LIVERWORT CONTROL IN CONTAINER-GROWN NURSERY CROPS

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LIVERWORT CONTROL IN CONTAINER-GROWN NURSERY CROPS

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VITA

Adam Franklin Newby was born to Gary and Mary Ann (Barrett) Newby of McMinnville, TN on April 4, 1981. He grew up on a field production nursery north of McMinnville, TN. He attended Warren County schools and graduated from Warren County High School in 1999. After two years of academic studies at Motlow State Community College, he transferred to Auburn University in August 2001. He received the degree of Bachelor of Science in Horticulture with an emphasis in nursery and greenhouse production in December 2003. He entered Graduate School in the Horticulture department of Auburn University in January 2004. Throughout his graduate program, he was employed as a graduate research assistant during which time he also volunteered his time as a graduate teaching assistant.

THESIS ABSTRACT

LIVERWORT CONTROL IN CONTAINER-GROWN NURSERY CROPS

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The objective of this study was to evaluate preemergence and postemergence liverwort control in container-grown nursery crops.

In Chapter II, experiments were to evaluate effectiveness of selected chemicals for postemergence liverwort control and crop safety in container nursery crops. In Experiment 1, Gentry provided 98% to 100% postemergence control on juvenile liverwort and 84% to 99% postemergence control on mature liverwort 14 DAT. TerraCyte provided moderate postemergence control on juvenile (79%) and mature (56%) liverwort 14 DAT. BroadStar provided 39% and 5% postemergence control on juvenile and mature liverwort, respectively. In Experiment 2, a Gentry concentration of 3.8 g ai/L (0.5 oz/gal) applied at 2036 L/ha (218 gal/A) provided 77% postemergence control 14 DAT, while the low Gentry rate provided 53% postemergence control. Ronstar

G provided 6% postemergence control, while BroadStar provided 13% control 14 DAT. TerraCyte provided 82% postemergence control 14 DAT. In Experiment 3, Gentry and Ronstar G caused no injury to *Achillea millefolium* L. 'Colorado', *Coreopsis grandiflora* Hogg ex Sweet 'Early Sunrise', and *Dianthus gratianopolitanus* L.'Spotti'. In Experiment 4, Gentry applied at concentrations of 1.9, 3.8, and 7.5 g ai/L applied at 2036 L/ha (218 gal/A) resulted in no significant plant injury or differences in plant indices to *Buddleia davidii* Franch, *Cotoneaster salicifolius* Franch, *Hosta* 'Francee', *Ilex x meserveae* S.Y. Hu, *Magnolia grandiflora* L., or *Rhododendron* x 'Midnight Flare.'

Experiments in Chapter III evaluated the effects of differing concentrations and spray volumes of Gentry with and without surfactant as well as the effects of TerraCyte and BroadStar on postemergence liverwort control in propagation. In Experiment 1, Gentry applied at a concentration of 3.8 g ai/L provided excellent control regardless of spray volume or surfactant. TerraCyte provided poor postemergence control throughout the experiment (<30%). In Experiment 2, Gentry provided excellent postemergence liverwort control (93%-100%) 3 and 14 DAT regardless of concentration, spray volume, or surfactant. TerraCyte provided good postemergence liverwort control (74%-88%) 3 and 14 DAT. BroadStar provided only 21% postemergence liverwort control 14 DAT. In Experiment 3, Gentry provided 100% postemergence liverwort control 3 and 14 DAT regardless of concentration, spray volume, or surfactant. TerraCyte and experimental TerraCyte treatments provided 90% to 97% postemergence control 3 and 14 DAT. BroadStar provided only 58% postemergence liverwort control 14 DAT.

The objective of studies in Chapter IV was to evaluate the of residual granular herbicides, Gentry, and diuron on preemergence liverwort control. In Experiment 1, BroadStar and Ronstar G provided the most effective preemergence liverwort control 17 WAT. In Experiment 2, by 18 WAT, liverwort coverage in containers treated with Gentry was similar to non-treated controls, while BroadStar, Ronstar G, and Rout 3G provided significant preemergence liverwort control. In Experiment 3, liverwort coverage in containers treated with Gentry was similar to non-treated controls 9 WAT. There was no liverwort present in containers treated with diuron applied at 0.56 and 1.12 kg ai/ha (0.5 and 1.0 lb ai/A). At 12 and 17 WAT, percent liverwort coverage in containers treated with Gentry was similar to non-treated controls, while no liverwort was present in containers treated with diuron.

Experiments in Chapter V evaluated the use of lower Gentry concentrations and spray volumes than currently recommended and evaluated diuron for postemergence liverwort control in containers. In Experiment 1, Gentry concentrations of 1.87 and 3.75 g ai/L applied at 509 and 1018 L/ha provided excellent postemergence liverwort control 7 and 14 DAT (81%-99%). Diuron applied at 1.12 kg ai/ha provided 86% postemergence liverwort control. Linuron provided no postemergence control. In Experiment 2, Gentry applied at concentrations of 3.75 g ai/L and spray volumes of 509 and 1018 L/ha provided superior postemergence control 7 and 14 DAT (82%-89%). Diuron applied at 1.12 kg ai/ha provided 60% postemergence liverwort control 14 DAT, however liverwort coverage in containers treated with diuron averaged only 1% by 63 DAT.

Style manual or journal used: Journal of Environmental Horticulture

Computer software used: Microsoft Word 2003, Microsoft Excel 2003, and SAS v 9.1.

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Chapter I

Introduction and Literature Review

Liverwort (*Marchantia polymorpha* L.) is a member of the family Marchantiaceae (Durand, 1908). It is more closely related to mosses and ferns than higher plants (Altland, 2003; Svenson, 1997). It is a primitive plant that lacks stems, leaves, and a vascular system and is identified by leaf-like structures known as thalli that grow prostrate along the substrate surface (Svenson, 1997). Although there are over 10,000 species of liverworts (Svenson, 1997), the species *M. polymorpha* L. is the one that most commonly infests container-grown plants and propagation material in southern nurseries.

Liverwort has two phases in its life cycle. In the sporophytic stage, spores are produced sexually when antheridia borne on stalked antheridiophores fertilize the archegonia borne on stalked archegoniophores. Antheridia are produced within sunken cavities on the upper surface of the antheridiophore. These antheridia fertilize the archegonia to produce sporogonia. Each sporogonium gives rise to a spore mother cell. The spore mother cell divides to produce four tetrahedral spores (Durand, 1908). Each archegoniophore's head can produce as many as 7 million spores (O'Hanlon, 1926). Spores can remain viable at room temperature for over one year (O'Hanlon, 1926).

Spores give rise to the gametophytic life cycle during which the plant propagates asexually by producing gemmae within structures called gemmae cups. Each gemmae cup gives rise to numerous gemmae that are released to the immediate area when splashed by water from irrigation or rain (Svenson, 1997). A single gemma gives rise to a new liverwort plant. Liverwort may also propagate asexually by fragmentation (Svenson, 1997).

Liverwort has historically been reported as a weed problem in cooler regions of the Northeast and Pacific Northwest regions of the United States. The optimum temperature for vegetative growth of liverwort is 18 to 22 C (64 to 72 F) (O'Hanlon, 1926). The optimum temperature for development of fruiting bodies is 10 to 15 C (50 to 59 F) (O'Hanlon, 1926). Nonetheless, reports from the southeastern U.S. indicate that liverwort is well adapted to nursery environments in warmer climates. Liverwort thrives in low UV light, high humidity, and substrates high in moisture (Svenson, 2002). All of these conditions are typical of most nurseries. Liverwort growth is especially optimized in high frequency irrigation (Svenson, 1998).

The prostrate growth of liverwort creates a mat over the container substrate surface (Svenson, 1997). An established infestation of liverwort within a container competes with nursery crops for nutrients and water and decreases the marketability of a crop (Svenson, 1997). Within the Southeast, liverwort is especially a weed problem in propagation where moisture is abundant.

Prevention of liverwort is the best means of control. Svenson (1998) reported that high frequency irrigation promotes liverwort growth. Practices that reduce the availability of water at the substrate surface help reduce liverwort vigor. Use of fast-drying mulches such as rice (*Oryza sativa* L.) hulls, hazelnut (*Corylus avellana* L.) shells, and pumice on the container media surface was shown to reduce liverwort growth (Svenson, 1997). In general, mulches have been shown to reduce weed growth in container grown nursery crops (File, 1999; Llewellyn, 2003). Liverwort also thrives when nitrogen is readily available. Increasing nitrogen levels promotes liverwort growth (Svenson, 1998). Liverwort establishment may be slowed if nitrogen levels lower than 75 parts per million (ppm) are applied (Svenson, 1997).

Use of preemergence herbicides to prevent liverwort was suggested as early as 1979 (Elmore et al., 1979). Svenson (1997) evaluated many preemergence herbicides for control of liverwort and reported that oxadiazon and oryzalin provided good preemergence control. A combination of mulch and oxadiazon provided excellent control (Svenson, 1998). Flumioxazin applied as SureGuard at 0.38 kg ai/ha (0.34 lb ai/A) provided 100% preemergence liverwort control 35 DAT and 74% preemergence control 60 DAT (Fausey, 2003). In another study, the same product applied at the same rate provided 98% preemergence control 60 DAT, while flumioxazin applied as a 0.17% granular at the same rate provided 95% preemergence control 60 DAT (Fausey, 2003).

Unfortunately, liverwort often grows in environments where residual preemergence herbicides cannot be used. Preemergence herbicides are not labeled for use in enclosed structures due to fear of volatilization and co-distillation of the herbicide and subsequent plant injury. Furthermore, many of the currently used preemergence herbicides are dinitroanilines (DNAs) which inhibit root growth. Because of the high amount of irrigation used during plant propagation, DNA herbicides move into the rooting media and inhibit root development of the propagated plant material (Thetford, 1988). There has been some success with the use of herbicides in propagation (Langmaid, 1987; Thetford, 1988). However, labels of herbicides for use in nursery corps clearly state that they may not be used in closed structures. Despite practices to prevent liverwort in all nursery and greenhouse settings, infestations are inevitable. Hand removal of weeds is costly and inefficient (Gilliam et al., 1990; Darden and Neal, 1999). Therefore, research in recent years has focused on the eradication and postemergence control of liverwort.

Many chemicals and products have been tried as postemergence liverwort controls. In 1975, dichlorophen was reported to provide postemergence liverwort control (Hammett, 1975). In 1997, Svenson indicated success with cinnamic aldehyde (sold as Cinnacure) and benzylkonium chloride (Svenson, 1997). However these products caused sporadic injury to ornamental crops depending on the season. Preemergence herbicides have been evaluated as a postemergence control with varying success (Mervosh and Ahrens, 2003; Fausey, 2003). Mervosh and Ahrens (2003) reported that flumioxazin spray and oxadiazon plus copper sulfate provided effective postemergence liverwort control (Mervosh and Ahrens, 2003). Senesac and Tsontakis-Bradley reported that dithiopyr and oxadiazon provided effective postemergence control (1997). Many nurseries in Oregon have used hydrogen peroxide for postemergence control of liverwort by injecting the product into overhead irrigation (personal communication with James Altland). However, injury of ornamental crops is common.

Gentry (quinoclamine, Chemtura Corp., Middlebury, CT) is a new product labeled for over-the-top application on nursery crops. It is labeled in other countries under the name Mogeton. It is currently undergoing EPA approval in the U.S. Gentry was shown to provide effective postemergence liverwort control and cause no phytotoxicity to *Rhododendron* 'Cannon's Double' (Svenson and Deuel, 2000). In a study conducted in 2003, Gentry provided 96% postemergence liverwort control 2 DAT and 94% control 45 DAT when applied at 28 kg ai/ha to mature liverwort (Altland, 2003). Furthermore, the product caused no injury to *Rudbeckia fulgida* var. *sullivantii* (C.L. Boynt and Beadle) 'Goldstrum', *Rhododendron* 'P.J.M.', or *Berberis thunbergii* DC 'Rose glow' (Altland, 2003). Gentry provided at least 93% postemergence control 2 weeks after treatment in a study by Stamps and Chandler (2004).

TerraCyte (BioSafe Systems, Inc., Glastonbury, CT), a granular form of sodium carbonate peroxyhydrate, has bee used with some success. Upon contact with water, it breaks down into hydrogen peroxide. Stamps and Chandler (2004) reported that TerraCyte provided excellent postemergence control 2 weeks after treatment. In contrast, Altland et al. (2003) reported TerraCyte to have poor to moderate control when applied at 248 kg ai/ha (221 lb ai/A) and has been injurious on some perennial crops.

While liverwort is an increasing concern within the nursery industry, there are potential controls that are safe for use on nursery crops. The following research examines several potential liverwort controls.

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Chapter II

Postemergence Liverwort Control in Container-grown Nursery Crops

Abstract

Experiments were conducted in Aurora, OR and Auburn, AL to evaluate effectiveness of selected chemicals for postemergence liverwort control and crop safety in container nursery crops. In Experiment 1, Gentry provided 98% to 100% postemergence control on juvenile liverwort and 84% to 99% postemergence control on mature liverwort 14 DAT. TerraCyte provided moderate postemergence control on juvenile (79%) and mature (56%) liverwort 14 DAT. BroadStar provided 39% and 5% postemergence control on juvenile and mature liverwort, respectively. In Experiment 2, a Gentry concentration of 3.8 g ai/L (0.5 oz/gal) applied at 2036 L/ha (218 gal/A) provided 77% postemergence control 14 DAT, while the low Gentry rate provided 53% postemergence control. Ronstar G provided 6% postemergence control, while BroadStar provided 13% control 14 DAT. TerraCyte provided 82% postemergence control 14 DAT. In Experiment 3, Gentry and Ronstar G caused no injury to *Achillea millefolium* L. 'Colorado', *Coreopsis grandiflora* Hogg ex Sweet 'Early Sunrise', and *Dianthus gratianopolitanus* L. 'Spotti'. In Experiment 4, Gentry applied at concentrations of 1.9, 3.8, and 7.5 g ai/L applied at 2036 L/ha (218 gal/A) resulted in no significant plant injury or differences in plant indices to *Buddleia davidii* Franch, *Cotoneaster salicifolius* Franch, *Hosta* 'Francee', *Ilex x meserveae* S.Y. Hu, *Magnolia grandiflora* L., or *Rhododendron* x 'Midnight Flare.'

Index words: quinoclamine, Gentry, TerraCyte, BroadStar, *Marchantia polymorpha* L.**Herbicides used in this study:** Gentry (quinoclamine), 2-amino-3-chloro-1,4-naphthoquinone; TerraCyte (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.

Species used in this study: Liverwort (*Marchantia polymorpha* L.); 'May Night' sage (*Salvia nemorosa* L. 'May Night'); 'Pink Mist' Scabiosa (*Scabiosa columbaria* L. 'Pink Mist'); 'P.J.M.' Rhododendron (*Rhododendron* 'P.J.M.'),; Black eyed Susan (*Rudbeckia fulgida* var. *sullivantii* C.L. Boynt and Beadle 'Goldstrum'); Colorado yarrow (*Achillea millefolium* L.'Colorado'); Largeflowered tickseed (*Coreopsis grandiflora* Hogg ex Sweet 'Early Sunrise'); Cheddar pinks (*Dianthus gratianopolitanus* L. 'Spotti'); Butterfly bush (*Buddleia davidii* Franch.); Willowleaf cotoneaster (*Cotoneaster salicifolius* Franch.); Francee hosta (*Hosta* 'Francee'); Blue holly (*Ilex* x *meserveae* S.Y. Hu); Southern magnolia (*Magnolia grandiflora* L.); Midnight Flare azalea (*Rhododendron* x 'Midnight Flare').

Significance to the Nursery Industry

Liverwort (*Marchantia polymorpha* L.) is one of the most difficult to control weeds in container-grown nursery crops throughout the United States. There are currently no postemergence herbicides labeled for liverwort control in container or greenhouse crops, thus nurseries must resort to hand weeding. This study demonstrates that Gentry and TerraCyte can be used for postemergence control of liverwort and that these products are safe on the nursery crops tested in this study. Gentry applied at rates of 7.1 kg ai/ha or higher provided effective postemergence liverwort control. TerraCyte applied at 249 kg ai/ha also provided effective postemergence liverwort control. Postemergence control varied depending on product, rate, liverwort maturity, and liverwort vigor.

Introduction

Liverwort is a physiological primitive plant within the phylum *Hepatohpyta*. It contains no vascular system. Of the more than 10,000 species of liverwort, *Marchantia polymorpha* L. is the species most often listed as a weed in container production. It is identified by leaf-like structures known as thalli that grow prostrate along substrate surfaces. Thalli can cover the entire substrate surface in a container and restrict water and nutrient movement into the root zone (Svenson, 1998). There are two phases in the life cycle that are often simultaneously present in containers. In the sporophytic phase, a sporophyte is formed when archegonia fertilize antheridia (each borne on stalks). As many as 7 million spores per stalked archegonia may be developed and released (O'Hanlon, 1926). Spores give rise to the gametophytic phase of the life cycle in which the plant propagates asexually by gemmae dispersal. Gemmae are diaspores formed in crater-like depressions on the thalli surface called gemmae cups. Each gemmae cup gives rise to numerous gemmae that are released to the immediate area when splashed by water. Liverwort can also propagate asexually by fragmentation. Liverwort thrives in low UV light, high humidity, and substrates high in moisture (Svenson, 2002). Its growth is optimized in high frequency irrigation (Svenson, 1998).

Currently there are no postemergence herbicides labeled for weed control in ornamental crops, and hand removal is costly and inefficient. Liverwort does not have roots, however it does have rhizoids. Rhizoids do not absorb water or nutrients; their only function is to anchor liverwort thalli to the top layer of substrate. As a result, hand removal of liverwort is difficult and often results in the removal of the top layer of substrate. New products are being tested that may provide postemergence liverwort control while causing no phytotoxicity to most ornamental crops. Gentry (quinoclamine) is an algaecide used in rice production. It is already labeled for nursery crops in some European countries. Chemtura Crop Protection (Middlebury, CT) is currently seeking a label for its use in nursery and greenhouse crops in the United States. The current recommendation for Gentry is 15.0 grams of product/L of water (2 oz product/gallon) applied at a spray volume of 2036 L/ha (2 quarts/100 ft^2 or 218 gal/A). This recommendation is equivalent to 7.6 kg/ha (6.8 lbs ai/A). TerraCyte (BioSafe Systems, Glastonbury, CT) has also been shown to have postemergence liverwort control. Previous research demonstrated that it has acceptable postemergence liverwort control in conditions unfavorable to liverwort growth (Altland, 2003). TerraCyte is a granular form of sodium carbonate peroxyhydrate that is labeled for control of mosses, liverwort, algae and slime mold in container nursery crops. It is also registered for use within greenhouses. Upon contact with water, TerraCyte breaks down into hydrogen peroxide which oxidizes the cell membranes of liverwort. Previous research showed that BroadStar (flumioxazin, Valent Corp.), a granular preemergence herbicide, provided postemergence liverwort control (Fausey, 2003). The objective of this research is to evaluate selected chemicals for postemergence control of liverwort in container-grown nursery production.

Materials and Methods

Experiments were conducted at the North Willamette Research and Extension Center (NWREC) in Aurora, OR and at Auburn University, AL to evaluate selected chemicals for postemergence liverwort control.

Experiment 1. Aurora, OR. Douglas fir (*Pseudotsuga menziesii* Mirb.) bark amended per m^3 (yd^3) with 9.5 kg (16 lb**)** Osmocote 18N-2.6P-10K (18N-6P-12K, Scotts Co., Marysville, OH) and 0.9 kg (1.5 lbs) Micromax (Scotts Co.) micronutrients was used to fill 2.8 L (trade gallon) containers. Bark substrate in each container was inoculated with liverwort in June 2003. The inoculation procedure consisted of blending 20 grams (0.7 oz) of liverwort thalli with 200 mL (6.8 fl. oz) of buttermilk and 1 L (1.1 qt) of water to produce slurry in which 50 mL was applied to the substrate surface of each container (Svenson, 1997). Containers were placed inside a retractable roof greenhouse with the roof open. A daily overhead irrigation rate of 1.27 cm (0.5 inch) split into two cycles per day, five hours apart, was applied. Chemical treatments were applied on July 22, 2003 to two groups of liverwort. In the first group, labeled as juvenile, approximately 25% of the container surface was covered by liverwort with no sporocarps. In the second group, labeled as mature, liverwort with antheridiophores and archegoniophores covered approximately 60% of the container surface. Gentry, a 25% wettable powder, was applied at 1.9, 3.7, and 7.5 g ai/L (0.25, 0.5, and 1.0 oz ai/gal) with a CO_2 backpack sprayer equipped with an 8008 flat fan nozzle at a pressure of 2.5 kg/cm^2 (35 psi) and calibrated to deliver 935 L/ha (100 gal/A). TerraCyte was applied at 249 kg ai/ha (222 lb ai/A), and BroadStar was applied at the labeled rate of 0.4 kg ai/ha (0.375 lb ai/A). A hand-held shaker was used to apply granular treatments. Non-treated controls for juvenile and mature liverworts were also included. Treatments were arranged in a completely randomized design with five single pot replications per group. Percent control was recorded at 2, 14 and 45 days after treatment (DAT) on a 0 to 100 scale where 0 equaled no control and 100 equaled death of the entire liverwort population. Data were subjected to analysis of variance, and means were separated with Duncan's Multiple Range Test (α=0.05).

Experiment 2. Aurora, OR. Treatments described in Experiment 1 were also applied over the top to eight single-pot replications of 'May Night' saliva (*Salvia nemorosa* L. 'May Night'), 'Pink Mist' scabiosa (*Scabiosa columbaria* L. 'Pink Mist'), P.J.M. rhododendron (*Rhododendron* 'P.J.M.'), and 'Goldustrum' black-eyed susan (*Rudbeckia fulgida* var. *sullivantii* C.L. Boynt and Beadle 'Goldstrum'). Plants were potted in 2.8 L (trade gallon) containers in spring 2003. Injury ratings were recorded on these species at 2, 14, and 45 DAT using a 0 to 10 scale where 0 equaled no injury and 10 equaled death. Species were randomized separately in a completely randomized design. Data were subjected to analysis of variance, and means were separated with Duncan's Multiple Range Test (α=0.05).

Experiment 3. Auburn, AL. Number one containers 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-12K, Pursell Technologies, Sylacauga, AL), 3.0 kg (5 lb) of dolomitic lime, and 0.9 kg (1.5 lb) of Micromax and inoculated with liverwort in November 2004 using the procedure described in Experiment 1. Liverwort was grown inside a temperature controlled greenhouse until treatment in spring of 2005. Treatments were applied on March 28, 2005 when liverwort covered 100% of the container surface. Gentry was mixed at a concentration of 3.8 g ai/L (0.5 oz ai/gal) and applied at a spray volume of either 1018 or 2036 L/ha (109 or 218 gal/A). Gentry treatments were applied using a CO_2 backpack sprayer fitted with an 8004 flat fan nozzle at 2.1 kg/cm^2 (30 psi). Ronstar G (2% ai) was applied at 4.5 kg ai/ha (4 lb ai/A). BroadStar (0.25% ai) was applied at 0.4 kg ai/ha (0.375 lb ai/A). TerraCyte (34% ai) was applied at 249 kg ai/ha (222 lb ai/A). Granular treatments were applied with a handheld shaker. A non-treated control group and treatments were arranged in a completely randomized design with six single pot replications. The study was conducted outdoors under a shade structure with 47% shade. Cyclic irrigation split into two daily cycles provided 0.64 cm (0.25 in) per day. Data recorded included percent control 7, 14, 28, and 35 DAT. Data were subjected to analysis of variance, and treatment means were separated using Duncan's multiple range test (α=0.05).

Experiment 4. Auburn University in Auburn, AL. Treatments described in Experiment 3 were applied to three perennial species in order to observe tolerance. Colorado yarrow (*Achillea millefolium* L. 'Colorado'), coreopsis (*Coreopsis grandiflora* Hogg ex Sweet 'Early Sunrise'), and cheddar pinks (*Dianthus gratianopolitanus* L. 'Spotti') were transplanted from 0.95 L (quart) containers to 2.8 L (trade gallon) containers with the same amended substrate described in Experiment 2 in May 2005. Plants were treated on 15 June 2005. Treatments were arranged in a completely randomized design with eight single pot replications along with a non-treated control group. The study was conducted in full sun. Cyclic overhead irrigation was applied at 1.27 cm (0.5 inches) per day. Plants were examined for injury every seven days for 56 DAT.

Experiment 5. Auburn, AL. The objective of this study was to evaluate six commonly used landscape species for tolerance to Gentry. Francee hosta (*Hosta* 'Francee') and Midnight Flare azalea (*Rhododendron* x 'Midnight Flare') were transplanted from 10 cm (4 in) liners into 2.8 L (trade gallon) containers in April 2005. Butterfly bush (*Buddleia davidii* Franch) were transplanted from 10 cm (4 in) liner trays into #1 containers in April 2005. Southern magnolia (*Magnolia grandiflora* L.) were transplanted from 10 cm (4 in) liner trays to #3 containers May 2005. Each species was potted in a 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-12K), 3.0 kg (5 lb) of dolomitic lime, and 0.9 kg (1.5 lb) of Micromax. Established willowleaf cotoneaster (*Cotoneaster salicifolius* Franch) was purchased in #1 containers, and established blue holly (*Ilex* x *meserveae* S.Y. Hu) was purchased in #3 containers. On June 13, 2005, plants were treated with three concentrations of Gentry: 1.9, 3.8, and 7.5 g ai/L (0.25, 0.5, and 1.0 oz ai/gallon). Each concentration was applied at 2036 L/ha (2 qt/100 ft^2 or 218 gal/A) and equated to rates of 3.8, 7.6, and 15.2 kg ai/ha (3.4, 6.8, and 13.6 lbs ai/A). Plants were arranged by species with a non-treated control group in a completely randomized design with eight replications per treatment. The study was conducted outdoors and irrigated daily with 1.27 cm (0.5 inches) split into two cycles. Francee hosta (*Hosta* 'Francee') and Midnight Flare azalea (*Rhododendron* x 'Midnight Flare') were placed under 47% shade, while the other species were grown in full sun.

Plant injury was recorded 7, 14, 21, and 30 DAT. Plant indices [(height + width + width) / 3] were measured at 30 and 90 DAT.

Results and Discussion

Experiment 1. In containers with juvenile liverwort, all rates of Gentry provided excellent postemergence control 2 DAT and 14 DAT (Table 2.1). Control was relatively unchanged by 45 DAT. TerraCyte provided moderate control (69-79%) throughout the experiment. Although BroadStar provided poor control throughout the study, control did increase as the study progressed. This suggests that BroadStar activity is accentuated over time and is much slower than Gentry and TerraCyte.

In containers with mature liverwort, all rates of Gentry provided similar control 2 DAT (89-96%). By 14 DAT, control declined slightly at the low Gentry rate, however excellent control was observed in containers treated with 3.7 and 7.5 g ai/L of Gentry. Sporocarps were still green and appeared to be the only living portions of the liverwort in these containers. All thalli (leaf-like structures) appeared dead. By 45 DAT, control had declined in containers treated with 1.9 and 3.7 g ai/L. Only containers treated with 7.5 g ai/L maintained greater than 90% control. TerraCyte provided moderate control (66%) 2 DAT, and efficacy declined thereafter. BroadStar provided almost no control of mature liverwort (3-5%) during the test. BroadStar and TerraCyte appear to be more effective on juvenile liverwort than mature liverwort. For example, at 45 DAT, BroadStar controlled 65% of the juvenile liverwort and only 3% of the mature liverwort.

Experiment 2. No treatment caused injury to any of the nursery crops evaluated (data not presented).

Experiment 3. At 7 DAT, Gentry applied at 2036 L/ha (7.6 kg ai/ha) and TerraCyte provided the highest postemergence control with 86% and 89%, respectively (Table 2.2). Gentry applied at 1018 L/ha (3.8 kg ai/ha) provided moderate postemergence control at 68%. Ronstar G and BroadStar provided no postemergence control compared to the non-treated control group. Control had not changed significantly by 14 DAT. By 35 DAT, postemergence control in containers treated with Ronstar G was similar to the non-treated control group, while Gentry, BroadStar, and TerraCyte provided similarly effective postemergence control as compared to the non-treated control group.

Experiment 4. Although species used in this experiment were herbaceous, no injury occurred throughout the study (data not shown).

Experiment 5. No significant plant phytotoxicity occurred on any of the species tested throughout the study. While some chemical residue remained present on plants treated with 15.2 kg ai/ha for several days after treatment, it caused no plant injury. Chemical residue was washed off by overhead irrigation over subsequent weeks. Plant indices of treated plants were similar to non-treated control plants at both 30 and 90 days after treatment (Table 2.3).

In summary, these data indicate that effective postemergence control of liverwort is obtainable. Gentry provided consistently effective postemergence control when applied at a rate of 7.5 kg ai/A. Liverwort efficacy with Gentry was higher in Experiment 1 than in Experiment 3. Experiment 1 was conducted in mid summer, while Experiment 3 was conducted in spring. Optimum temperatures provided by spring weather may account for increased liverwort vigor and, thus, decreased efficacy in Experiment 3. TerraCyte also provides postemergence liverwort control in this study. Liverwort stage and physiology may affect postemergence control with these products. BroadStar provided moderate postemergence liverwort control on juvenile liverwort in Experiment 1 and in Experiment 3. While effects of BroadStar are not immediate, postemergence control increased as the studies progressed. Ronstar G provided little postemergence liverwort control.

All treatments were safe when applied to diverse herbaceous and woody nursery crops. Gentry applied at high rates left some chemical residue, however it caused no plant injury.

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Table 2.1 Effect of selected herbicides on postemergence liverwort control in Experiment 1. Aurora, OR.

			Juvenile[z] liverwort			Mature[y] liverwort		
Herbicide	Concentration (g ai/L)	Rate (kg ai/ha)	2 DAT[x]	14 DAT	45 DAT	2 DAT	14 DAT	45 DAT
Gentry	1.9	1.8	99[w] a[v]	98 a	92 c	89 a	84 b	49 a
Gentry	3.8	3.6	100 a	100 a	98 b	94 a	97 ab	78 a
Gentry	7.5	7.1	100 a	100 a	99 a	96 a	99 a	94 a
TerraCyte		249	67 b	79 b	69 d	66 b	56 c	29 b
BroadStar		0.43	20 c	39 c	65 e	3 c	5 d	3 b
Control			2 d	3 d	31 e	0 c	3 d	3 c

[z] Approximately 25% container surface coverage with no sporocarps.
[y] Approximately 60% container surface coverage with sporocarps.
[x] Days after treatment. Treated July 22, 2003.
[w] Percent postemergence control.
[v] Means separated within a column using Duncan's Multiple Range Test (α=0.05).

Table 2.2 Effect of selected herbicides on postemergence liverwort control in Experiment 3. Auburn, AL.

Herbicide	Concentration (g ai/L)	Spray volume (L/ha)	Rate (kg ai/ha)	7 DAT[z]	14 DAT	35 DAT
Gentry	3.8	1018	3.8	68[y] b[x]	53 b	62 a
Gentry	3.8	2036	7.6	86 a	77 a	75 a
Ronstar G			4.5	1 c	6 c	45 ab
BroadStar			0.4	2 c	13 c	72 a
TerraCyte			249	89 a	82 a	79 a
Control				0 c	6 c	18 b

[z] Days after treatment. Treated March 28, 2005.
[y] Percent postemergence control.
[x] Means separated within a column using Duncan's Multiple Range Test (α=0.05).

Table 2.3 Effects of Gentry on growth indices of species in Experiment 5. Auburn, AL.

Herbicide	Concentration (g ai/L)	Rate (kg ai/ha)	Azalea		Meserve holly		Butterfly bush		Hosta		Southern magnolia		Willowleaf cotoneaster	
			30 DAT[z]	90 DAT	30 DAT	90 DAT	30 DAT	90 DAT	30 DAT	90 DAT	30 DAT	90 DAT	30 DAT	90 DAT
Gentry	1.9	3.8	42.8[y]	50.6	62.7	82.3	62.8	84.7	24.9	30.9	36.0	49.5	69.5	113.3
Gentry	3.8	7.6	43.8	51.2	66.1	81.2	60.0	86.2	24.5	28.4	33.1	47.2	79.5	115.6
Gentry	7.5	15.2	45.2	52.8	67.3	84.8	59.2	88.1	25.6	29.8	33.8	47.7	67.6	117.4
Control			46.2	52.3	66.5	81.7	64.0	90.0	24.8	31.2	31.1	43.6	79.3	110.8
p-value[x]			0.11	0.58	0.52	0.86	0.43	0.47	0.96	0.62	0.12	0.26	0.16	0.89

[z] Days after treatment. Treated June 13, 2005.

[y] Growth indices in cm ([height+widest width+perpendicular width]/3).

[x] Significance according to analysis of variance.

Chapter III

Postemergence Liverwort Control in Propagation

Abstract

Three experiments were conducted in Aurora, OR (Experiment 1) and Auburn, AL (Experiments 2 and 3) in order to evaluate the effects of differing concentrations and spray volumes of Gentry with and without surfactant as well as the effects of TerraCyte and BroadStar on postemergence liverwort control in propagation. In Experiment 1, Gentry applied at a concentration of 3.8 g ai/L provided excellent control regardless of spray volume or surfactant. TerraCyte provided poor postemergence control throughout the experiment (<30%). In Experiment 2, Gentry provided excellent postemergence liverwort control (93%-100%) 3 and 14 DAT regardless of concentration, spray volume, or surfactant. TerraCyte provided good postemergence liverwort control (74%-88%) 3 and 14 DAT. BroadStar provided only 21% postemergence liverwort control 14 DAT. In Experiment 3, Gentry provided 100% postemergence liverwort control 3 and 14 DAT regardless of concentration, spray volume, or surfactant. TerraCyte and experimental TerraCyte treatments provided 90% to 97% postemergence control 3 and 14 DAT. BroadStar provided only 58% postemergence liverwort control 14 DAT.

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

Herbicides used in this study: Gentry (quinoclamine), 2-amino-3-chloro-1,4-naphthoquinone; TerraCyte (sodium carbonate peroxyhydrate), $2Na_2 CO_3.3H_2O_2$; 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.

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

Significance to the Industry

Liverwort (*Marchantia polymorpha* L.) is an established weed in container nursery crops across the U.S. It is well adapted to nursery environments, especially within propagation. A postemergence herbicide for liverwort control that can be tolerated by nursery crops would be an effective tool against liverwort infestations. This research indicates that Gentry applied at a rate of 3.8 kg/ha (3.4 oz ai/gal) provides consistently effective postemergence liverwort control. TerraCyte provides moderately effective control when applied at the label rate of 252 kg ai/ha (222 lb ai/A). Postemergence liverwort control wit BroadStar was inconsistent and depended on liverwort vigor.

Introduction

Liverwort has spread throughout the nursery industry of the United States. The cause of its spread is most likely due to the transportation of nursery liners form one region of the country to another (Fausey, 2003). Liverwort thrives in low UV light, high humidity, and substrates high in moisture (Svenson, 2002). Therefore liverwort is especially problematic in shaded areas with frequent irrigation. It competes with nursery crops for nutrients and water, and decreases crop marketability (Svenson, 1997). Some preemergence controls have been evaluated (Elmore, 1979; Fausey, 2003; Svenson, 1997; Svenson, 1998). However these products cannot be used in closed structures, and they are not traditionally used in propagation due to concerns of inhibiting root growth. Thus there is a need for postemergence liverwort controls in propagation. Herbicides that provide postemergence liverwort control and that are safe on nursery crops would be an effective management tool for liverwort control.

TerraCyte (BioSafe Systems, Glastonbury, CT), a granular form of sodium carbonate peroxyhydrate, has been evaluated for postemergence liverwort control. Upon contact with water, TerraCyte breaks down into hydrogen peroxide which oxidizes the cell membranes of liverwort. It is labeled for control of mosses, liverwort, algae and slime mold in container nursery crops and is registered for use within greenhouses. Previous research demonstrated that is has acceptable postemergence liverwort control in conditions unfavorable to liverwort growth (Altland, 2003).

BroadStar (Valent Corp.), a granular preemergence herbicide, is also reported to have postemergence liverwort control (Fausey, 2003). The active ingredient, flumioxazin, is classified as a PPO inhibitor. It inhibits the production of protoporphyrinogen oxidase (PPO), an enzyme necessary for the production of chlorophyll (Duke et al., 1990).

Gentry (quinoclamine, Chemtura Corp., Middlebury, CT), a 25% wettable powder product is an effective postemergence herbicide for liverwort control (Svenson, 2000; Altland, 2003). The current recommendation for Gentry is 3.75 grams of ai/L of water (2 oz product/gal) applied at a spray volume of 2036 L/ha (2 quarts/100 ft^2 or 218 gal/A). This recommendation is equivalent to 7.62 kg/ha (6.8 lbs ai/A). These concentrations and spray volumes are higher than those of traditional herbicides used in the nursery industry. Since liverwort has no vascular system, complete and uniform application of Gentry to the thallus surface is necessary (Altland, 2005). Addition of surfactants to foliar-applied herbicides increases uniformity of the spray (Klingman and Ashton, 1982). With addition of a surfactant, lower concentrations and spray volumes of Gentry may provide effective postemergence liverwort control.

Studies were conducted at the North Willamette Research and Extension Center (NWREC) in Aurora, OR and at Auburn University in Auburn, AL in order to determine the effects of concentration, spray volume, and surfactant on postemergence liverwort control with Gentry as well as the effects of TerraCyte and BroadStar on postemergence liverwort control.

Materials and Methods

Experiment 1. Aurora, OR. Nursery containers [2.8 L (trade gallon)] were filled with 100% Douglas fir bark substrate amended per m^3 (yd^3) with 9.5 kg (16 lb) of Osmocote 18N-2.6P-10K (18N-6P-12K, Scotts Co., Marysville, OH) and 0.9 kg (1.5 lb) of Micromax (Scotts Co.). Substrate was inoculated by a procedure described by Svenson (Svenson, 1997). Treatments were applied on April 28, 2004 when liverwort covered at least 60% of the substrate surface and was actively growing with some antheridiophores and archegoniophores present. Gentry was applied at concentrations of 1.9 or 3.8 g ai/L (0.25 or 0.5 oz ai/gal) with or without Silwet L-77 (organosilicone surfactant, Helena Chem. Co., Collierville, TN) at 1018 L/ha or 2036 L/ha (109 or 218 gal/A). Treatments were applied using a CO_2 backpack sprayer fitted with an 8004 flat fan nozzle at 35 psi. TerraCyte was applied at 252 kg ai/ha (222 lb ai/A) using a handheld shaker. Gentry and TerraCyte treatments were compared to non-treated controls. All treatments consisted of eight single pot replications in a completely randomized design. The study was conducted outdoors. Mist irrigation was applied 3 times per day for six minutes per cycle. Percent postemergence control (0% = no control, 100% = death of entire liverwort) was recorded at 2, 7, and 14 DAT. Since liverwort often begins to re-colonize after this period, percent of substrate surface covered with living liverwort were recorded 21 DAT and 45 DAT to measure long term control of re-growth.

Experiment2. Auburn, AL. This study was conducted concomitantly with experiment 1 and was similar in nature with the following exceptions. Number one containers 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-12K, Pursell Technologies, Sylacauga, AL), 3.0 kg (5 lb) of dolomitic lime, and 0.9 kg (1.5 lb) of Micromax (Scotts Co.). Substrate surfaces of the containers were inoculated with liverwort and treated April 16, 2004 when liverwort was mature and covered at least 60% of the container surface. Only a few sporocarps were present at treatment. Gentry concentrations and spray volumes were the same as those listed in Experiment 1 and were applied with a CO_2 backpack sprayer with an 8005 flat fan nozzle at 2.1 kg/cm^2 (30 psi). TerraCyte (34% ai) was applied at 168 kg ai/ha (148 lb ai/A) and 252 kg ai/ha (222 lb ai/A). In addition an experimental TerraCyte formulation (ETC) with twice the amount of active ingredient (68% ai) was applied at 218 or 336 kg ai/ha (192 or 296 lb ai/A). BroadStar was applied at the labeled rate of 0.43 kg ai/ha (0.375 lb ai/A). TerraCyte, ETC, and BroadStar treatments were applied with a handheld shaker. A non-treated control was included. Treatments were arranged in a completely randomized design with 6 single pot replications. The experiment was maintained in a double layer plastic covered greenhouse under mist irrigation (6 sec/ 4 min). Percent postemergence control was recorded 1, 3, 7, 14, and 21 DAT. Percent of the substrate surface covered with liverwort was also recorded 56 DAT.

Experiment 3. Auburn, AL. Experiment 3 was similar to experiment 2 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 seconds every 5 minutes.

Results and Discussion

Experiment 1. By 2 DAT, the higher concentration of Gentry provided excellent postemergence liverwort control (94% to 99%) (Table 3.1). The lower concentration of Gentry produced variable results 2 and 14 DAT with 61% to 98% and 44% to 99%, respectively, depending on surfactant and spray volume. By 45 DAT, liverwort coverage varied from 15% to 57%. The higher concentration of Gentry provided better control; however, the lower concentration of Gentry applied with surfactant at 2061 L/ha (218 gal/A) provided similar control.

Among containers treated with the low Gentry concentration, the addition of surfactant enhanced control 2 and 14 DAT. However, control was similar among all containers treated with the high concentration of Gentry 2 and 14 DAT regardless of surfactant. Contrast analysis of containers treated with the low Gentry concentration show that differences in liverwort coverage 45 DAT were significant depending on surfactant use ($\alpha = 0.05$), despite similar grouping by Duncan's multiple range test.

Surfactant use had no effect on liverwort coverage within the high Gentry concentration treatments.

Spray volume of 2061 L/ha provided better control than 1030 L/ha among containers treated with the low Gentry concentration 2 and 14 DAT. By 45 DAT, liverwort coverage was similar between differing spray volumes when other factors were the same. Among treatments using the high Gentry concentration, spray volume had no effect.

TerraCyte provided poor postemergence control throughout the study (<50%) (Table 3.1).

Experiment 2. At 3 and 14 DAT, Gentry provided excellent postemergence liverwort control regardless of concentration, spray volume, and surfactant. Gentry provided 98% to 100% control 3 DAT. TerraCyte applied at 252 kg ai/ha and both rates of ETC provided similar control to Gentry (Table 3.2). TerraCyte applied at 168 kg ai/ha provided moderate control (76%). BroadStar control was similar to the non-treated controls 3 DAT. At 14 DAT, Gentry provided 93% to 100% control, while ETC treatments provided similar control (87%). TerraCyte treatments provided less control than Gentry, while BroadStar postemergence control was still poor (21%).

Orthogonal contrast analysis revealed that the Gentry rate affected liverwort coverage 56 DAT despite similar grouping from Duncan's multiple range test. Very little liverwort was present in containers treated with the high concentration of Gentry. Liverwort coverage in these containers ranged from 0% to 3%. Liverwort coverage among containers treated with TerraCyte was similar to those treated with ETC which has twice the amount of active ingredient. Liverwort coverage within containers treated with BroadStar was similar to that of the non-treated controls.

Superior liverwort control was attained in this study compared to Experiment 1. Increased heat and UV exposure in Alabama, compared to Oregon, are environmental conditions that likely cause increased stress on liverwort, which may have enhanced effectiveness of the applied products. The optimum temperature for vegetative growth of liverwort is 18 C to 22 C (64 F to 72 F) (O'Hanlon, 1926).

Experiment 3. Among Gentry treatments, concentration, spray volume, and surfactant had no effect on liverwort control and coverage throughout the study. All Gentry treatments provided 100% control 3 and 14 DAT. TerraCyte and ETC provided similar control (>90%) 3 and 14 DAT. BroadStar provided poor control 3 and 14 DAT.

By 56 DAT, liverwort coverage among containers treated with the high concentrations of Gentry ranged from 0% to 1%, while coverage ranged from 0% to 2% in containers treated with the low concentration. Liverwort coverage was low (5% to 19%) among containers treated with TerraCyte, ETC, or BroadStar. This is in contrast to Experiment 2 where BroadStar, for example, had 68% coverage at 56 DAT compared to 16% in this experiment.

TerraCyte provided similar control to Gentry in this study, although it provided less control than Gentry in Experiment 2. While not compared statistically, overall liverwort control in this study was greater than that in Experiment 2. This study was conducted in the summer, while Experiment 2 was conducted in the spring. Increased heat and UV levels during summer likely increased stress, and therefore resulted in more effective liverwort control.

Concentration and spray volume of Gentry application may best be determined by individual growers. Heavy infestations during peak conditions that favor liverwort growth require higher concentrations and/or spray volume. In contrast as temperatures and UV light increase, concentrations and spray volume may be lowered.

In conclusion, Gentry provides consistently effective postemergence liverwort control. Concentration and spray volume may be lowered depending on environmental conditions and the vigor of actively growing liverwort. Furthermore, TerraCyte and BroadStar provided effective postemergence control when liverwort growing conditions were less than favorable.

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Table 3.1 Effect of selected herbicides, surfactant, and spray volume on postemergence liverwort control in Experiment 1. Aurora, OR.

Herbicide	Concentration (g ai/L)	Spray Volume (L/ha)	Surfactant[x]	Rate (kg ai/ha)	Postemergence control (%)[z] 2 DAT[w]	Postemergence control (%)[z] 14 DAT	Percent coverage (%)[y] 45 DAT
Gentry	1.9	1018	no	1.9 kg/ha	61 d[v]	44 d	57 b
Gentry	1.9	2036	no	3.8 kg/ha	83 bc	82 bc	41 bc
Gentry	1.9	1018	yes	1.9 kg/ha	80 c	74 c	31 bcd
Gentry	1.9	2036	yes	3.8 kg/ha	98 a	99 a	15 cd
Gentry	3.8	1018	no	3.8 kg/ha	94 ab	93 ab	12 d
Gentry	3.8	2036	no	7.6 kg/ha	99 a	100 a	12 d
Gentry	3.8	1018	yes	3.8 kg/ha	98 a	98 a	16 cd
Gentry	3.8	2036	yes	7.6 kg/ha	99 a	100 a	6 d
Terracyte				252 kg ai/ha	29 e	23 e	49 b
Control					0 f	3 f	94 a

[z] Percent postemergence control.
[y] Percent substrate surface covered with living liverwort.
[x] Organosilicone surfactant was mixed at 0.25% by volume. Silwet L-77.
[w] Days after treatment. Treated April 29, 2004.
[v] Means separated within column using Duncan's Multiple Range Test (α=0.05).

Table 3.2 Effect of selected herbicides on postemergence liverwort control in Experiment 2. Auburn, AL.

Herbicide	Concentration (g ai/L)	Spray Volume (L/ha)	Surfactant[x]	Rate (kg ai/ha)	Postemergence control 3 DAT[Z]	Postemergence control 14 DAT	Percent Coverage 56 DAT
Gentry	1.9	1018	no	1.9 kg/ha	99[Y] a[X]	93 a	28[W] cdef
Gentry	1.9	2036	no	3.8 kg/ha	100 a	100 a	5 ef
Gentry	1.9	1018	yes	1.9 kg/ha	98 a	93 a	20 cdef
Gentry	1.9	2036	yes	3.8 kg/ha	100 a	100 a	6 def
Gentry	3.8	1018	no	3.8 kg/ha	100 a	99 a	3 f
Gentry	3.8	2036	no	7.6 kg/ha	100 a	100 a	0 f
Gentry	3.8	1018	yes	3.8 kg/ha	100 a	99 a	3 f
Gentry	3.8	2036	yes	7.6 kg/ha	100 a	100 a	0 f
TerraCyte				168 kg ai/ha	76 b	74 b	48 bc
TerraCyte				252 kg ai/ha	88 a	77 b	33 cde
Exp. TerraCyte				218 kg ai/ha	88 a	87 ab	34 cd
Exp. TerraCyte				336 kg ai/ha	95 a	87 ab	27 cdef
BroadStar				0.43 kg ai/ha	5 c	21 c	68 ab
Control					0 c	8 c	75 a

[z] Days after treatment. Treated April 16, 2004.
[y] Percent control of liverwort where 0%=no control and 100%=death of entire liverwort.
[x] Means separated within a column using Duncan's Multiple Range Test (α=0.05).
[w] Percent coverage of liverwort within the container.

Table 3.3 Effect of selected herbicides on postemergence liverwort control in Experiment 3. Auburn, AL.

Herbicide	Concentration (g ai/L)	Spray Volume (L/ha)	Surfactant[x]	Rate (kg ai/ha)	Postemergence control 3 DAT[z]	14 DAT	Percent Coverage 56 DAT
Gentry	1.9	1018	no	1.9 kg/ha	100[Y] a[X]	100 a	0[W] b
Gentry	1.9	2036	no	3.8 kg/ha	100 a	100 a	0 b
Gentry	1.9	1018	yes	1.9 kg/ha	100 a	100 a	2 b
Gentry	1.9	2036	yes	3.8 kg/ha	100 a	100 a	0 b
Gentry	3.8	1018	no	3.8 kg/ha	100 a	100 a	1 b
Gentry	3.8	2036	no	7.6 kg/ha	100 a	100 a	0 b
Gentry	3.8	1018	yes	3.8 kg/ha	100 a	100 a	0 b
Gentry	3.8	2036	yes	7.6 kg/ha	100 a	100 a	0 b
TerraCyte				168 kg ai/ha	92 a	94 a	9 b
TerraCyte				252 kg ai/ha	94 a	95 a	5 b
Exp. TerraCyte				218 kg ai/ha	93 a	90 a	19 b
Exp. TerraCyte				336 kg ai/ha	97 a	96 a	10 b
BroadStar				0.43 kg ai/ha	18 b	58 b	16 b
Control					5 c	17 c	76 a

[z] Days after treatment. Treated June 3, 2004.

[y] Percent control of liverwort where 0%=no control and 100%=death of entire liverwort.

[x] Means separated within a column using Duncan's Multiple Range Test (α=0.05).

[w] Percent coverage of liverwort within the container.

Chapter IV

Preemergence control of *Marchantia polymorpha*

Abstract

Three experiments were conducted at Auburn University, AL to evaluate the effectiveness of residual granular herbicides, Gentry, and diuron on preemergence liverwort control. In Experiment 1, BroadStar and Ronstar G provided the most effective preemergence liverwort control 17 WAT. In Experiment 2, by 18 WAT, liverwort coverage in containers treated with Gentry was similar to non-treated controls, while BroadStar, Ronstar G, and Rout 3G provided significant preemergence liverwort control. In Experiment 3, liverwort coverage in containers treated with Gentry was similar to non-treated controls 9 WAT. There was no liverwort present in containers treated with diuron applied at 0.56 and 1.12 kg ai/ha (0.5 and 1.0 lb ai/A). At 12 and 17 WAT, percent liverwort coverage in containers treated with Gentry was similar to non-treated controls, while no liverwort was present in containers treated with diuron.

Index words: quinoclamine, Gentry, weed control

Herbicides used in this study: Gentry (quinoclamine), 2-amino-3-chloro-1,4-naphthoquinone; 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;

Kansel+ (oxadiazon + pendimethalin), {2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ-1, 3, 4-oxadiazolin-5-one}+{ N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine}; OH2 (oxyfluorfen + pendimethalin), {2-chloro-1-(3-ethoxy-4-nitrophenoxy)4-(trifluromethyl)} + { N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine}; Pendulum 2G (pendimethalin), N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine; Regal O-O (oxyfluorfen + oxadiazon), {2-chloro-1-(3-ethoxy-4-nitrophenoxy)4-(trifluromethyl)} + {2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ-1, 3, 4-oxadiazolin-5-one}; RegalKade 0.5G (prodiamine), 5-dipropylamino-α,α,α-trifluoro-4,6-dinitro-*o*-toluidine; RegalStar (oxadizaon + prodiamine), {2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ-1, 3, 4-oxadiazolin-5-one} + {5-dipropylamino-α,α,α-trifluoro-4,6-dinitro-*o*-toluidine}; Ronstar G (oxadiazon), 2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ-1, 3, 4-oxadiazolin-5-one; Rout 3G (oxyfluorfen + oryzalin), {2-chloro-1-(3-ethoxy-4-nitrophenoxy)4-(trifluromethyl)} + {4-(dipropylamino)-3,5-dinitrobenzenesulfonamide}; Snapshot 2.5TG (trifluralin + isoxaben), {α, α, α-trifluoro-2,6-dinitro-*N*, *N*-dipropyl-*p*-toluidine} + {*N*-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide and isomers; Direx 4L (diuron), 3-(3-(3,4-dichlorophenyl)-1,1-dimethylurea.

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

Significance to the Industry

Liverwort is an increasing problem in container-grown ornamental production throughout the Southeast. Since it is still an emerging weed problem in the South, little research exists on preemergence controls. Results of this research indicate that BroadStar, Regal O-O, RegalStar, Ronstar G, and Rout 3G applied at the label rate provide adequate preemergence liverwort control. Furthermore, these studies also indicate that Gentry provides slight and brief residual preemergence liverwort control, but the product should be primarily used for postemergence control.

Introduction

Liverwort (*Marchantia polymorpha* L.) continues to spread throughout the South. Prostrate leaf-like structures of liverwort known as thalli create a mat over media surfaces in containers. Not only is liverwort unsightly, it can impede water and nutrient movement into the root zone (Svenson, 1998).

Nursery producers in the Southeastern United States have limited knowledge about its control. There are promising new products for postemergence liverwort control, but preventing liverwort infestations would be more desirable.

Liverwort propagates sexually by spores and asexually by gemmae. It thrives in low UV light, high fertility and high moisture environments (Svenson, 1997). Moisture is particularly important to liverwort survival. Thalli have little control over loss of water due to transpiration. As a result, liverwort must readily absorb water (McConaha, 1941). All plants within the phylum Hepatophyta (liverworts) have rhizoids instead of roots. It is commonly believed that the only function of rhizoids is anchorage. However, some research suggests that rhizoids do have some absorptive function. McConaha (1941) suggests that rhizoids do facilitate capillary water flow to absorptive areas of the thalli. After studying many species of the phylum Hepatophyta, Pocock and Duckett (1985) suggested that only those species with “branched and swollen” rhizoids absorb water. It was noted that rhizoids of *M. polymorpha* lacked these properties. The function of rhizoids is an important topic since many of the preemergence herbicides used in nursery production are either root inhibitors or absorbed by the roots. Shoot absorption is also a major point of media-applied herbicide entry (McWhorter and Gebhardt, 1987). It is theorized that microscopic liverwort thalli arising from spores and gemmae is the point of absorption of media-applied herbicides.

Some preemergence herbicides have been reported to be effective. Fausey reported that flumioxazin (SureGuard) applied at 0.4 kg ai/ha (0.3 lb ai/A) provided 100% preemergence liverwort control 5 weeks after treatment and 74% preemergence control 11 weeks after treatment. Flumioxazin applied as BroadStar (0.25% ai granular) at the same rate provided 95% preemergence control 9 weeks after treatment. Furthermore, oxyfluorfen (Goal) applied at 2.2 kg ai/ha (2.0 lb ai/A) provided 98% preemergence liverwort control 5 weeks after treatment (Fausey, 2003).

Diuron is a photosynthesis-active substituted urea herbicide registered for selective preemergence weed control in agronomic crops such as cotton, sugarcane, and alfalfa (Stranger and Appleby, 1972). It has been suggested by previous research that selected nursery crops have tolerance to diuron (Ahrens, 2003). Data by Simpson et al. (2004) showed that diuron caused slight to no injury on camellia and liriope when applied over the top. Diuron works by inhibiting photosynthetic electron transport within the chloroplast membrane. Although not labeled, it is used for postemergence liverwort control in Germany (personal communication with Dr. Heinrich Loesing).

The objective of this study was to evaluate products for preemergence liverwort control and determine residual efficacy of several commonly used granular preemergence herbicides as well as Gentry and diuron. Experiments were conducted at Auburn University, AL.

Materials and Methods

Experiment 1. Full gallon (3.8 L) containers 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-12K, Pursell Technologies, Sylacauga, AL), 3.0 kg (5 lb) of dolomitic lime, and 0.9 kg (1.5 lb) of Micromax (Scotts Co., Marysville, OH). Ten granular herbicides commonly used in the nursery industry were applied at the recommended label rate to the substrate surface on July 6, 2004. Treatments included BroadStar at 0.4 kg ai/ha (0.375 lb ai/A), Kansel+ at 3.6 kg ai/ha (3.25 lb ai/A), OH2 at 3.4 kg ai/ha (3 lb ai/A), Pendulum 2G at 4.5 kg ai/ha (4 lb ai/A), Regal O-O at 3.4 kg ai/ha (3 lb ai/A), RegalKade 0.5G at 1.1 kg ai/ha (1 lb ai/A), RegalStar at 2.7 lb ai/A (2.4 lb ai/A), Ronstar G at 4.5 kg ai/ha (4 lb ai/A), Rout 3G at 3.4 kg ai/ha (3 lb ai/A), and Snapshot 2.5TG at 5.6 kg ai/ha (5 lb ai/A). Each treatment and a non-treated control group consisted of 4 replications with 4 containers per replication. Treatments were applied using a handheld shaker. After treatment, each replication was placed around a container of mature liverwort in order to provide a source of inoculation. Replications were placed in a completely randomized design. The study was conducted outdoors under 47% shade. Overhead irrigation was applied daily at 0.6 cm (0.25 in) split into two cycles. Percent of the substrate surface covered in liverwort was recorded 6, 11, and 17 weeks after treatment (WAT). Data were subjected to analysis of variance, and treatment means were separated with Duncan's multiple range test (α=0.05).

Experiment 2. The objective of this experiment was to evaluate Gentry for preemergence liverwort control as compared to three granular herbicides that provided effective preemergence liverwort control in Experiment 1. Number one (3.8 L) containers were filled with pine bark:sand (6:1, v/v) substrate amended as previously described. Treatments were applied to containers on September 23, 2004. Gentry was applied at 1.9, 3.8, and 7.6 kg ai/ha (1.7, 3.4, and 6.8 lb ai/A) in a spray chamber equipped with an 8005 flat fan nozzle at a pressure of 2.5 kg/cm^2 (35 psi) and calibrated to deliver 1018 L/ha (109 gal/A). Herbicide treatments included BroadStar (0.25% ai) at 0.4 kg ai/ha (0.375 lb ai/A), Ronstar G (2% ai) at 4.5 kg ai/ha (4 lb ai/A), and Rout 3G at 3.4 kg ai/ha (3 lb ai/A) and were applied with a handheld shaker. Each treatment consisted of 4 replications with 4 containers per replication. After treatment, each replication was placed around a container of mature liverwort for inoculation. Treatments and a non-treated control group were arranged in a completely randomized design under 47% shade. Overhead irrigation was applied at 0.6 cm (0.25 in) per day split into 3 cycles. Percent of the substrate surface covered in liverwort was recorded 6, 11, and 18 WAT. Data were subjected to analysis of variance, and treatment means were separated with Duncan's multiple range test (α=0.05).

Experiment 3. The objective of this experiment was to determine if lower concentrations and spray volumes of Gentry provide preemergence liverwort control and to determine if diuron provides preemergence liverwort control. Full gallon containers were filled with pine bark:sand (6:1, v/v) substrate amended as previously described. Treatments were applied to container surface on March 14, 2005. Gentry was applied at concentrations of 0.94, 1.9, or 3.8 g ai/L (0.13, 0.25, or 0.5 oz ai/gal) at spray volumes of 255, 509, or 1018 L/ha (27, 54, or 109 gal/A). Diuron was applied as Direx 4L (Griffin LLS, Valdosta, GA) at 0.56 or 1.12 kg ai/ha (0.5 or 1.0 lb ai/A). All treatments were applied with a CO_2 backpack sprayer equipped with an 8004 flat fan nozzle at a pressure of 2.1 kg/cm^2 (30 psi). Treatments and a non-treated control group were arranged in a completely randomized design with six single pot replications. A container with established liverwort was placed between every other container to provide liverwort inoculation. The study was conducted under 47% shade on a container bed receiving 1.3 cm (0.5 in) overhead irrigation per day split into two cycles. Percent of the substrate covered with liverwort was recorded 9, 12, and 17 WAT. Data were subjected to analysis of variance, and treatment means were separated with Duncan's Multiple Range Test (α=0.05).

Results and Discussion

Experiment 1. Liverwort covered an average of 25.9% of the substrate surface on non-treated controls 6 WAT (Table 4.1). Liverwort was similar in containers treated with Kansel+, Pendulum 2G, and RegalKade 0.5G with 19%, 15%, and 16% coverage on substrate surface, respectively. Containers treated with BroadStar and Ronstar G contained the lowest liverwort coverage with 0%. All other treatments provided similar control.

By 11 WAT, liverwort coverage in non-treated controls averaged 60%. Liverwort coverage was similar to non-treated control containers in containers treated with Kansel+, OH2, Pendulum 2G, RegalKade 0.5G, and Snapshot 2.5TG. In containers treated with

BroadStar and Ronstar G, liverwort coverage averaged only 3% and 9%, respectively. Regal O-O, RegalStar, and Rout 3G provided similar control to BroadStar and Ronstar G.

At 17 WAT, liverwort covered an average of 74% of the substrate surface in non-treated controls. Containers treated with BroadStar contained only 12% liverwort coverage. Ronstar G provided similar control (33%) to BroadStar. Liverwort coverage in containers treated with Regal O-O was statistically lower than non-treated controls with 55%. All other treatments resulted in similar liverwort coverage as non-treated controls.

Experiment 2. Liverwort coverage averaged 55.6% by 6 WAT in non-treated control containers (Table 4.2). Gentry provided acceptable preemergence control with liverwort coverage averaging below 2% in containers. BroadStar, Ronstar G, and Rout 3G provided excellent control with 0% liverwort coverage.

Liverwort covered 64% of the substrate surface in non-treated control containers 10 WAT. Gentry control decreased after 6 WAT. Liverwort coverage in containers treated with Gentry ranged from 10% to 12%. BroadStar, Ronstar G, and Rout 3G continued to provide excellent control with 1% or less liverwort coverage in containers treated with these products.

By 18 WAT, about 95% of the substrate was covered with liverwort in the control containers. Gentry efficacy decreased considerably. Liverwort coverage in containers treated with Gentry at 3.8 and 7.6 kg ai/ha was similar to non-treated control containers with 91% and 93%, respectively. Containers treated with Gentry at 1.9 kg ai/ha contained 79% liverwort coverage. Preemergence control had begun to drop in containers treated with BroadStar, Ronstar G, and Rout 3G, however these products provided good control 18 WAT compared to Gentry and non-treated controls.

Experiment 3. Lower concentrations and spray volumes of Gentry provided acceptable preemergence liverwort control. At 9 WAT, liverwort coverage averaged only 10% in control containers (Table 4.3). Containers treated with Gentry had liverwort coverage from 1% to 4% on the substrate surface. There was no liverwort present in containers treated with diuron. According to analysis of variance, there were no significant differences between treatments (p=0.433).

By 12 WAT, liverwort coverage in non-treated control containers averaged 45%. Liverwort coverage in containers treated with Gentry was similar to non-treated control containers ranging from 21% to 45%. There was no liverwort in containers treated with diuron.

By 17 WAT, liverwort coverage in non-treated control containers averaged 44%. Liverwort coverage in containers treated with Gentry was similar to non-treated controls. With the exception of containers treated with the lowest concentration and spray volume of Gentry, liverwort coverage decreased from 12 WAT to 17 WAT. Summer conditions during this experiment affected liverwort vigor and are most likely due to the decrease in liverwort coverage.

In conclusion, BroadStar, Regal O-O, RegalStar, Ronstar G, and Rout 3G provided effective preemergence liverwort control up to 11 WAT. BroadStar and Ronstar G provided superior preemergence liverwort control 17 WAT. These findings concur with reports by Fausey that flumioxazin and oxyfluorfen provide preemergence liverwort control (Fausey, 2003). They also concur with Senesac who rported that oxadiazon (Ronstar G) provided effective preemergence liverwort control (Senesac, 1997). All of these herbicides are PPO inhibitors, which disrupt cell membrane development by inhibiting PPO enzyme production (Vencill, 2002).

Gentry provides little to no long term residual control depending on the relative vigor of liverwort in its present growing conditions. While Gentry did provide effective preemergence control in Experiment 2 for 6 to 10 weeks, it provided poor control compared to granular preemergence herbicides beyond 10 weeks. Gentry also provided effective preemergence control in Experiment 3 for 9 weeks with control declining rapidly thereafter. It should be noted that preemergence residual herbicides cannot be used inside structures, and few can be used in propagation. Gentry is labeled for greenhouse use, and it has been proven safe on a broad range of woody and herbaceous plant material (Altland, 2003; Svenson, 2000). Gentry could be used to provide short term preemergence liverwort control in conditions where traditional preemergence herbicides cannot be used.

Diuron provided excellent preemergence control throughout the 17 week study. It has been reported safe for over-the-top application on many container nursery crops (Ahrens, 2003). Furthermore, it has been reported that diuron caused no injury to newly planted woody ornamentals when applied as a preemergence including blue holly, rhododendron, heavenly bamboo, dwarf burning bush, butterfly bush, arborvitae, and juniper (Ahrens, 2004). Diuron has potential for use as a registered herbicide in container crops.

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Table 4.1 Preemergence liverwort control with common granular herbicides in Experiment 1.

Herbicide	Rate (kg ai/ha)	% Liverwort coverage of medium		
		6 WAT[Z]	11 WAT	17 WAT
BroadStar	0.4	0[Y] d[X]	3 d	12 f
Kansel+	3.6	19 ab	58 a	79 abc
OH2	3.4	6 bcd	49 abc	80 abc
Pendulum 2G	4.5	15 abc	61 a	86 ab
Regal 0-0	3.4	4 cd	20 d	55 de
RegalKade 0.5G	1.1	16 abc	53 ab	75 abc
RegalStar	2.7	4 cd	28 bcd	66 cde
Ronstar G	4.5	0 d	9 d	33 ef
Rout 3G	3.4	4 cd	25 cd	73 bcd
Snapshot 2.5TG	5.6	12 bcd	65 a	90 a
Non-treated control		26 a	60 a	74 abc

[Z] Weeks after treatment. Treated July 6, 2004.
[Y] Percent coverage of liverwort within container.
[X] Duncan's Multiple Range Test (α=0.05). Means with same letter are not signifcantly different.

Table 4.2 Preemergence liverwort control with Gentry and common granular herbicides in Experiment 2.

Herbicide	Rate (kg ai/ha)	% Liverwort coverage of substrate 6 WAT[z]	10 WAT	18 WAT
Gentry	1.9	2[Y] b[X]	10 b	79 b
Gentry	3.8	2 b	12 b	91 a
Gentry	7.6	2 b	10 b	93 a
BroadStar	0.4	0 b	1 c	13 c
Ronstar G	4.5	0 b	0 c	23 c
Rout 3G	3.4	0 b	0 c	21 c
Control		56 a	64 a	95 a

[z] Weeks after treatment. Treated September 23, 2004.

[y] Percent substrate surface covered with liverwort.

[v] Means separated within column using Duncan's Multiple Range Test (α=0.05).

Table 4.3 Preemergence liverwort control with quinoclamine and diuron in Experiment 3.

Herbicide	Concentration (g ai/L)	Spray Volume (L/ha)	Rate (kg ai/ha)	% Liverwort coverage of substrate 9 WAT[z]	12 WAT	17 WAT
Gentry	0.94	255	0.24	2	24 ab[Y]	29 abc
		509	0.48	2	28 ab	19 abc
		1018	0.95	4	45 a	35 ab
	1.87	255	0.48	1	32 a	30 abc
		509	0.95	2	33 a	48 a
		1018	1.91	2	42 a	33 ab
	3.75	255	0.95	3	23 ab	22 abc
		509	1.91	2	21 ab	13 bc
		1018	3.81	2	22 ab	24 abc
	Main effects[X]	concentration		NS	NS	NS
		spray volume		NS	NS	NS
		concentration*volume		NS	NS	NS
diuron		374	0.56	0	0 b	0 c
		374	1.12	0	0 b	0 c
Control				10	45 a	44 ab

[Z] Days after treatment. Treated March 14, 2005.

[Y] Means within a column with the same letter are similar according to Duncan's multiple range test (α=0.05).

[X] Main effects of concentration, spray volume, and interaction thereof among Gentry treatements.

NS, *, **, *** represent nonsignificant or significant at the 0.05, 0.01, 0.001 level, respectively.

Chapter V

Postemergence Liverwort Control with Diuron and Low Rates of Gentry

Abstract

Two experiments were conducted at Auburn University, AL to evaluate the use of lower Gentry concentrations and spray volumes than currently recommended and to evaluate diuron for postemergence liverwort control. In Experiment 1, Gentry concentrations of 1.87 and 3.75 g ai/L applied at 509 and 1018 L/ha provided excellent postemergence liverwort control 7 and 14 DAT (81%-99%). Diuron applied at 1.12 kg ai/ha provided 86% postemergence liverwort control. Linuron provided no postemergence control. In Experiment 2, Gentry applied at concentrations of 3.75 g ai/L and spray volumes of 509 and 1018 L/ha provided superior postemergence control 7 and 14 DAT (82%-89%). Diuron applied at 1.12 kg ai/ha provided 60% postemergence liverwort control 14 DAT, however liverwort coverage in containers treated with diuron averaged only 1% by 63 DAT.

Index words: quinoclamine, Gentry, weed control

Herbicides used in this study: Gentry (quinoclamine), 2-amino-3-chloro-1,4-naphthoquinone; Direx 4L (diuron), 3-(3-(3,4-dichlorophenyl)-1,1-dimethylurea.

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

Significance to the Industry

Gentry is a promising new product for postemergence liverwort control. The label recommends applying 3.75 grams of ai/L of water (0.5 oz ai/gal) applied at a spray volume of 2036 L/ha (2 quarts/100 ft^2 or 218 gal/A). Results of this research indicate that Gentry concentrations as low as 1.87 g ai/L (0.25 g ai/gal) applied at spray volumes as low as 509 L/ha (54 gal/A) provide effective postemergence liverwort control. Furthermore diuron provides effective postemergence liverwort control and has potential for use as a postemergence weed control for nursery crops.

Introduction

Liverwort (*Marchantia polymorpha* L.), commonly known as liverwort, has become an established weed problem throughout the United States. Some preemergence herbicides have been proven effective for preemergence control (Svenson, 1998; Fausey, 2003), however these products are not labeled for use in enclosed structures or propagation. Propagation environments and greenhouses provide ideal conditions for liverwort.

Potential postemergence controls include Gentry (quinoclamine, Chemtura, Middlebury, CT) and diuron. Gentry was originally used in Japan as an algaecide in rice production and proven to have effective postemergence liverwort control and is safe on a broad range of ornamental crops (Altland, 2003). Chemtura is pursuing a label for Gentry, a 25% wettable powder, in nursery and greenhouse crops for postemergence liverwort control. The proposed recommendation by its company is 3.75 grams of ai/L of water (0.5 oz ai/gal) applied at a spray volume of 2036 L/ha (2 quarts/100 ft^2 or 218 gal/A). This recommendation is equivalent to 7.62 kg/ha (6.8 lbs ai/A). In a previous study, Gentry concentration of 1.9 g/L (1 oz/gal) applied at 1018 L/ha (1 quart/100 ft^2 or 109 gal/A) provided similar postemergence control compared to the recommended rate (Newby et al, 2004).

Diuron is an older herbicide registered for preemergence weed control on cotton, alfalfa, and other crops. It is classified as a substituted urea (Stranger and Appleby, 1972) and inhibits photosynthetic electron transport within the chloroplast membrane at photosystem II. Selected nursery crops have tolerance to diuron (Ahrens, 2003). Previous research demonstrated that over the top applications of diuron on camellia and liriope had postemergence activity on oxalis while causing slight to no injury to the nursery crops (Simpson, 2004). Diuron is used for postemergence liverwort control in Germany (personal communication with Dr. Heinrich Loesing). Ahrens et al. reported that 1.12 kg ai/ha (1.0 lb ai/A) provided 100% postemergence liverwort control 2 months after treatment (Ahrens, 2003).

The objective of this research was to evaluate the use of lower Gentry concentrations and spray volumes than currently recommended and to evaluate diuron for postemergence liverwort control. Experiments were conducted at Auburn University, AL.

Materials and Methods

Experiment 1. Number one containers 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-12K Pursell Technologies, Sylacauga, AL), 3.0 kg (5 lb) of dolomitic lime, and 0.9 kg (1.5 lb) of Micromax (Scotts Co.). The substrate surface of containers were inoculated with

Marchantia polymorpha L. and grown under mist irrigation until it covered at least 60% of the container surface. Treatments were applied on 4 November 2004. Gentry was applied in a factorial arrangement consisting of four rates and three spray volumes. Concentrations of 0.47, 0.94, 1.87, or 3.75 g ai/L (0.06, 0.13, 0.25, or 0.5 oz ai/gal) were each applied at spray volumes of 255, 509, and 1018 (0.25, 0.5, or 1.0 qt/100 ft^2; 27, 54, or 109 gal/A). Diuron was applied as Direx 4L (Griffin LLC, Valdosta, GA) at 0.56 or 1.12 kg ai/ha (0.5 or 1.0 lb ai/A). Linuron, another substituted urea herbicide with similar chemistry to diuron, was also applied at 0.56 or 1.12 kg ai/ha (0.5 or 1.0 lb ai/A). Both diuron and linuron were applied at a spray volume of 374 L/ha (40 gal/A). All treatments were applied with a backpack sprayer fitted with an 8004 flat fan nozzle at a pressure of 2.1 kg/cm^2 (30 psi) and calibrated to deliver the specified spray volume. Treatments were arranged with a non-treated control group in a completely randomized design with six single pot replications. Data included percent postemergence control at 3, 7, 14, and 28 DAT on a 0 to 100 percent scale where 0 equals no control and 100 equals death of entire liverwort within the container. As a comparison of liverwort re-growth, percent liverwort coverage of the container surface was recorded 35 and 70 DAT. Treatments were also applied to six single pot replications of Rabbit foot fern (*Humata tyermanii* T. Moore) and Poinsettia (*Euphorbia pulcherrima* Willd. Ex Klotzsch) and compared to a non-treated control group in order to evaluate plant tolerance. These species are typically grown in environments conducive to liverwort growth. The study was conducted in a temperature-controlled greenhouse that remained at or above 65 F. Overhead irrigation was applied daily at 0.64 cm (0.25 in) split into two cycles.

Experiment 2. Liverwort was grown in full gallon containers as described in Experiment 1. Treatments were applied on 14 March 2005 when liverwort covered at least 60% of the container surface. Nine Gentry treatments were applied in a factorial arrangement consisting of three rates and three spray volumes. Concentrations of 0.94, 1.87, or 3.75 g ai/L (0.125, 0.25, and 0.5 oz ai/gal) were each applied at spray volumes of 255, 509, or 1018 (0.25, 0.5, or 1.0 qt/100 ft^2; 27, 54, or 109 gal/A). Direx 4L was applied at 0.56 or 1.12 kg ai/ha (0.5 or 1.0 lb ai/A) with a spray volume of 374 L/ha (40 gal/A). All treatments were applied with a backpack sprayer fitted with an 8004 flat fan nozzle at a pressure of 2.1 kg/cm^2 (30 psi) and calibrated to deliver the specified spray volume. A non-treated control group was maintained. Treatments consisted of 6 single pot replications arranged in a completely randomized design. The study was conducted under a shade house with 47% shade. Cyclic overhead irrigation was applied daily at 1.27 cm (0.5 inches) per day split into two cycles. Percent liverwort control was recorded 7, 14, and 21 DAT. Percent liverwort coverage within the container was recorded 35 and 63 DAT.

Results and Discussion

*Experiment 1***.** Main effects of Gentry concentration, spray volume, as well as their interaction were found to be significant according to analysis of variance ($p \leq 0.05$) 7 DAT and 14 DAT. In general, control increased as concentration increased and as spray volume increased. At 7 DAT, concentrations of 0.94, 1.87, and 3.75 g ai/L applied at 1018 L/ha provided 88%, 97%, and 99% postemergence control, respectively (Table 5.1). Similarly, concentrations of 1.87 and 3.75 g ai/L applied at just 509 L/ha provided 93%

and 81% postemergence control, respectively. By 14 DAT, rates of 0.94, 1.87, and 3.75 g ai/L applied at 1018 L/ha provided 83% to 98% postemergence control. Rates of 1.87 and 3.75 g ai/L applied at just 509 L/ha provided similarly effective postemergence control. Percent liverwort coverage 70 DAT was lowest in containers treated with 3.75 g ai/L applied at 509 and 1018 L/ha.

Diuron and linuron treatment means were compared to Gentry treatments and the non-treated control group using Duncan's multiple range test (α=0.05). At 7 DAT, diuron provided minimal postemergence control. Linuron treatments had no postemergence effect when compared to the non-treated controls. However, diuron applied 0.56 and 1.12 kg ai/ha provided effective postemergence control 14 DAT. Diuron applied at 1.12 kg ai/ha provided similar control to the most effective Gentry treatments. Percent liverwort coverage 70 DAT in containers treated with 1.12 kg ai/ha diuron was lowest at 16% and similar to Gentry at 3.75 g ai/L applied at 509 and 1018 L/ha.

Rabbit-foot fern (*Humata tyermanii* T. Moore) and poinsettia (*Euphorbia pulcherrima* Willd. Ex Klotzsch), though considered sensitive plants, displayed no injury throughout the course of the study.

*Experiment 2***.** As in Experiment 1, main effects of Gentry concentration, spray volume, as well as the interaction thereof were found to be significant throughout the study ($p \leq 0.05$) The concentration of 3.75 g ai/L applied at 509 and 1018 L/ha provided superior control at 83% and 89% postemergence control 7 DAT (Table 5.2). Rates of 0.94 and 1.87 g ai/L did not provide adequate postemergence control regardless of spray volume.

Results were similar 14 DAT. Liverwort covered 66% and 67% of the substrate surface 63 DAT in containers treated with 3.75 g ai/L applied at 509 and 1018 L/ha, respectively.

Diuron treatments did not provide significant postemergence control 7 DAT. By 14 DAT, diuron at 1.12 kg ai/ha provided 60% postemergence control, while diuron at 0.56 kg ai/ha provided 35% postemergence control. By 63 DAT, percent liverwort coverage in containers treated with diuron were significantly lower than containers treated with the highest rate and spray volume of Gentry. Percent coverage in containers treated with diuron at 1.12 kg ai/ha was only 1%, while percent coverage in containers treated with diuron at 0.56 kg ai/ha was 23%. These findings concur with Ahrens et al. (2003) who reported that 0.56 kg ai/ha diuron provided 80% postemergence control and 1.12 kg ai/ha diuron provided 100% postemergence control 2 months (60 days) after treatment.

Gentry concentration and spray volume influence postemergence liverwort control. These data indicate that recommended concentrations and spray volumes can be reduced to provide effective postemergence control. Heavy liverwort infestations may require a higher concentration/spray volume, while lighter liverwort infestations may be controlled by a lower concentration/spray volume.

Percent postemergence control attained by Gentry treatments was higher in Experiment 1 when compared to similar treatments in Experiment 2. Experiment 1 was conducted in a temperature-controlled greenhouse. Experiment 2 was conducted outdoors, and treatments were applied in March. Gentry activity is quick to affect liverwort vitality. After treatment applications in March, the temperature dropped to 6.1 C (43 F) and remained below 18.3 C (65 F) for 7 days. The decline in postemergence control in Experiment 2 could be accounted for by the cooler temperatures. Physiological activity of the liverwort would have been lower in cooler temperatures.

Diuron provides excellent postemergence liverwort control when applied at 1.12 kg ai/ha. This product is not registered for use on nursery crops; however it caused no injury to crops treated in this study. Diuron has potential as a postemergence herbicide for weed control in container nursery crops.

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Table 5.1 Effects of low Mogeton rates, diuron, and linuron on postemergence liverwort control in Experiment 1.

Herbicide	Concentration (g ai/L)	Spray Volume (L/ha)	Rate (kg ai/ha)	% Control 7 DAT[Z]	% Control 14 DAT	% Coverage 70 DAT
Gentry	0.47	255	0.12	33 ef[Y]	28 fg	97 a
		509	0.24	46 ed	36 ef	97 a
		1018	0.48	61 cd	53 de	87 a
	0.94	255	0.24	58 cd	61 cd	89 a
		509	0.48	71 bc	66 cd	73 ab
		1018	0.95	88 ab	87 abc	79 ab
	1.87	255	0.48	34 ef	28 fg	88 a
		509	0.95	93 ab	94 ab	59 bc
		1018	1.91	97 a	83 abc	54 bc
	3.75	255	0.95	82 abc	78 abcd	73 ab
		509	1.91	81 abc	97 a	40 cde
		1018	3.81	99 a	98 a	22 de
	Main effects[X]	concentration		***	***	***
		spray volume		***	***	***
		concentration*volume		***	**	NS
diuron		374	0.56	35 e	70 bcd	44 cd
diuron		374	1.12	33 ef	86 abc	16 e
linuron		374	0.56	25 efg	17 fgh	94 a
linuron		374	1.12	10 fg	4 gf	100 a
Control				2 g	1 h	100 a

[Z] Days after treatment. Treated November 4, 2004.

[Y] Means within a column with the same letter are similar according to Duncan's multiple range test (α=0.05).

[X] Main effects of concentration, spray volume, and interaction thereof among Gentry treatements.

NS, *, **, *** represent nonsignificant or significant at the 0.05, 0.01, 0.001 level, respectively.

Table 5.2 Effects of low Gentry ratesand diuron on postemergence liverwort control in Experiment 2.

Herbicide	Concentration (g ai/L)	Spray Volume (L/ha)	Rate (kg ai/ha)	% Control 7 DAT[Z]	% Control 14 DAT	% Coverage 63 DAT
Gentry	0.94	255	0.24	13 ef[Y]	6 de	93 ab
		509	0.48	14 ef	12 de	95 ab
		1018	0.95	29 cd	20 cde	93 ab
	1.87	255	0.48	18 de	8 de	96 ab
		509	0.95	40 c	18 cde	92 ab
		1018	1.91	68 b	63 b	83 b
	3.75	255	0.95	35 c	19 cde	98 a
		509	1.91	83 a	82 a	66 c
		1018	3.81	89 a	83 a	67 c
	Main effects[X]	concentration		***	***	***
		spray volume		***	***	***
		concentration*volume		***	***	**
diuron		374	0.56	3 f	35 c	23 d
diuron		374	1.12	5 f	60 b	1 e
Control				6 ef	2 e	100 a

[Z] Days after treatment. Treated March 15, 2005.

[Y] Means within a column with the same letter are similar according to Duncan's multiple range test (α=0.05).

[X] Main effects of concentration, spray volume, and interaction thereof among Gentry treatements.

NS, *, **, *** represent nonsignificant or significant at the 0.05, 0.01, 0.001 level, respectively.

Chapter VI
Conclusion

Data in chapter two demonstrate that effective postemergence liverwort control can be provided by some products. Gentry (quinoclamine, Chemtura Corp., Middlebury, CT) is a chemical being introduced for over-the-top application on nursery crops as a postemergence liverwort control. TerraCyte, a granular form of sodium carbonate peroxyhydrate, is labeled for postemergence control of liverwort, as well as mosses, algae, and slime mold in container nursery crops and greenhouses. Previous research suggests that BroadStar (flumioxazin, Valent Corp., Walnut Creek, CA) provides postemergence liverwort control (Fausey, 2003).

In chapter two, Gentry provided consistently effective postemergence control when applied at a rate of 7.5 kg ai/A or higher. Gentry at rates as low as 1.8 kg ai/ha provided excellent postemergence control in Experiment 1. In Experiment 2, Gentry applied at 7.6 kg ai/ha provided effective postemergence liverwort control, while a rate of 3.8 kg ai/ha provided moderate control. Experiment 1 was conducted in mid summer, while Experiment 2 was conducted in spring. Mild temperatures in the spring may account for increased liverwort vigor and, thus, decreased efficacy in Experiment 2. TerraCyte provided moderate postemergence liverwort control in Experiment 1. In Experiment 2, TerraCyte provided postemergence liverwort control as effective as the highest rate of Gentry. The reasons for these discrepancies are not clear;

however it is presumed that liverwort stage and physiology affect postemergence control with these products in varying ways. BroadStar provided poor postemergence liverwort control 14 DAT in both experiments. However, BroadStar provided 65% postemergence liverwort control of juvenile liverwort in experiment 1 and 72% postemergence liverwort control in experiment 2. BroadStar activity on liverwort is augmented over time and seems to be much slower than Gentry and TerraCyte.

Gentry at rates as high as 7.6 kg ai/ha (8.5 lb ai/A) were found to be safe on three herbaceous perennials. Gentry at rates as high as 15.2 kg ai/ha (13.6 lbs ai/A) were found to be safe on a wide range of nursery crops.

In chapter three, the effects of differing concentrations and spray volumes of Gentry application with and without surfactant were explored. In Experiment 1, the higher concentration of Gentry provided consistently effective postemergence liverwort control 2 and 14 DAT (>92%). The lower concentration of Gentry applied with surfactant at 2061 L/ha (218 gal/A) provided similar control. In Experiments 2 and 3, Gentry provided effective postemergence liverwort control regardless of concentration, spray volume, or surfactant. TerraCyte provided poor control in Experiment 1 but effective control in Experiments 2 and 3 when applied at the same or higher rate. As in chapter 2, these differences in postemergence liverwort control with Gentry and TerraCyte are most likely due to differing environmental conditions and liverwort vigor.

Chapter 4 evaluated products for preemergence liverwort control. BroadStar (flumioxazin), Regal O-O (oxyfluorfen + oxadiazon), RegalStar (oxadiazon + prodiamine), Ronstar G (oxadiazon), and Rout 3G (oxyfluorfen + oryzalin) provided effective preemergence liverwort control 11 WAT. All of these products disrupt cell membrane production. Gentry applied at 1.9 to 7.6 kg ai/ha (1.7 to 6.8 lb ai/A) provided effective preemergence liverwort control for 6 WAT in Experiment 2. Diuron applied at 0.56 and 1.12 kg ai/ha (0.5 and 1 lb ai/A) provided excellent preemergence liverwort control for 17 WAT in Experiment 3.

Research from chapter five illustrated that Gentry concentration and spray volume affect postemergence liverwort control and that the label concentration and spray volume can be lowered. In both experiments, the recommended Gentry concentration of 3.75 g ai/L (0.5 oz ai/gal) provided effective postemergence liverwort control when applied at 509 or 1018 L/ha (54 or 109 gal/A). In experiment 2, Gentry concentration of 1.87 g ai/L (0.25 oz ai/gal) applied at 1018 L/ha (109 gal/A) provided similarly effective control as the higher concentration. Diuron applied at 1.12 kg ai/ha (1 lb ai/A) provided excellent postemergence liverwort control in both experiments.

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