, liverwort thalli grow on top of each other in multiple layers. Thalli can cover the entire substrate surface in a container and restrict entry of both water and nutrients into the root zone (12). The thallus has distinct dorsal and ventral surfaces covered with a cutinized epidermal cell layer. Pores analogous to stomata cover the dorsal surface providing gas exchange between internal air chambers and the external atmosphere (3). These pores do not close like stomata of higher plants during times of water stress. This mandates that liverwort grow in humid or moist habitats with abundant available water. Along the dorsal surface is a thin photosynthetic layer comprised of air chambers lined with highly chlorophyllose filaments, analogous to chlorenchyma of higher plants (3). Beneath the photosynthetic layer is a much thicker layer of non-photosynthetic, parenchymatous storage tissue.

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Along the ventral surface are unicellular rhizoids (root-like structures) and two rows of multicellular scales. Rhizoids anchor the plant to the substrate surface. They have no absorptive function; however, in conjunction with ventral scales they aid in capillary movement of water and dissolved nutrients along the external ventral surface (6).

Liverworts have two alternate life cycles that are often present simultaneously in containers. In the sporophytic stage, a sporophyte is formed when antheridia fertilize archegonia (each borne on stalks). Each archegoniophore produces up to 7 million spores (98). A heavily infested 2.8 liter (0.7 gal) container can have up to 75 archegoniophores (personal observation) with the potential to produce up to 525 million spores. Spores readily germinate immediately after release and are viable up to 1 year in a protected environment (9). Spores give rise to the dominant gametophytic stage (the thallus) in which the plant can propagate asexually by gemmae dispersal. Gemmae are diaspores formed in crater-like depressions on the thallus surface called gemmae cups. Each gemmae cup gives rise to numerous gemmae that are dispersed to the immediate area when splashed by water droplets. Gemmae can be dispersed up to 1.6 m (5.2 ft) from the mother plant (4) depending on water droplet size. This is the primary mechanism by which liverwort spreads throughout a nursery or greenhouse. Liverwort can also propagate asexually by fragmentation. Fragmentation is not important in terms of liverwort spread, although it does mandate thorough handweeding to completely remove a liverwort population. In addition, regeneration from fragmentation allows the thallus to regenerate after treatment with contact herbicides that do not completely cover and kill the entire thallus.

Liverwort is a weed problem primarily in the relatively cool Northeast and Pacific Northwest regions of the United States (1, 10). Despite its preference for cooler temperatures, it has been also identified as an important weed in nurseries throughout the Southeast U.S. (7). Liverwort thrives in conditions typical of most propagation and container production environments: high light (9), low UV radiation (14), high humidity and/or soil moisture (13), and high fertility. Optimum light periodicity for vigorous growth is 13 to 15 hours, typical of spring and early summer. The optimum temperature for vegetative growth of liverwort is 18 to 22C (64 to 72F) and the optimum temperature for development of archegoniophores and antheridiophores is 10 to 15C (50 to 59F) (9). Liverwort is more vigorous from March through May, which coincides with the reported optimum temperatures and light period for growth and reproduction.

Currently there are few postemergence herbicides labeled for weed control in container crops, leaving only expensive hand weeding to remove weeds that escape preventative control efforts. Rhizoids that grow along the ventral surface of the thallus make hand removal difficult. It is often necessary to remove the surface 2.5 cm (1 in) layer of the substrate in order to remove liverwort from containers (personal observation). This necessitates adding new substrate to fill the container.

A 34% granular formulation of sodium carbonate peroxyhydrate (TerraCyte (SCP-34), BioSafe Systems, Glastonbury, CT) is currently labeled for control of moss, liverwort, algae, and slime mold in container nursery and greenhouse crops. Upon contact with water, SCP-34 breaks down into sodium carbonate and hydrogen peroxide (H_2O_2). The mode of action for this compound has not been studied extensively, although it probably is due to contact oxidation (from H_2O_2) of the thin photosynthetic layer on the thallus surface. A 0.25% granular formulation of flumioxazin (BroadStar, Valent U.S.A., Walnut Creek, CA) is a preemergence herbicide reported to provide postemergence liverwort control (5). Flumioxazin is a protoporphorinogen oxidase inhibitor, and like other herbicides with this mode of action, has been shown to provide contact postemergence weed control of small seedlings. Granular herbicides are not often used for postemergence weed control in container crops due to poor contact with weed foliage. However, because the liverwort thallus is prostrate to the soil surface, granular application of flumioxazin could result in sufficient coverage to have postemergence activity. Quinoclamine (Gentry 25-WP, Chemtura Corp., Middlebury, CT), is a 25% wettable powder currently labeled for liverwort control in nursery crops in parts of Europe. Mode of action for this compound is electron-withdrawal at the terminal part of photosystem I which prevents reduction of NADP, CO_2 assimilation, and oxygen evolution (personal communication, Chemtura Corporation). Light-induced radical formation leads to deterioration of the photosynthetic system and rapid pigment bleaching. This product is marketed as Mogeton in other parts of the world, and until recently has been researched in the U.S. under the same name. Chemtura Corp. is currently seeking a Section 3 label for quinoclamine, under the trade name of Gentry, in nursery and greenhouse crops in the United States (submitted to the Environmental Protection Agency February 26, 2006). Extensive evaluation through the IR-4 program has demonstrated that a broad spectrum of nursery crops is tolerant of broadcast applications in outdoor or greenhouse production sites (16). The proposed label states that quinoclamine should be mixed at 3.8 g ai/liter (0.5 oz ai/gal), and this concentration should be applied in a spray volume of 1019 to 2037 liters/ha (1 to 2 qt/100 ft^2). Spray volumes in the proposed label are high compared to most commonly used postemergence herbicides. Spray volumes used in this manuscript reflect the proposed label.

Preemergence herbicides provide liverwort control (8); however, no preemergence herbicide is labeled for use in enclosed structures. The objective of this research was to evaluate the potential usefulness of quinoclamine and other selected chemicals for postemergence liverwort control in container crops.

Materials and Methods

General information. Liverwort used in Alabama experiments were collected from local nurseries in Baldwin County, AL. Liverwort in Oregon experiments were from preexisting populations at the research station. In all experiments, quinoclamine was applied with a CO_2 backpack sprayer equipped with flat fan nozzles and set to a pressure of 2.5 kg/cm^2 (35 psi). A hand-held shaker was used to apply granular herbicides. Average daily high temperature and UV Index was recorded for the week following application in each experiment as an indicator of liverwort stress during the period of time most critical to postemergence herbicide activity. UV Index is a rating of UV light levels assigned by the National Weather Service for the U.S., and is on a scale from 0 to 16 where higher index numbers correlate to increased UV exposure. Liverwort control was rated on a 0 to 100 scale where 0 = no control and 100 = complete control. All data were subjected to repeated measures analysis, and means were

separated with Duncan's multiple range test ($\alpha = 0.05$). Contrast analyses were used to make specific comparisons among groups of treatments where appropriate.

Experiment 1. Aurora, OR. On June 5, 2003, 2.8 liter (#1) containers were filled with Douglas fir (*Psuedotsuga menziesii* (Mirbel) Franco) bark amended per m^3 (yd^3) with 9.5 kg (16 lb**)** Osmocote 18N–2.6P–10K (18N–$6P_2O_5$–$12K_2O$, Scotts Co., Marysville, OH) and 0.9 kg (1.5 lb) Micromax micronutrients (Scotts Co.). Containers were inoculated with liverwort June 12, 2003. The inoculation procedure consisted of blending 20 g (0.7 oz) of liverwort thalli with 200 mL (6.8 oz) buttermilk and 1 liter (1.1 qt) water to produce a slurry from which 50 ml (1.7 oz) was applied to the substrate surface of each container (9). Containers were placed inside a retractable roof greenhouse with the roof open. Daily overhead irrigation was applied as 1.3 cm (0.5 in) split into two cycles per day, 5 hr apart. Chemical treatments were applied July 22, 2003, to two groups of liverwort. In the first group, characterized as lightly infested, approximately 25% of the container surface was covered by liverwort with neither antheridiophores nor archegoniophores (hereafter referred to collectively as sporocarps) present. In the second group, characterized as moderately infested, liverwort with sporocarps covered approximately 60% of the container surface. Quinoclamine was applied at 1.9, 3.8, and 7.6 g ai/liter (0.3, 0.5, and 1.0 oz ai/gal) in a spray volume of 935 liters/ha (100 gal/A). These herbicide concentrations when applied at the aforementioned volumes are equivalent to 1.8, 3.5, and 7 kg ai/ha (1.6, 3.2, and 6.3 lb ai/A). The sprayer was equipped with a 3-nozzle boom and 8008 flat fan nozzles. SCP-34 was applied at 249 kg ai/ha (222 lb ai/A), and flumioxazin was applied at 0.42 kg ai/ha (0.38 lb ai/A), the maximum labeled rate for each product. Non-treated controls for light and moderate liverwort infestations were maintained. Irrigation was withheld on quinoclamine-treated containers for 24 hr. Irrigation of 1.3 cm (0.5 in) was applied to all other containers immediately following herbicide application. There were eight single container replications per treatment of lightly infested liverwort containers and ten single container replications of moderately infested containers. Lightly and moderately infested containers were arranged separately in a completely randomized design. Percent control was recorded 2, 14 and 42 days after treatment (DAT).

Experiment 2. Aurora, OR. On March 4, 2004, 2.8 liters (trade gallon) containers were filled with the same substrate used in Experiment 1 and inoculated with a liverwort slurry (10). Treatments were applied on April 28, 2004, when liverwort covered at least 60% of the substrate surface with a few sporocarps present. Quinoclamine was applied at concentrations of 1.9 or 3.8 g ai/liter (0.25 or 0.5 oz ai/gal) with or without Silwet L-77 (organosilicone surfactant, Helena Chem. Co., Collierville, TN) applied at 0.25% (by vol) in 1019 or 2037 liters/ha (1 or 2 qt/100 ft^2). SCP-34 was applied at 249 kg ai/ha (222 lb ai/A). Non-treated controls were also maintained. All treatments consisted of eight single container replications in a completely randomized design. Irrigation was withheld for 24 hr, after which a total of 1.3 cm (0.5 in) was applied in two equal cycles daily. Percent postemergence liverwort control was recorded at 2, 7, 14, and 45 DAT.

Experiment 3. Auburn, AL. This study was conducted similarly to Experiment 2 with the following exceptions. Containers (#1) were filled with pine bark:sand (6:1, v/v) substrate amended per m^3 (yd^3) with 8.3 kg (14 lb) of Polyon 18N–2.6P–10K (18N–$6P_2O_5$–$12K_2O$, Pursell Technologies, Sylacauga, AL), 3.0 kg (5 lb) of dolomitic lime, and 0.9 kg (1.5 lb) of Micromax micronutrients. At the time of treatment on April 16, 2004, liverwort covered approximately 60% of the container surface with only a few sporocarps present. The CO_2 sprayer was equipped with a single 8005 flat fan nozzle. SCP-34 was applied at 166 or 249 kg ai/ha (148 or 222 lb ai/A). SCP-50 (GreenClean, 50% sodium carbonate peroxyhydrate, BioSafe Systems), which is similar to SCP-34 but with a higher concentration of peroxyhydrate, was applied at 183 or 244 kg ai/ha (163 or 218 lb ai/A). Flumioxazin was applied at 0.42 kg ai/ha (0.38 lb ai/A). Treatments were arranged in a completely randomized design with six single container replications per treatment. The experiment was maintained in a double layer plastic covered greenhouse under mist irrigation (6 sec every 4 min). Postemergence liverwort control was recorded 3, 14, and 56 DAT.

Table 1. Postemergence liverwort (*Marchantia polymorpha*) control (%) with herbicides applied July 22, 2003 (Experiment 1, Aurora, OR).

Herbicide	Spray concentration (g/L)	Rate (kg ai/ha)	Light infestation[z]			Moderate infestaion[y]		
			2 DAT[x]	14 DAT	42 DAT	2 DAT	14 DAT	42 DAT
quinoclamine	7.5	1.8	99a[w]	98a	92a	89a	84b	49c
quinoclamine	15	3.5	100a	100a	98a	94a	97ab	78b
quinoclamine	30	7.0	100a	100a	99a	96a	99a	94a
SCP-34[v]		732	67b	79b	69b	66b	56c	29d
flumioxazin		168	20c	39c	65b	3c	5d	3e
Control			2d	3d	31c	0c	3d	3e

[z]Light infestation refers to containers with approximately 25% of the substrate surface covered with liverwort, with no archgoniophores or antheridiophores present.

[y]Moderate infestations refer to containers with approximately 60% of the substrate surface covered with liverwort, with some archegoniophores and antheridiophores present.

[x]Days after treatment.

[w]Means within a column with different letters are significantly different, Duncan't multiple range test ($\alpha = 0.05$).

[v]Sodium carbonate peroxyhydrate, 34% active ingredient.

Table 2. Postemergence liverwort (*Marchantia polymorpha*) control (%) in Aurora, OR, with quinoclamine using modified application procedures (spray concentration, surfactant, and volume), treated April 28, 2004, when liverwort covered approximately 60% of the substrate surface (Experiment 2, Aurora, OR).

Herbicide	Spray concentration (g/L)	Surfactant[z]	Spray volume (L/ha)	Rate (kg ai/ha)	Liverwort control (%)			
					2 DAT[y]	7 DAT	14 DAT	45 DAT
quinoclamine	7.5	no	1019	1.9	61d[x]	59c	44d	43c
quinoclamine	7.5	yes	1019	1.9	80c	76b	74c	69abc
quinoclamine	7.5	no	2037	3.8	83bc	83b	82bc	59bc
quinoclamine	7.5	yes	2037	3.8	98a	99a	99a	85
quinoclamine	15	no	1019	3.8	94ab	96a	93ab	88a
quinoclamine	15	yes	1019	3.8	98a	99a	98a	84ab
quinoclamine	15	no	2037	7.6	99a	100a	100a	88a
quinoclamine	15	yes	2037	7.6	99a	100a	100a	94a
SCP-34[w]				249	29e	13d	23e	51c
Control					0f	1d	3f	6d
Contrast analysis					**Significance (Pr > F)**			
Quinoclamine concentration					0.0001	0.0001	0.0001	0.0001
Surfactant					0.0005	0.0001	0.0001	NS
Spray volume					0.0046	0.0040	0.0012	0.0277
Quinoclamine rate					0.0001	0.0001	0.0001	0.0004

[z]Surfactant was 0.25% by volume, nonionic surfactant.

[y]Days after treatment

[x]Means within a column with different letters are significantly different, Duncan't multiple range test ($\alpha = 0.05$).

[w]Sodium carbonate peroxyhydrate, 34% active ingredient.

Experiment 4. Auburn, AL. The experiment was similar to Experiment 3 with the following exceptions. Treatments were applied on June 3, 2004. The study was conducted in an outdoor propagation area under 50% shade with a mist interval of 5 sec every 5 min.

Results and Discussion

Experiment 1. In this and all experiments, repeated measures analysis revealed and interaction between treatment and time ($p < 0.0001$). This interaction indicates that control from treatments changed over time, some differently from others. In containers with light infestations of liverwort, all rates of quinoclamine provided excellent (>90%) postemergence control throughout the experiment while SCP-34 provided moderate control (67–79%) (Table 1). Control provided by flumioxazin increased as the study progressed and by 42 DAT was similar to SCP-34, but still not acceptable. Fausey (5) reported that flumioxazin with the same formulation and rates provided increasing postemergence liverwort control up to 2 months after application, with control peaking at 95%. Control from flumioxazin in our experiment increased over time, but did not approach the level reported by Fausey.

In containers with moderate liverwort infestations, all rates of quinoclamine provided similar control 2 DAT (89–96%). By 14 DAT, control declined slightly at the lowest quinoclamine rate, however excellent control was observed in containers treated with 3.8 and 7.6 g ai/liter (0.5 and 1 oz ai/gal). Sporocarps were still green and appeared to be the only living portions of liverwort in these containers. All thalli (leaf-like structures) appeared dead. Physiological characteristics of sporocarps may render them more tolerant to quinoclamine than thalli. By 42 DAT, control had declined in containers treated with 1.9 and 3.8 g ai/liter (0.3 and 0.5 oz ai/gal). Only containers treated with 7.6 g ai/liter (1.0 oz ai/gal) maintained greater than 90% control through the end of the evaluation period. Greater control at 42 DAT with 7.6 g ai/liter (1.0 oz ai/gal) could be the result of greater postemergence control and thus slower regrowth from surviving thalli; it could also imply some level of residual control. Svenson and Deuel (13) reported that quinoclamine at 3.4 and 6.7 kg ai/ha provided 96 to 100% postemergence liverwort control through 30 DAT. In their study, control remained 82 to 90% by 60 DAT. Svenson did not describe the size or appearance of the liverwort population at the time of treatment. Svenson (11) has stated that quinoclamine is best used for preemergence control implying it does offer residual control, but offers no justification or supporting data.

SCP-34 provided moderate control (66%) 2 DAT, and efficacy declined thereafter. SCP-34 causes contact injury, so that any portion of the thallus not contacted with the compound could survive and begin growing soon after application. Senesac (10) also reported poor to moderate control using SCP-34, with liverwort beginning to recover before 30 DAT. Flumioxazin provided almost no control of moderate liverwort infestations (3–5%). While not compared statistically, all products appear more effective on light infestations of liverwort. This could be due in part to the aforementioned greater tolerance of sporocarps to quinoclamine compared to thalli. As the number of sporocarps in a container increase, the appearance of control decreases despite the level of control on thalli. Senesac (10) evaluated 1.9 and 3.9 kg ai/ha (1.7 and 3.5 lb ai/A) on liverwort he defined as immature (thallus only) and mature (with numerous sporocarps). Both

Table 3. Postemergence liverwort (*Marchantia polymorpha*) control (%) in Auburn, AL, with quinoclamine using modified application procedures (spray concentration, surfactant, and volume), treated April 16, 2004, when liverwort covered approximately 60% of the substrate surface (Experiment 3, Auburn, AL).

Herbicide	Spray concentration (g/L)	Spray volume (L/ha)	Surfactant[x]	Rate (kg ai/ha)	Liverwort control (%)		
					3 DAT[y]	14 DAT	56 DAT
quinoclamine	7.5	1019	no	1.9	99a[x]	93a	72abcd
quinoclamine	7.5	1019	yes	1.9	98a	93a	80abcd
quinoclamine	7.5	2037	no	3.8	100a	100a	95ab
quinoclamine	7.5	2037	yes	3.8	100a	100a	94abc
quinoclamine	15	1019	no	3.8	100a	99a	97a
quinoclamine	15	1019	yes	3.8	100a	99a	97a
quinoclamine	15	2037	no	7.6	100a	100a	100a
quinoclamine	15	2037	yes	7.6	100a	100a	100a
SCP-34[w]				166	76b	74b	52de
SCP-34				249	88a	77b	67bcd
SCP-50				183	88a	87ab	66cd
SCP-50				244	95a	87ab	73abcd
flumioxazin				0.42	5c	21c	32ef
Control					0c	8c	25f
Contrast analysis					**Significance (Pr > F)**		
Quinoclamine concentration					NS	NS	0.0379
Surfactant					NS	NS	NS

rates provided better control of immature liverwort compared to mature liverwort.

For the week following application, the average daily high temperature in our experiment was 32C (90F) and the UV Index was 7.5. These environmental conditions are not favorable for liverwort growth, and may have caused them to be more susceptible to control and less capable of regenerating quickly.

Experiment 2. The high spray concentration (3.8 g ai/liter (0.5 oz ai/gal)) provided excellent control throughout the study regardless of spray volume or surfactant inclusion (Table 2). This spray concentration led to rates of 3.8 or 7.6 kg ai/ha (3.4 or 6.8 lb ai/A), depending on spray volume. The low quinoclamine concentration (1.9 g ai/liter (0.25 oz ai/gal)) resulted in variable control, with the only acceptable (>90%) treatment being that concentration applied at 2037 liters/ha (2 qt/100 ft^2) with a surfactant. At 1.9 g ai/liter (0.3 oz ai/gal), adding surfactant improved control within each level of spray volume. Senesac (10) also reported that a surfactant improved control of mature liverwort, but only when used with lower rates of quinoclamine. Use of relatively inexpensive surfactants may be one way in which control with reduced quinoclamine rates may be improved. Among containers treated with the low spray concentration, liverwort treated with the higher spray volume resulted in greater control than those treated with the lower spray volume, as would be expected considering twice the amount of active ingredient is applied in the higher spray volume treatments. SCP-34 provided poor control throughout the study. For the week following treatment the average daily high temperature was 24C (76F) and the UV Index was 5. These conditions are more favorable for liverwort growth than those experienced in Experiment 1. Liverwort control at 14 DAT with the low quinoclamine rate (1.8 and 1.9 kg ai/ha (1.6 and 1.7 lb ai/A)) was 98%, and 44 to 74% in Experiments 1 and 2, respectively.

Experiment 3. Quinoclamine provided excellent postemergence liverwort control 3 and 14 DAT, regardless of concentration, surfactant, or spray volume (Table 3). SCP-34 applied at 249 kg ai/ha (222 lb ai/A) and both rates of SCP-50 provided control similar to quinoclamine. SCP-34 applied at 166 kg ai/ha (148 lb ai/A) provided moderate control (76%). Flumioxazin provided poor postemergence liverwort control throughout the study.

At 56 DAT, quinoclamine applied at 1.9 kg ai/ha (1.8 lb ai/A) provided less (72 to 80%) control than quinoclamine at 3.8 to 7.6 kg ai/ha (3.4 to 6.8 lb ai/A) (94 to 100%) ($p = 0.0147$). Liverwort control among containers treated with SCP-34 was similar to those treated with SCP-50.

Although not compared statistically, control was generally greater in this study compared to Experiment 2. Average daily high temperatures for the week following application was 26C (80F) and the UV Index was 6.7. Higher temperatures and UV light levels in Alabama compared to Oregon likely cause increased stress on liverwort, which may have increased treatment efficacy. The optimum temperature for vegetative growth of liverwort is 18 to 22C (64 to 72F) (9). Liverwort vigor is also reduced by high UV exposure. True et al. (14) demonstrated that liverwort gemmae exposed to elevated levels of UV light grew slower and produced fewer and shorter rhizoids than plants shielded from UV light. Alabama, and the southeast in general, is exposed to higher UV levels than Oregon and the Pacific Northwest during the

Table 4. Postemergence liverwort (*Marchantia polymorpha*) control (%) in Auburn, AL, with quinoclamine using modified application procedures (spray concentration, surfactant, and volume), treated June 3, 2004 (Experiment 4, Auburn, AL).

Herbicide	Spray concentration (g/L)	Spray volume (L/ha)	Rate Surfactant[z]	(kg ai/ha)	Liverwort control (%) 3 DAT[y]	14 DAT	56 DAT
quinoclamine	7.5	1019	no	1.9	100a[x]	100a	100a
quinoclamine	7.5	2037	no	3.8	100a	100a	100a
quinoclamine	7.5	1019	yes	1.9	100a	100a	98a
quinoclamine	7.5	2037	yes	3.8	100a	100a	100a
quinoclamine	15	1019	no	3.8	100a	100a	99a
quinoclamine	15	2037	no	7.6	100a	100a	100a
quinoclamine	15	1019	yes	3.8	100a	100a	100a
quinoclamine	15	2037	yes	7.6	100a	100a	100a
SCP-34[w]				166	92a	94a	91a
SCP-34				249	94a	95a	95a
SCP-50				183	93a	90a	81a
SCP-50				244	97a	96a	90a
flumioxazin				0.42	18b	58b	84a
Control					5c	17c	24b
Contrast analysis					**Significance (Pr > F)**		
Quinoclamine concentration					NS	NS	NS
Surfactant					NS	NS	NS
Spray volume					NS	NS	NS
Quinoclamine rate					NS	NS	NS

[z]Surfactant was 0.25% by volume, nonionic surfactant.

[y]Days after treatment.

[x]Means within a column with different letters are significantly different, Duncan't multiple range test ($\alpha = 0.05$).

[w]Sodium carbonate peroxyhydrate, 34% active ingredient.

month of April (2). Differences in control might also be explained by differences in liverwort populations between the two regions. While it is possible that Alabama and Oregon have similar populations introduced from common nursery crops, it is also possible that populations are distinct. Underwood (15) described liverwort (*M. polymorpha* specifically) as almost universally distributed throughout our borders (the U.S.) and the world. This description of the plants' range predates interstate nursery trade. Thus locally adapted liverwort populations may dominate containers in both Alabama and Oregon and respond differently to herbicide products.

Experiment 4. Quinoclamine provided complete liverwort control throughout the study period regardless of spray concentration, surfactant, or spray volume (Table 4). SCP-34 and SCP-50 provided similar control (≥90%) 3 and 14 DAT. BroadStar provided poor control 3 and 14 DAT, although control improved to 84% by 56 DAT.

SCP-34 provided control similar to quinoclamine, although it generally provided less control than quinoclamine in other experiments. Overall liverwort control in this study was generally greater than that in Experiments 2 or 3 (not compared statistically). This study was conducted in the summer, while Experiments 2 and 3 were conducted in the spring. Average daily high temperatures for the week following application was 28C (84F) and average UV Index at this site was 7.5. Temperatures and UV levels were higher than Experiments 2 or 3, likely resulting in reduced liverwort vigor and improved treatment efficacy.

In summary, flumioxazin generally provided poor postemergence liverwort control. SCP-34 provided poor to moderate control, with control generally improving as liverwort vigor declined (mostly due to climate). Quinoclamine consistently provided effective postemergence liverwort control. Liverwort vigor is affected by temperature (9) and UV light (14). Conditions that favor liverwort growth seem to reduce quinoclamine efficacy, especially at lower rates. Liverwort control is generally more difficult in the Pacific northwest than the southeast U.S. However, even in Oregon when temperatures and UV levels were high (as they were in Experiment 1), efficacy of quinoclamine and other products is improved compared to when conditions are typically cool with low UV light levels.

Quinoclamine should be applied before liverworts cover 30 to 40% of the substrate surface and before sporocarps develop. Sporocarps are less sensitive to quinoclamine than thallus tissue. Presence of sporocarps will reduce control or at least the appearance of control. Repeated applications over the course of a production cycle may be required. Cool spring conditions should favor liverwort vigor and necessitate more frequent applications. Conversely, dryer, warmer conditions should require lower quinoclamine rates with fewer and less frequent applications.

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