Postemergence Control of English Ivy (*Hedera helix* L.) and Moisture Effects on Preemergence Weed Control with Flumioxazin

by

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Abstract

English ivy (*Hedera helix* L.) is an invasive vine in at least 28 states in the United States. This species has excellent environmental adaptability, grows as a ground cover and climbs into tree canopy. More potential herbicides for English ivy control were registered in 2000's. Four experiments were conducted to evaluate English ivy response to old and new postemergence herbicides in different season applications with a series of application rates. Results indicated English ivy was not controlled by aminopyralid and fluroxypyr (i.e. experiment I & II). Metsulfuron provided excellent control of English ivy when the rate was above 0.21 kg ha^{-1} at any application timing (i.e. experiment II, III & IV). Sulfometuron provided excellent control in summer application (experiment III), but not in spring application (experiment IV). The old herbicides, i.e. glyphosate and 2,4-D (2,4-Dichlorophenoxyacetic acid), usually provided better control at the higher rates. However, the best control was obtained with summer application. Therefore, we assumed that higher temperatures perhaps reduce English ivy tolerance to the herbicides.

Another research component was to evaluate the effect of substrate moisture on preemergence weed control with flumioxazin. Flumioxazin is a commonly used herbicide in nursery production for preemergence weed control. Moisture is an important component to activate preemergence herbicides; however, this aspect had not been investigated in soilless substrate. The objective of this research was to evaluate the influence of both pre-application moisture levels and post-application irrigation levels in the preemergence control of hairy bittercress (*Cardamine* *hirsuta* L.) and spotted spurge (*Chamaesyce maculata* L.) with flumioxazin in a pine bark substrate. Similar experiments were conducted. Treatments were a factorial arrangement: three pre-application moisture levels (dry, medium and wet), two flumioxazin formulations (granular and spray), two flumioxazin rates [0.28 and 0.42 kg ha^{-1} (0.250 and 0.375 lb ai A^{-1})] and four post-application irrigation levels [0.6, 1.3, 2.5 and 5.1 cm (0.25, 0.50, 1.00 and 2.00 in)]. Each pot was overseeded with 25 weed seeds after herbicide application. Weed germination was counted weekly, and shoot fresh weights were taken after the last weed count. Results showed pre-application moisture did not affect the flumioxazin efficacy. The spray formulation provided maximum reduction of weed counts, regardless of rate, pre-moisture level or post-irrigation level. Conversely, the granular formulation was less effective, and the higher rate was generally more effective than lower rate. For granular herbicides, more water was needed to break the herbicide coating. This process is likely improved by higher temperature.

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I want to thank my parents, my sister for supporting my decision to attend the graduate school of Auburn University. Without them, I could not have come to the United States to get this good experience and education. To my main advisor Dr. Charles Gilliam, thank you for encouraging me and helping me in both study and life, and teaching me how to face the challenges of my life. To my co-advisor Dr. Glenn Wehtje, thank you for your patience and help with my research. I also want to thank all the teachers who gave me so much knowledge these two years, including my committee numbers: Dr. McElroy and Dr. Sibley. Without you, I could not complete my study and get my Master's degree.

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List of Abbreviations and Symbols

2,4-D - 2,4-Dichlorophenoxyacetic acid

A – acre

ae - acid equivalent

ai - active ingredient

AL - Alabama

ANOVA - analysis of variance

CIPC - isopropyl-*N*-(3-chorophenyl) carbamate

DAT - days after treatment

DNBP - 4, 6-dintro ortho secondary butylphenol

EPTC - ethyl N, N-dipropylthiocarbamate

GLM - general linear model

F.W. - fresh weight

in - inch

GPA - gallon per A

gran. - granular

ha - hectare

lb - pound

LSD - least significant difference

kg - kilogram

m - meter

NRCS - Natural Recourses Conservation Service

USDA - United State Department of Agriculture

VWC - volumetric water content

WAS - weeks after seeding

WAT - weeks after treatment

WDG - water dispersible granular

yd - yard

Chapter I: Introduction and literature review

Part 1: Postemergence control of English ivy (*Hedera helix* L.)

Introduction

English ivy (*Hedera helix* L.) is a native species in Europe, Western Asia and Northern Africa. This species was introduced into North America by early settlers for ornamental use in the colonial era (Wyman, 1994; Randall, 1996). English ivy is an evergreen vine growing from full sun to deep shade (Gilman, 1999), which is widely used in ornamental landscapes, and considered a good ground cover species in the Great Plains and Midwest (Beck, et al., 2008). English ivy leaves are dark green and a have waxy or glossy surface. Plants in the juvenile phase have foliage with 3-5 lobes per leaf and rhizomes begin to grow as a ground cover. Adult plants have thick heart-shaped leaves, grow upright, and become woody (Sulgrove, 2004).

In the United States, many native species have been impacted by invasive species (Reichard and White, 2001). English ivy can grow well in both acidic and basic soils (Reichard, 2000), and competes with many native plants for light, nutrition and soil and reduces animal feeding habitats (Morisawa, 1999). English ivy is also considered as a nitrogen indicator species. When soil nitrogen increases, shoots density has increased over time (Lameire, et al., 2000). Additionally, English ivy vines aggressively climb up tree trunks (0.9 meter per year) and grow into the tree canopy, resulting in host tree death in a few years (Soll, 2005). This species has invaded Southern, mid-Atlantic and Pacific Northwest forestry areas of the United States (Randall, 1996; Miller, 2007). From the report of USDA-NRCS (2002), English ivy is present in

28 states. Westbrook (1998) described an 'ivy desert' as a forest area that has limited number of canopy species with entangling English ivy wildly climbing and reaching out into the canopy. In an ivy desert, there is an absence of native ground cover plants as a result of the dense ivy groundcover.

Control Method

In the Willamette valley of Oregon, high-density, short-duration goat (doe-kid) browsing was evaluated to control English ivy in 2006 and 2007. Results showed English ivy can be controlled by goat browsing (Claudia and Michael, 2010), and the repetition of browsing for a second year was more effective. However, this method is not adapted in any area, and no native species recovery was reported.

Prasad (2002) reported that the use of bio-herbicides with the fungus *Chondrostereum purpureum* has been applied to English ivy, but the efficacy had not been proved.

The most effective way to completely remove English ivy was to pull up the plant by hand, because this way was effective and environmentally safe for native species recovery compared with glyphosate application. Plots treated by hand pulling had 8.5±0.56 species recovery, while plots treated by 20% glyphosate solution only had 1.7±0.15 species recovered (Biggerstaff et al., 2007). In landscape production, manual pulling costs were assumed from $2,000 to $8,000 per acre even at minimum wage (Soll, 2005). For reducing population, volunteers were useed to hand remove English ivy in the forest parks, Oregon (Chaker, 2010). However, manual control may also cause soil surface erosion (Soll, 2005).

Chemical control often provides incomplete control English ivy, but total cost range from $100 to $500 per acre assuming $25-100 per hour for operator cost and $50 per gallon for chemicals (Soll, 2005).

Research in 1985 on glyphosate application on selected woody ornamentals showed both timing and rate were important factors to influence postemergence control of English ivy. Glyphosate applied at 3.0 kg ha^{-1} in March caused 98% injury to English ivy at 25 days after treatment; while June application caused 82% injury at 3.0 kg ha^{-1}; August to September application provided average 55% control; but only 38% control was obtained in November application (Neal and Skrock, 1985). Neal (1998) emphasized that the best timing to control English ivy is applying 2 or 3% glyphosate (Roundup-Pro) in early spring.

Derr (1993) evaluated 7 treatments applied in June, including glyphosate at 2.2 and 4.5 kg ha^{-1} with or without surfactant, 2, 4-D amine (2,4-Dichlorophenoxyacetic acid) at 1.1 kg ha^{-1}, dicamba (Banvel) at 0.6 kg ha^{-1}, and triclopyr (Garlon) at 0.6 kg ha^{-1}. Result shows that glyphosate applied at 4.5 kg ha^{-1} without surfactant provided 81% control of fresh shoot, but only 58% control at the 2.2 kg ha^{-1} rate. Shoot fresh weights were similar with glyphosate (2.2 kg ha^{-1}), 2, 4-D, dicamba and triclopyr. Glyphosate at 4.5 kg ha^{-1} rate with surfactant also controlled the old growth. Usually, glyphosate at the higher rate and two applications were needed to control vines (Soll, 2005). On the other hand, Morisawa (1999) stated that an application on cut stems of either 25% solution of glyphosate or 2% solution of 2, 4-D provided good control.

Miller (2007) recommended thoroughly wetting all leaves until runoff with one of the following herbicides with a surfactant in July to October: 3-5% Garlon 3A or Garlon 4 (triclopyr) solution or 4% Roundup-Pro (glyphosate) solution. Miller (2007) also reported applying Garlon 4 as 20% solution in basal oil, vegetable oil, crop oil concentrate, diesel fuel, or kerosene.

Most herbicides tested in early research belong to auxin-mimicking groups (growth regulators), which can stimulate plant growth at low rates. However, the majority of injured plants can grow back without multiple applications (Derr, 1993). Therefore, more research is needed to investigate the way to completely control English ivy. Recently, new herbicides have been registered in the 2000's. Fluroxypyr (Vista, Figure 1), which was registered on May 2, 2006, has the same mode of action as triclopyr (Garlon) and is labeled for broadleaf invasive plant management in pine plantations and non-crop sites. Aminopyralid (Milestone, Figure 2.), which was registered on February 7, 2007, has the same mode of action with fluroxypyr, triclopyr and 2, 4-D, is a newly available herbicide for land management to control kudzu. Escort (metsulfuron, Figure 3), which was registered on October 4, 2001, is for site preparation of conifer plantations, and is widely recommended for kudzu (*Pueraria Montana* var. *lobata*) control (Weaver and Lyn, 2007). Oust (sulfometuron), which was registered on August 21, 2008, belongs to the same chemical group with Escort and has a similar chemical structure (Figure 4), and provides non-selected weed control. Because kudzu is an invasive broadleaf vine as well, we speculated that these herbicides could be also active for English ivy control.

Statement of Research Objective

Since 2000, several new herbicides with potential for English ivy control have been registered. This study was conducted to evaluate the efficacy of those potential herbicides chemistries compared to glyphosate and 2, 4-D for English ivy control at varied rates and in different season of the year. The objective of this study was to find the most effective treatment in terms of herbicide, timing and rate to provide excellent control of English ivy.

Part 2. Moisture effect on preemergence weed control with flumioxazin

Introduction

Preemergence herbicide application is the most popular method of weed control in nursery production (Everest et al., 1998). Weed control is one of the biggest problems for nursery managers. With increasing labor cost, hand-weeding cost is becoming more and more expensive. Research by Darden and Neal (1999) reported that hand weeding 1,000 pots cost as much as $1,376 over a four month period at a time when the minimum wage was $5.15 per hour compared with $7.25 per hour in 2012. Growers are becoming increasingly aware of labor saved by the application of preemergence herbicide, and typically make 3 to 6 preemergence herbicides applications annually (Gilliam et al., 1990). Both hairy bittercress (*Cardamine hirsuta* L.) and spotted spurge (*Chamaesyce maculata* L.) are major noxious weeds in the Southeast container nursery production (Ryan, 1977). Both are annual broadleaf (dicot) weeds. Hairy bittercress is a cool-season weed, emerging from early spring to the end of fall. Each seed pod can produce 20 to 50 seeds, and 600 to 5,000 seeds can be produced by one plant. Spotted spurge is a warm season weed; seed germination occurs within a temperature range of 60 to 100 F, and can flower and produce seed within 5 weeks.

Soil moisture is an important factor affecting the absorption of herbicides by germinating weeds (Menges, 1963), because water can dissolve granular herbicides, move the herbicides into substrate to enhance herbicide-substrate contact and allow herbicides to contact the roots of target weed plants. Research in 1960's showed irrigation volume affected effectiveness of preemergence herbicides with different ingredients and volatility (Knake et al., 1967). As pointed out by Audus (1964), the relationship between soil moisture and absorption of herbicides into the soil exchange complex may affect the availability of herbicides for uptake by the plant. Other research with diuron on cotton (*Gossypium hirsutum* L.) showed that diuron was more effective under high post-moisture conditions than under low moisture condition, but CIPC (isopropyl-N-(3-chorophenyl) Carbamate) and DNBP (dintro ortho secondary butylphenol) were not influenced by soil moisture (Upchurch, 1957). In a study on foxtail control with 25, 31 and 37% soil moisture (Stickler et al., 1969), the effectiveness of atrazine and EPTC (ethyl N, N-dipropylthiocarbamate) increased with increasing soil moisture. Other research indicated that 5 cm (2 in) preplant irrigation with pronamide reduced weed density compared with no preplant irrigation in a field study (Shem-tov et al., 2006).

Flumioxazin inhibits protoporphyrinogen oxidase, which is an enzyme involved in chlorophyll synthesis (Scalla and Matringe, 1994). Flumioxazin is absorbed by both roots and foliage of targeted weeds and has both preemergence and postemergence activity, but it is used predominately for preemergence control. Flumioxazin is reported to safely control many broadleaf weed species when applied preemergence in many crops (Cranmer et al., 2000; Kelly et al., 2006). A study in 2010 reported that 90% hairy bittercress control can be obtained with 0.33 kg ha^{-1} of flumioxazin applied alone in container substrate (Wehtje et al., 2010). Over 95% spotted spurge control was obtained with flumioxazin at 0.11 to 0.43 kg ha^{-1} within at least 6 weeks after treatment (Wehtje et al., 2010).

The herbicide products used in this research were BroadStar 0.25G® (Anonymous, 2010) and SureGuard 51WDG® (Anonymous, 2009). Both herbicides have flumioxazin as the only active ingredient, but their formulations are different. BroadStar is granular formulation with 0.25% active ingredient. This product was first registered in 2003 for use in container and field grown woody shrubs, trees and groundcovers. This product typically provides 8-12 weeks of preemergence control. A new coating was added in 2009 to BroadStar® to prevent foliar damage from over-top application. Some growers have expressed dissatisfaction with the new formulation in terms of weed control. SureGuard is a water dispersible granular formulation containing 51% active ingredient, registered for directed application in container and field-grown conifers and deciduous trees. Recent research indicated that flumioxazin provided approximately 7 weeks of complete (100%) hairy bittercress control regardless of rate. No spurge control was evident after about 8 weeks in pine bark and sand substrate (Wehtje et al., 2012).

Most previous research concerning the effects of moisture in weed control was conducted in field studies, and the results differed among the herbicides evaluated. Pine bark both aged and fresh is the primary commercial substrate used for container production of nursery crops. It is available and economical. It offers an excellent balance of water retention and drainage; is relatively sanitary; and its light weight minimizes transportation cost (Davidson et al., 2000). However, little research has been conducted in soilless substrate to evaluate moisture level effect for preemergence weed control in nursery production.

Statement of Research Objective

Within the container nursery industry development, pine bark substrate and herbicides have been used to achieve higher plant quality. More studies are needed to help container growers manage substrate moisture in appropriate way. The objective of this study was to evaluate the influence of flumioxazin formulation, pre-application moisture and post-application irrigation on preemergence control of hairy bittercress and spotted spurge in pine bark substrate.

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Figure 1. Chemical structure of fluroxypyr

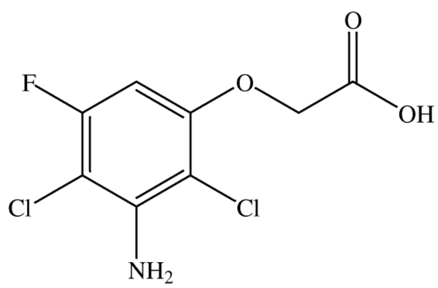
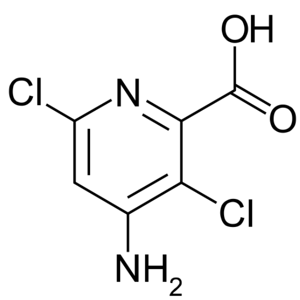


Figure 2. Chemical structure of aminopyralid.



Figurre 3. Chemical structure of metsulfuron.

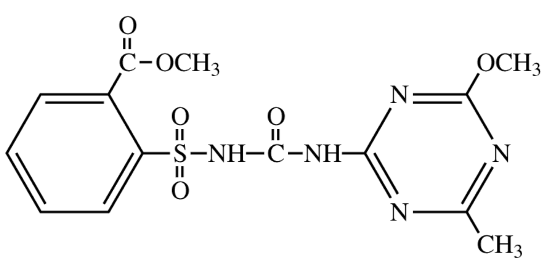
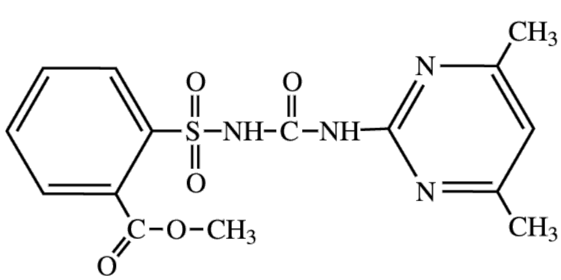


Figure 4. Chemical structure of sulfometuron.



Chapter II: Postemergence Control of English Ivy (*Hedera Helix* L.)

Abstract

English ivy (*Hedera helix* L.) has invaded most part of the United States, which was invited from Europe, Western Asia and Northern Africa. This species has excellent environmental adaptability, and it can grow as a ground cover and climb into tree canopy. More potential herbicides for English ivy control were registered in 2000's. Four experiments were conducted to evaluate English ivy response to old herbicides and potential postemergence herbicides in different season applications with a series of application rates. Results indicated English ivy had good tolerance to aminopyralid and fluroxypyr (Experiment I & II). Metsulfuron provided excellent control of English ivy when the rate was above 0.21 kg ha^{-1} in any application timing (Experiment II III & IV). Sulfometuron and tank mix of glyphosate and 2,4-D provided excellent control in summer application (experiment III), but not in spring application (Experiment IV). The old herbicides, i.e. glyphosate and 2,4-D, usually provided better control at the higher rates or higher temperature. The best control timing was obtained with summer application. Therefore, we assumed that higher temperatures perhaps reduce English ivy tolerance to the herbicides.

Nomenclature: glyphosate; 2,4-D; fluroxypyr; aminopyralid; metsulfuron; sulfometuron; English ivy, *Hedera helix* L.

Key words: timing, herbicides, English ivy

Introduction

English ivy (*Hedera helix* L.) is a native species in Europe, Western Asia and Northern Africa, which was introduced into North America by early settlers for commercial use purpose in the colonial era (Wyman, 1994; Randall, 1996). English ivy is an evergreen vine growing from full sun to deep shade (Gilman, 1999), which is widely used in ornamental landscape, and considered a good ground cover species in the Great Plains and Midwest (Beck, et al., 2008). However, many native species have been impacted by invasive species (Reichard and White, 2001). English ivy can grow well in acidic and basic soils (Reichard, 2000), and competes with many native plants for light, nutrition and soil and reduces animal feeding habitats (Morisawa, 1999). Additionally, English ivy vines aggressively climb up tree trunks (30 feet per year) and spread into the canopy, and may result in the host tree death in a few years (Soll, 2005). This species has invaded Southern, mid-Atlantic and Pacific Northwest forestry areas in the United States (Randall, 1996; Miller, 2007). From the report of USDA-NRCS (2002), English ivy is present in 28 states.

One method of English ivy control is goat browsing (Claudia and Micheal, 2010) with repetition of browsing for a second year providing effective control. Another method to control English ivy is to pull up the plant by hand (Biggerstaff and Christophen, 2007). This way was effective and environmentally safe for native species recovery. However, manual pulling costs were used from $2,000 to $8,000 per acre even at minimum wage (Soll, 2005). Volunteers were used to hand remove English ivy in forest parks in Oregon (Chaker, 2010). However, manual control may also cause soil surface erosion and other weed species invasion. Chemical control cost ranged $100-500 per acre assuming $25-100 per hour for operator cost and $50 per gallon for chemical (Soll, 2005). A study done in 1985 on glyphosate application on selected woody ornamentals showed glyphosate applied at 3.0 kg ha^{-1} in March caused 98% injury to English Ivy at 25 days after treatment; while June application caused 82% injury at 3.0 kg ha^{-1}; August to September application caused an average 55% of injury; but only 38% of injury was obtained in November application (Neal and Skroch, 1985). In 1998, Neal emphasized that the best control of English ivy was by applying 2 or 3% glyphosate (Roundup-Pro) in early spring. Derr applied 7 treatments in June, including glyphosate (Roundup) at 2.2 and 4.5 kg ha^{-1} with or without surfactant, 2,4-D amine at 1.1 kg ha^{-1}, dicamba (Banvel) at 0.6 kg ha^{-1}, and triclopyr (Garlon) at 0.6 kg ha^{-1}. Result shows that glyphosate applied at 4.5 kg ha^{-1} provided 81% control of fresh shoot weight, but only 58% control at the 2.2 kg ha^{-1} rate. Shoot fresh weights were similar with glyphosate (2.2 kg ha^{-1}), 2,4-D, dicamba and triclopyr. Glyphosate at 4.5 kg ha^{-1} rate with surfactant also controlled the old growth (Derr, 1993). Usually, glyphosate at higher rate and two applications were needed to control vines (Soll, 2005). On the other hand, Morisawa (1999) reported that an application of 25% solution of glyphosate provided good control after cutting stems, whereas triclopyr provided no control.

Recently new herbicides have been registered in 2000's. Fluroxypyr (Vista), which was registered on May 2, 2006 (Anonymous, 2006), has been labeled for broadleaf invasive plant management in pine plantations and non-crop sites. Aminopyralid (Milestone), which was registered on February 7, 2007 (Anonymous, 2007), belongs to the same chemical family as triclopyr and fluroxypyr: picolinic acid, and shared the same mode of action with 2,4-D: auxin-mimic. It is a newly available herbicide to land management for kudzu control. Metsulfuron (Escort), which was registered on October 4, 2001 (Anonymous, 2001), as a site preparation herbicide for conifer plantation, and is an effective herbicide recommended for kudzu (*Pueraria Montana* var. *lobata*) control (Weaver and Lyn, 2007). Sulfometuron (Oust) belongs to the same chemical group with Escort, which provides complete vegetation control. Because kudzu is an invasive broadleaf vine as well, it is possible that these herbicides have potential activity on English ivy control. The objective of this study was to evaluate new herbicides chemistry with glyphosate and 2,4-D for English ivy control at varied rates and in different seasons of the year.

Materials and Methods

This study was conducted at the Paterson Greenhouses Complex, Auburn, AL. Four experiments were included from 2010-2012. The substrate used was pine bark: sand (6:1 v:v) which had been previously amended with 8.3 kg m^{-3} (14 lb yd^{-3}) of 17N-2.2P-4.2K(17-5-11) Polyon® control-release fertilizer[1] (10 to 12 month), 3.0 kg m^{-3} (5 lb yd^{-3}) of ground dolomitic limestone, and 0.9 kg m^{-3} (1.5 lb yd^{-3}) of Micromax® micronutrient[2]. Each treatment included 5 replications, except Experiment IV (4 replications). A non-treated group was included in each experiment. Herbicides were applied as overhead foliar spray to English Ivy using an enclosed spray cabinet, which was calibrated to deliver at 30 GPA (gallons per A) with Teejet 8002vs flat fan nozzles. After herbicides were applied, all pots were randomized completely, and maintained under 40% shade cover. The irrigation system was cut off until 24 hours after application. Overhead irrigation provided 1.3 cm (0.5 in) daily. Plants visual injury was rated at 7, 15, 30 and 45 days after treatment, based on the scale 1 to 10, where 1 indicated no difference from non-treated control, and 10 indicated a dead plant. English ivies were cut back to about 5.1 cm (2 in) of stems after the final rating, and fresh shoots were weighted. Data of injury rating and fresh weight were subjected to ANOVA using the PROC GLM statement in SAS (SAS version 9.1)[3]. Means between and within different herbicides were separated using Duncan's multiple range test at P = 0.05.

Experiment I (Fall, 2010)

Liners of English ivy were potted on May 7, 2010, 2 plants in one trade gallon pot containing pine bark: sand (6: 1 v: v). Herbicides were applied on August 23, 2010 to actively growing English ivy. All pots were hand weeded before treatment. Applied herbicides included glyphosate[4] at 0.34, 0.60, 1.08, 1.70, 2.27 and 3.41 kg ha^{-1} (0.30, 0.53, 0.95, 1.50, 2.00 and 3.00 lb ae A^{-1}); 2,4-D[5] at 0.23, 0.40, 0.72, 1.14, 1.52 and 2.27 kg ha^{-1} (0.20, 0.35, 0.63, 1.0, 1.34 and 2.0lb ae A^{-1}); fluroxypyr[6] at 0.06, 0.10, 0.18, 0.28, 0.39 and 0.57 kg ha^{-1} (0.05, 0.09, 0.16, 0.25, 0.34 and 0.50 lb ae A^{-1}); and aminopyralid[7] at 0.028, 0.05, 0.09, 0.12, 0.19 and 0.28 kg ha^{-1} (0.025, 0.045, 0.08, 0.11, 0.17 and 0.25 lb ae A^{-1}). Plant visual injury was rated by two researchers at 7 (Aug 30), 15 (Sep 7), 30 (Sep 23) and 45 (Oct 8) days after treatment. Fresh shoot weights were recorded at 52 days (Oct 15) after treatment.

Experiment II (Spring, 2011)

A similar experiment was conducted on March 31, 2011. Liners of English ivy were potted on July 21, 2010. The two lowest rates of each herbicide in Experiment I were removed, and two higher rates were added. An additional herbicide, metsulfuron, was also evaluated in this experiment. Applied herbicides included glyphosate at 1.08, 1.70, 2.27, 3.41, 5.45 and 8.63 kg ha^{-1} (0.95, 1.5, 2.0, 3.0, 4.8 and 7.6 lb ae A^{-1}); 2,4-D at 0.72, 1.14, 1.52, 2.27, 3.64 and 5.68 kg ha^{-1} (0.63, 1.0, 1.34, 2.0, 3.2 and 5.0 lb ae A^{-1}); fluroxypyr at 0.18, 0.28, 0.39, 0.57, 0.91 and 1.36 kg ha^{-1} (0.16, 0.25, 0.34, 0.50, 0.80 and 1.20 lb ae A^{-1}); aminopyralid at 0.09, 0.12, 0.19, 0.28, 0.45 and 0.71 kg ha^{-1} (0.08, 0.11, 0.17, 0.25, 0.40 and 0.63 lb ae A^{-1}); metsulfuron[8] at 0.04, 0.07, 0.14, 0.21, 0.28 and 0.35 kg ha^{-1} (0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 oz ae A^{-1}). Plant control was rated at 14 (Apr 14), 28 (Apr 28) and 42 (May 12) days after treatment. Fresh shoot weights were recorded after the last rating (May 12).

Experiment III (Summer, 2011)

Another similar experiment was conducted on June 9, 2011. Liners of English ivy were potted on July 16, 2010. Both Vista and Milestone were removed because of low efficacy in the previous experiment. Applied herbicides included glyphosate 1.08, 1.70, 2.27, 3.41, 5.45 and 8.63 kg ha^{-1} (0.95, 1.5, 2.0, 3.0, 4.8 and 7.6 lb ae A^{-1}); 2,4-D at 0.72, 1.14, 1.52, 2.27, 3.64 and 5.68 kg ha^{-1} (0.63, 1.0, 1.34, 2.0, 3.2 and 5.0 lb ae A^{-1}); metsulfuron at 0.02, 0.04, 0.07, 0.14, 0.21, 0.28 and 0.35 kg ha^{-1} (0.2, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 oz ae A^{-1}); sulfometuron[9] at 0.04, 0.07 and 0.14 kg ha^{-1} (0.5, 1.0 and 2.0 oz ae A^{-1}); tank mix of glyphosate + 2,4-D at 2.27 + 1.52 and 3.41 + 2.27 kg ha^{-1} (2.0 + 1.34 and 3.0 + 2.0 lb ae A^{-1}). Plant injury was rated at 7 (Jun 16), 15 (Jun 24), 32 (Jul 11) and 45 (Jul 25) days after treatment. Fresh shoot weights were recorded after the last rating (Jul 25).

Experiment IV (Spring, 2012)

English ivy cuttings were propagated on July 6, 2011. Liners were transplanted to full gallon pots with one cutting per pot on September 21, 2011. The same treatments as Experiment III were applied on March 27, 2012. Plant control was rated at 15 (Apr 11), 30 (Apr 27) and 45 (May 11) days after treatment. Fresh shoot weights were recorded at the day after the last rating (May 12).

Results and Discussion

Experiment I: Examination of the herbicides means revealed that glyphosate and 2,4-D were the more effective herbicides for English ivy control (Table 1). Both fluroxypyr and aminopyralid were ineffective. The highest rate of glyphosate evaluated (3.41 kg ha^{-1}) was the most effective. However, this rate did not provide complete control. Control ratings with glyphosate at 3.41 kg ha^{-1} did not exceed 5.6 (45 DAT), and fresh weight reduction was only 78%. Glyphosate rates below 3.41 kg ha^{-1} were progressively less effective. Neal and Skroch (1985) reported glyphosate at 3.41 kg ha^{-1} caused an average of 55% injury from August to September. Maximum effectiveness with 2,4-D was obtained with 2.27 and 1.52 kg $ha^{-1.}$ However, these treatments also did not provide complete control. No control rating with 2,4-D exceeded 5.2, and fresh weight of this treatment at the highest rate (1.52 kg ha^{-1}) was only 61%. Rates below 1.52 kg ha^{-1} were progressively less effective.

In experiment I, glyphosate at 3.41 kg ha^{-1} provided the highest final control rating (5.6) and fresh weight reduction (78%). However, none of treatments controlled English ivy to the level desired (control rating above 8).

Experiment II: Examination of the herbicides means revealed that metsulfuron was the single most effective herbicide for English icy control (Table 2). This was followed by glyphosate, which was approximately equal in efficacy. Treatments with fluroxypyr, 2,4-D and aminopyralid were ineffective. The highest rate of metsulfuron evaluated (0.35 kg ha^{-1}) was the most effective. Control ratings with metsulfuron at rate above 0.21 kg ha^{-1} exceeded 9.0 at 42 DAT, and the highest fresh weight reduction (92%) was obtained by the highest rate. Metsulfuron at 0.21, 0.28 and 0.35 kg ha^{-1} almost completely controlled English ivy, i.e. ≥ 87%. Metsulfuron rates below 0.35 kg ha^{-1} were progressively less effective. Maximum efficacy with glyphosate was obtained with 8.63 kg ha^{-1}. However, treatments with glyphosate did not provide excellent control. Control rating with glyphosate at 8.63 kg ha^{-1} did not exceed 5.6, which is same with glyphosate at 3.42 kg ha^{-1} in experiment I, and fresh weight reduction was only 63%. Rates below 8.63 kg ha^{-1} were progressively less effective. However, glyphosate was reported to provide best control (98% at 0.41 kg ha^{-1}) with a March application (Neal and Skroch, 1985).

In experiment II, metsulfuron above 0.21 kg ha^{-1} provided ≥87% control of English ivy. Glyphosate was also effective, but did not provide excellent control. Fluroxypyr, 2,4-D and aminopyralid were not effective on English ivy in this application, and rate did not affect the results.

Experiment III: In this experiment, examination of the herbicides means revealed that metsulfuron, sulfometuron and 2,4-D were most effective, and followed by glyphosate for English ivy control (Table 3). Most English ivy plants in this experiment, except glyphosate below 1.70 kg ha^{-1}, were completely controlled. Rate did not influence metsulfuron and glyphosate rates below 2.27 kg ha^{-1} were progressively less effective. Derr (1993) reported glyphosate applied at 4.5 kg ha^{-1} provided 81% control of fresh shoot, and only 58% control provided by glyphosate at 2.2 kg ha^{-1} and 2,4-D at 1.1 kg ha^{-1} in June application. Another study reported June application of glyphosate caused 82% injury of English ivy (Neal and Skroch, 1985). Meanwhile, tank mix of glyphosate and 2,4-D at low and high combinations also provided excellent control of English ivy in June application. All herbicides evaluated in this experiment controlled English ivy to the level desired.

In experiment III all rates of metsulfuron, sulfometuron and 2,4-D provided excellent control of English ivy. Glyphosate at 2.27, 3.41, 5.45 and 8.63 kg ha^{-1} also provided effective and desired control level (control rating above 8). Results of all herbicides in this experiment were more effective than results reported previously (Derr, 1993; Neal and Skroch, 1985).

Experiment IV: Examination of the herbicides means revealed that metsulfuron was the most effective herbicide for English ivy control (Table 4). This was followed by glyphosate, 2,4-D and sulfometuron. Control ratings with metsulfuron at rates above 0.07 kg ha^{-1} ranged from 8.1 to 10.0 at 46 DAT, and provided about 90% fresh weight reduction. The maximum effectiveness in each herbicide was obtained with the highest rate of glyphosate (5.6 control rating, 82% fresh weight reduction), 2,4-D (7.5 control rating, 82% fresh weight reduction) and sulfometuron (5.9 control rating, 76% fresh weight reduction). However, these rates did not provide excellent control of English ivy. Control was progressively less effective with glyphosate, 2,4-D and sulfometuron. Tank mix of glyphosate and 2,4-D did not further improve English ivy control.

In experiment IV, metsulfuron at 0.21, 0.28 and 0.35 kg ha^{-1} provided excellent control of English ivy. The other rate of sulfometuron, 2,4-D and glyphosate at higher rates were also effective, but did not reach the level desired.

In summary, metsulfuron provided nearly 100% control of English ivy when the rates were above 0.21 kg ha^{-1} at any application timing. English ivy was not controlled by aminopyralid and fluroxypyr. Sulfometuron provided excellent control with a summer application, but not excellent in spring. Glyphosate and 2,4-D usually provided higher control at the higher rates. However, the best control was obtained with summer application. 2,4-D provided better control in experiment IV (spring, 2012) than in experiment II (spring, 2011). In Alabama, spring 2012 was warmer than spring 2011. Therefore, we speculated that higher temperature perhaps reduces English ivy tolerance to the herbicides.

Sources of Materials

[1] Granular, slow-release fertilizer, Polyon® 17N-5P-11K, Harrell's Fertilizer, Inc., 203 West 4th Street, Sylacauga, AL 35105

[2] Micronutrient fertilizer, Micromax®, O. M. Scotts Crop, 14111 Scotts Lawn Road, Marysville, OH 43401.

[3] SAS® Statistical Analysis System software, Release 9.1, SAS Institute, Inc., Box 8000, SAS Circle, NC 27513.

[4] Isopropylamine salt of glyphosate, 0.480 kg ai L^{-1} or 0.356 kg ai L^{-1}, Roundup Pro®, Monsanta Company, 800 N Lindbergh Boulevard, St. Louis, MO 63167.

[5] 2,4-D Amine 4. Agriliance, St. Paul, MN 55164. EPA Reg. No. 1381-103.

[6] Fluroxypyr, Vista®, Dow AgroSciences LLC, Indianapolis, IN 46268.

[7] Aminopyralid, Milestone®, Dow AgroScience, Indianapolis, IN 46268.

[8] Metsulfuron, Escort®, E. I. du Pont de Nemours and Company, 1007 Market Street, Wilmington, DE 18989.

[9] Sulfometuron, Oust®, E. I. du Pont de Nemours and Company, 1007 Market Street, Wilmington, DE 18989.

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Table 1. Efficacy of selected post-applied treatments for English ivy control: experiment I (August 23, 2010).

Treatment		Control rate[1, 2]		Fresh weight[3]	
Herbicide	Rate (kg ha^{-1})	15DAT	45DAT	g pot^{-1}	Reduction (%)
glyphosate	0.34	2.6c	1.0c	69.9c	0c
	0.60	2.8c	1.0c	60.4c	11c
	1.08	3.0c	1.8c	36.4b	46b
	1.70	3.4bc	3.6b	33.2ab	51ab
	2.27	4.2ab	4.2b	19.4ab	71ab
	3.41	4.6a	5.6a	14.9a	78a
	Mean	3.4A	2.9A	39.0A	42A
2,4-D	0.23	1.0c	1.0c	47.9b	29b
	0.40	2.0ab	1.0c	44.0b	35b
	0.72	1.4bc	2.4b	36.5ab	47ab
	1.14	2.2ab	3.2b	35.7ab	46ab
	1.52	2.6a	5.0a	26.4a	61a
	2.27	2.4ab	5.2a	27.7a	59a
	Mean	1.9B	3.0A	36.4A	46A
fluroxypyr	0.06	1.6b	1.0b	67.9c	0c
	0.10	1.6b	1.0b	54.9abc	19abc
	0.18	1.6b	1.0b	61.8bc	9bc
	0.28	2.6ab	1.0b	71.7c	0c
	0.36	2.2ab	1.0b	45.5ab	33ab
	0.57	3.0a	2.0a	37.2a	45a
	Mean	2.1B	1.2B	57.7B	17B
aminopyralid	0.03	1.8a	1.8a	54.5a	20a
	0.05	2.0a	1.0a	58.3a	14a
	0.09	2.0a	1.6a	57.3a	15a
	0.12	1.0a	1.0a	45.1a	34a
	0.19	2.0a	1.2a	49.0a	28a
	0.28	2.0a	1.6a	50.9a	25a
	Mean	1.8B	1.3B	52.2B	23B
Additional treatment:					
Non-treated		1.0	1.0	67.7	0
$LSD_{0.05}$		0.9[4]	0.8	18.3	26

[1] Rating scale: 1 = no control and 10 = death.

[2] Treatment means within a column of an individual herbicide that are followed by the same lower case letter are statistical equivalent according to Duncan's multiple range test (p = 0.05). Herbicide means within a common column and followed by the same upper case letter are also equivalent according to the same test.

[3] Treated plant foliar weight was determined 52 days after treatment. Reduction is relative to the non-treated.

[4] $LSD_{0.05}$ value is for the comparison on any two treatment means within a common column.

Table 2. Efficacy of selected post-applied treatments for English ivy control: experiment II (March 31, 2011).

Treatment		Control rate[1, 2]		Fresh weight[3]	
Herbicide	Rate (kg ha^{-1})	15DAT	42DAT	g pot^{-1}	Reduction (%)
glyphosate	1.08	3.7c	1.3d	71.8c	24c
	1.70	4.6b	2.1c	59.7bc	37bc
	2.27	5.1b	4.1b	32.0a	66a
	3.41	6.3a	3.6b	39.9ab	58ab
	5.45	5.4b	4.1b	38.2ab	59ab
	8.63	5.5ab	5.6a	35.3a	63a
	Mean	5.1A	3.5B	46.2B	51B
2,4-D	0.72	2.1b	1.8c	89.3a	5a
	1.14	2.3b	2.2abc	78.6a	17a
	1.52	2.2b	2.0bc	84.8a	10a
	2.27	3.0b	2.6abc	71.2a	24a
	3.64	3.2ab	2.8ab	83.9a	11a
	5.68	3.4a	3.1a	70.8a	25a
	Mean	2.7B	2.4C	79.8CD	15CD
fluroxypyr	0.18	1.8b	1.0c	99.9a	0a
	0.28	2.3ab	1.4bc	98.0a	0a
	0.36	2.3ab	1.7b	86.8a	8a
	0.57	2.1ab	1.4bc	108.1a	0a
	0.91	2.3ab	1.9b	75.5a	20a
	1.36	3.0a	2.7a	70.3a	25a
	Mean	2.3BC	1.7C	89.8D	5D
aminopyralid	0.09	2.0a	1.0b	73.0a	23a
	0.12	1.4a	1.5ab	77.1a	18a
	0.19	1.9a	1.7ab	64.6a	31a
	0.28	2.2a	2.0ab	73.3a	22a
	0.45	2.7a	2.6a	66.5a	29a
	0.71	2.1a	2.6a	64.6a	31a
	Mean	2.1CD	1.9C	52.2C	26C
metsulfuron	0.04	1.7a	2.7c	40.8c	57c
	0.07	2.0a	6.5b	22.2b	76b
	0.14	1.5a	7.4b	22.6b	76b
	0.21	1.7a	9.1a	12.6ab	87ab
	0.28	2.1a	9.3a	11.8ab	88ab
	0.35	1.6a	9.5a	7.8a	92a
	Mean	1.8D	7.4A	19.7A	79A
Additional treatment:					
Non-treated		1.0	1.0	94.2	0
$LSD_{0.05}$		0.9[4]	0.8	32.2	34

[1] Rating scale: 1 = no control and 10 = death.

[2] Treatment means within a column of an individual herbicide that are followed by the same lower case letter are statistical equivalent according to Duncan's multiple range test ($p = 0.05$). Herbicide means within a common column and followed by the same upper case letter are also equivalent according to the same test.
[3] Treated plant foliar weight was determined 42 days after treatment. Reduction is relative to the non-treated.
[4] $LSD_{0.05}$ value is for the comparison on any two treatment means within a common column.

Table 3. Efficacy of selected post-applied treatments for English ivy control: experiment III (June 9, 2011).

Treatment		Control rate[1, 2]		Fresh weight[3]	
Herbicide	Rate (kg ha^{-1})	15DAT	45DAT	g pot^{-1}	Reduction (%)
glyphosate	1.08	2.1a	4.9c	41.3b	30b
	1.70	3.0a	7.7ab	22.6ab	62ab
	2.27	2.5a	9.6ab	15.7a	73a
	3.41	3.1a	9.6ab	14.6a	75a
	5.45	2.5a	9.0b	24.4ab	58ab
	8.63	2.9a	9.8a	10.5a	82a
	Mean	2.7B	8.4B	21.5B	63B
2,4-D	0.72	2.7a	8.6a	18.7a	68a
	1.14	2.9a	9.9a	10.0a	83a
	1.52	2.9a	10.0a	6.7a	89a
	2.27	3.7a	9.7a	8.8a	85a
	3.64	3.9a	10.0a	6.7a	89a
	5.68	3.5a	9.9a	7.6a	87a
	Mean	3.3AB	9.7A	9.8A	83A
metsulfuron	0.02	2.7bc	9.4a	12.9a	78a
	0.04	2.1c	9.5a	10.1a	83a
	0.07	2.6bc	9.9a	10.5a	82a
	0.14	2.6bc	10.0a	9.2a	84a
	0.21	4.5a	10.0a	6.6a	89a
	0.28	3.8ab	10.0a	8.1a	86a
	0.35	3.0bc	10.0a	10.6a	82a
	Mean	3.0AB	9.8A	9.7A	83A
sulfometuron	0.04	3.4a	10.0a	6.4a	89a
	0.07	2.8a	10.0a	9.9a	83a
	0.14	4.3a	10.0a	7.0a	88a
	Mean	3.4A	10.0A	8.0A	86A
Additional treatment:					
gly. + 2,4-D	2.27 + 1.52	3.5	9.8	9.1	84
gly. + 2,4-D	3.41 + 2.27	4.4	10	6.6	89
Non-treated		1.0	1.0	94.2	0
$LSD_{0.05}$		1.2[4]	1.3	15.4	26

[1] Rating scale: 1 = no control and 10 = death.

[2] Treatment means within a column of an individual herbicide that are followed by the same lower case letter are statistical equivalent according to Duncan's multiple range test (p = 0.05). Herbicide means within a common column and followed by the same upper case letter are also equivalent according to the same test.

[3] Treated plant foliar weight was determined 45 days after treatment. Reduction is relative to the non-treated.

[4] $LSD_{0.05}$ value is for the comparison on any two treatment means within a common column.

Table 4. Efficacy of selected post-applied treatments for English ivy control: experiment IV (March 27, 2012).

Treatment		Control rate		Fresh weight[3]	
Herbicide	Rate (kg ha^{-1})	15DAT	46DAT	g pot^{-1}	Reduction (%)
glyphosate	1.08	1.8b4	1.8b	92.3c	34c
	1.70	1.8b	2.0b	57.8b	59b
	2.27	2.1b	2.9b	39.3ab	72ab
	3.41	3.5a	4.4a	33.0a	76a
	5.45	3.5a	5.4a	30.8a	78a
	8.63	3.8a	5.6a	24.6a	82a
	Mean	2.7A	3.7B	46.3A	67B
2,4-D	0.72	1.5b	2.6e	75.9a	46a
	1.14	1.5b	2.8e	77.6a	45a
	1.52	1.9ab	3.6d	68.7a	51a
	2.27	1.9ab	4.9c	62.7a	55a
	3.64	2.0ab	5.9b	60.5a	57a
	5.68	2.3a	7.5a	24.8a	82a
	Mean	1.8B	4.5B	61.7B	56B
metsulfuron	0.02	1.4ab	2.6b	59.3b	58b
	0.04	1.3b	4.3b	49.3b	65b
	0.07	1.3b	8.1a	15.8a	89a
	0.14	1.5ab	9.6a	15.8a	89a
	0.21	1.8ab	9.6a	12.8a	91a
	0.28	1.9a	10.0a	13.1a	91a
	0.35	1.6ab	10.0a	14.5a	90a
	Mean	1.5BC	7.8A	25.8A	82A
sulfometuron	0.04	1.3a	2.0a	84.7b	40b
	0.07	1.4a	2.4a	65.7ab	53ab
	0.14	1.3a	5.9a	34.3a	76a
	Mean	3.4A	3.4B	61.6B	56B
Additional treatment:					
gly. + 2,4-D	2.27 + 1.52	2.1	3.6	50.3	64
gly. + 2,4-D	3.41 + 2.27	2.6	5.0	44.9	68
Non-treated		1.0	1.0	140.3	0
$LSD_{0.05}$		0.6[4]	1.9	30.1	21

[1] Rating scale: 1 = no control and 10 = death.

[2] Treatment means within a column of an individual herbicide that are followed by the same lower case letter are statistical equivalent according to Duncan's multiple range test (p = 0.05). Herbicide means within a common column and followed by the same upper case letter are also equivalent according to the same test.

[3] Treated plant foliar weight was determined 46 days after treatment. Reduction is relative to the non-treated.

[4] $LSD_{0.05}$ value is for the comparison on any two treatment means within a common column.

Chapter III: Effect of Pre and Post Moisture Level and Formulation on Preemergence Control of Hairy Bittercress (*Cardamine hirsuta* L.) with Flumioxazin

Abstract

Moisture is an important component to activate preemergence herbicides; however, this aspect had not been investigated in soilless substrate. The objective of this study was to evaluate the influence of pre-application moisture levels and post-application irrigation levels in the preemergence control of hairy bittercress with flumioxazin in a pine bark substrate. Three similar experiments were conducted. Treatments were a factorial arrangement: three pre-application moisture levels (dry, medium and wet), two flumioxazin formulations (granular and spray), two flumioxazin rates [0.28 kg ha^{-1} and 0.42 kg ha^{-1} (0.25 and 0.375 lb ai A^{-1})] and four levels of single-event, post-application irrigation [0.6, 1.3, 2.5 and 5.1 cm (0.25, 0.50, 1.00 and 2.00 in)]. Treated pots were overseeded with 25 hairy bittercress at 1 week after herbicide application. Weed germination was counted weekly, and shoot fresh weights were taken after the last weed count. Results showed the spray formulation provided maximum reduction in weed counts up to 12 weeks after application, regardless of rate, pre-moisture level or post-irrigation level. Conversely, the granular formulation was less effective and the higher rate generally provided better hairy bittercress control than lower rate. Pre-application moisture did not affect the flumioxazin efficacy. The efficacy of granular formulation tended to be improved by the higher levels of the post-application irrigation in cooler season.

Index word: container substrate, irrigation

Species used in this study: hairy bittercress (*Cardamine hirsuta* L.).

Chemical used in this study: flumioxazin (BroadStar®, SureGuard®).

Significance to the Nursery Industry

For preemergence control, moisture is important to activate and transfer herbicides into the substrate. Growers are generally instructed to apply irrigation after application of preemergence herbicides. However, little or no research has been conducted in soilless substrates evaluating effects of moisture levels. More data is needed to guide growers about how to best manage moisture levels for the best weed control. Therefore, this research evaluated the effects of pre-application moisture levels, post-application irrigation levels and flumioxazin rates in two different formulations: granular - BroadStar 0.25G® and spray - SureGuard 51WDG® on preemergence control of hairy bittercress. Pre-moisture level of the substrate had no effect on flumioxazin efficacy. SureGuard provided excellent control of hairy bittercress regardless of post-application irrigation level and rate. BroadStar needed both higher rate and irrigation to remove the coating on the new formulation.

Introduction

Weed control is one of the biggest problems for nursery managers. With increasing labor cost, hand-weeding cost is becoming more and more expensive. Research reported that hand weeding 1,000 pots cost as much as $1,376 over a four-month period based on the minimum wage ($5.15) in the 1990's (Darden and Neal, 1999), which had increased to $1,937 based on the minimum wage in 2011 ($7.25). Growers are becoming increasingly aware of labor saved by the application of preemergence herbicide, and typically make 3-6 preemergence herbicides applications annually (Gilliam, et al., 1990). Hairy bittercress (*Cardamine hirsuta* L.) is one of top 10 noxious weeds in Southeast container nursery (Ryan, 1977). It is an annual broadleaf (dicot) weed, emerging from early spring to the end of fall. Each seed pod can produce 20 to 50 seeds, and 600 to 5,000 seeds can be produced by one plant.

Soil moisture is an important factor affecting the absorption of herbicides by germinating weeds (Menges, 1963), because water can dissolve granular herbicides, move the herbicides into substrate to enhance herbicide-substrate contact and allow herbicides to contact the roots of target weed plants. Previous research in 1960's showed irrigation volume affected effectiveness of preemergence herbicides with different ingredients and volatility (Knate, et al., 1967). As pointed out by Audus (1964), the relationship between soil moisture and absorption of herbicides into the soil exchange complex may affect the availability of herbicides for uptake by the plant. Other research with diuron on cotton (*Gossypium hirsutum* L.) showed that diuron was more effective under high post-moisture conditions than under low moisture condition (Upchurch, 1957). In a study on foxtail control with 25, 31 and 37% soil moisture (Stickler, et al., 1969), the effectiveness of atrazine and EPTC (ethyl N, N-dipropylthiocarbamate) increased with increasing soil moisture. In a more recent study, research indicated that 5.1 cm preplant irrigation with pronamide reduced weed density compared with the no preplant irrigation (Shem-tov, et al., 2006).

Flumioxazin inhibits protoporphyrinogen oxidase, which is an enzyme involved in chlorophyll synthesis (Scalla and Matringe, 1994). Flumioxazin is absorbed by both roots and foliage of targeted weeds and has both preemergence and postemergence activity, but it is used predominately for preemergence and absorbed by roots (Kelly, et al., 2006). Flumioxazin is reported to safely control many broadleaf weed species when applied as a preemergence in many crops (Cranmer, et al., 2000). A study in 2010 reported that 90% hairy bittercress control can be obtained by 0.37 kg ha^{-1} of flumioxazin applied alone in container substrate (Wehtje, et al., 2010). The herbicide products used in this research were BroadStar 0.25G® (Anonymous, 2010) and SureGuard 51WDG® (Anonymous, 2009). Both herbicides have flumioxazin as the only active ingredient, but the formulation is different. BroadStar is granular formulation with 0.25% active ingredient. This product was first registered in 2003 for use in container and field grown woody shrubs, trees and groundcovers, and provides 8 to 12 weeks of preemergence control. In 2009 a new coating was added to BroadStar to prevent foliar damage from over-top application. Some growers have expressed issues with the new formulation. SureGuard is a water dispersible granular formulation containing 51% active ingredient. This product was registered for directed application in container and field grown conifers and deciduous trees.

Most previous research about the effect of moisture in weed control was conducted in field studies, and the results differed among different herbicides. Pine bark is the primary substrate used for container production of nursery crops and little research has been conducted looking at moisture levels for preemergence weed control in nursery production. The objective of this study was to evaluate the influence of flumioxazin formulation, pre-application moisture and post-application irrigation on preemergence control of hairy bittercress in container substrate.

Materials and Methods

Experiment 1.

On 25 February 2011, trade gallon pots were filled with pine bark and sand (6:1, volume:volume) substrate previously mixed with 9.3 kg m^{-3} (15 lb yd^{-3}) of Polyon® (17-5-11) control-released (7-8 months) fertilizer, 3.1 kg m^{-3} (5 lb yd^{-3}) of dolomitic limestone and 0.9 kg m^{-3} (1.5 lb yd^{-3}) Micromax. Pots were separated into three moisture levels, i.e. low, medium, and high. Container weights and container metric water contents for each moisture level were measured with 10 samples for each moisture level before herbicides were applied. A Decagon® Soil Moisture Sensor was used to measure volumetric water content (VWC). For low moisture, no water was applied 4 days before treatment; average pot weight was 1.58 kg, and water content was 16%. For medium, no water was applied 1 day before treatment; average pot weight was 1.73 kg, and water content was 20%. For high, pots were watered to saturation imsubstratetely before treatment; average pot weight was 1.88 kg, and water content was 27%. Flumioxazin treatments were applied on 1 March 2011. Treatments included BroadStar 0.25G at 0.28 and 0.42 kg ha^{-1} (0.250 and 0.375 lb ai A^{-1}) and SureGuard 51WDG at 0.28 and 0.42 kg ha^{-1} (0.250 and 0.375 lb ai A^{-1}). BroadStar was applied with a hand-shaker. SureGuard was applied by an enclosed-cabinet sprayer, which had been calibrated to deliver at 30 GPA (gallon per acre) with a Teejet 8002 flat fan nozzle.

This experiment was conducted as a factorial treatment arrangement: three pre-application moisture levels (dry, medium and wet), two flumioxazin formulations (granular and spray), two flumioxazin rates (0.28 and 0.42 kg $ha^{-}1$) and four post-application irrigation levels (0.6, 1.3, 2.5 and 5.1 cm). With additional non-treated control, there were 49 treatments in total. Each treatment was replicated six times. A completely random experimental design was observed. After herbicides application (7 March 2011) and 1 day after completion of the single-event irrigation, a 0.5 in/day irrigation schedule was started. This schedule was maintained for the duration of the experiment. Pots were seeded with 25 hairy bittercress seeds 1 week after completion of the single-event irrigation. Number of hairy bittercress seedlings was counted weekly for 10 weeks after seeding. Hairy bittercress fresh weight was collected at 10 weeks after seeding (10 May 2011).

Data were subjected to analysis of variance which reflected the factorial treatment arrangement. Data were pooled over non-significant experimental variables. Treatment means for experimental variables that were significant as either main effect, or as two-way interactions were separated by Duncan's multiple range test at the 0.05 level.

Experiment 2.

Experiment 2 was a repeat of experiment 1. Pots were filled 1 April 2011. Container weights and container metric water content were as follows: low moisture -1.54 kg and 16%, medium moisture - 1.63 kg and 22%, high moisture - 1.71 kg and 30%. Herbicides treatments were applied 7 April 2011. Pots were overseeded 14 April 2011. Because the weather warmed in May, fresh weight was collected 8 weeks after seeding (10 June 2011).

Experiment 3.

Experiment 3 was also a repeat of Experiment 1. Pots were filled 5 December 2011. Container weights and container metric water content were as follows: low moisture - 1.29 kg and 19%, medium moisture - 1.35 kg and 23%, high moisture - 1.47 kg and 27%. Herbicides treatments were applied 8 December 2011. Pots were overseeded 15 December 2011. Pots were maintained outside until 31 December 2011, at which time pots were moved into a greenhouse to prevent forest damage. Hairy bittercress fresh weight was collected 11 weeks after seeding (01 March 2012).

Results and Discussion

Experiment 1. March 2011

Weed counts were consistently influenced only by the main effect of formulation (Table 5). Conversely, weed counts were not influenced by the main effects of rate, pre-application moisture and post-application irrigation. Bittercress fresh weight was also only influenced by the main effect of formulation. Only the two-way interaction of formulation and post-irrigation were significant at 2 and 10 weeks after seeding (WAS). Consequently, data were pooled over formulation and post-irrigation variable for further analysis (Table 6).

Between the two formulations, weed counts with the spray formulation was consistently and significantly lower than with the granular formulation. The spray formulation obtained higher (99.9%) average fresh weight control than the granular (94.3%). Within the spray formulation, irrigation consistently had no effect on both weed counts and fresh weight, since almost no hairy bittercress emergence was observed. All spray formulation treatments achieved about 100.0% control regardless of herbicides rate, pre-application moisture and post-irrigation level. Within granular formulation, irrigation at 0.6 cm was less effective than the higher irrigation levels at 2 WAS. At 6 and 10 WAS, irrigation at 0.6 cm and 5.1 cm had higher weed counts, but the results were not significantly different from irrigation at 0.50 and 1.00 in. For fresh weights, irrigation at 0.6 cm provided 92% control of bittercress, which was similar to irrigation at 5.1 cm (91%).

Irrigation at 1.3 and 2.5 cm both provided 97% control; therefore, the irrigation treatments at 0.6 and 5.1 cm were less effective than irrigation at 1.3 and 2.5 cm.

Experiment 2. April 2011

Weed counts were consistently influenced by the main effect of formulation (Table 7). The main effect of rate was also frequently significant (i.e. 5 and 8 WAS). Conversely, the main effect of pre-moisture and post-irrigation consistently did not influence counts. Only the two-way interaction of formulation and rate significantly influenced counts frequently (i.e. 5 and 8 WAS). Fresh weight was influenced by the main effects of both formulation and rate, and by the two-way interaction of formulation and rate. Consequently, data were pooled over pre-moisture level and post-irrigation level for future analysis.

Examination of the formulation and rate variables (Table 8) revealed that between the two formulations, counts were significantly lower with the spray. All spray treatments achieved almost 100% control regardless of rate. With the granular formulation, the 0.42 kg ha^{-1} was more effective in reducing both counts and fresh weight than the 0.28 kg ha^{-1} rate.

Experiment 3. December 2011

Weed counts were consistently influenced by the main effect of formulation, which was the same as the prior two experiments (Table 9). The main effects of rate and irrigation also affected weed counts, but not consistently. Conversely, the main effect of pre-moisture consistently did not influence either weed counts or fresh weight. The two-way interactions of formulation by rate, formulation by post-irrigation and rate by post-irrigation were frequently, but not consistently significant. The two-way interactions including pre-moisture were never significant. Fresh weight was only influenced by the main effect of formulation and rate, and the two-way interaction of formulation and rate, which result was similar with the second experiment. Therefore, data were pooled so as to examine the effects of the formulation, rate, and irrigation variables (Table 10).

Within the spray formulation treatments, 100% hairy bittercress control was obtained, regardless of the herbicide rate and the post-irrigation level. Conversely, within granular formulation, rate had an effect. Treatments with higher rate consistently had lower weed counts and fresh weights than treatments with lower rate, but weed counts were still significantly higher than spray formulation. Post-irrigation did not affect granular formulation at 0.28 kg ha^{-1}. For granular formulation at higher rate, post-irrigation at 0.6 cm had higher weed counts than the other irrigation levels after 2 WAS (i.e. 6 and 11 WAS). Fresh weight was decreased when irrigation increased, and fresh weight present control was increasing (Figure 5). Irrigation at 5.1cm (77.5%) obtained significantly higher hairy bittercress fresh weight control than irrigation at 0.6 cm (63.5%).

In summary, the spray formulation provided maximum reduction of weed counts, regardless of rate, pre-moisture level or post-irrigation level. Conversely, the granular formulation was less effective, and flumioxazin at 0.42 kg ha^{-1} generally provided better hairy bittercress control than flumioxazin at 0.28 kg ha^{-1}. Pre-application moisture at dry, medium and wet level did not affect the flumioxazin efficacy in either treatment. The efficacy of granular formulation tended to be improved by additional post-irrigation in cooler season (i.e. experiment 1 & 3). We speculated that the new coating of BroadStar tended to be removed faster during summer (April 2011).

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Table 5. Response of hairy bittercress (*Cardamine hirsuta* L.) to the main effects of all experimental variables and their two-way interactions [z]. (Experiment 1)

	Weed counts /pot (WAS[y])			
Source of variation	2	6	10	F.W.[x]
Main effects	----------------------------probability----------------------------			
Formulation (form.)	<0.01	<0.01	<0.01	<0.01
Rate	0.58	0.34	0.34	0.08
Moisture (moist.)	1.00	0.09	0.06	0.29
Irrigation (irrig.)	0.06	0.76	0.87	0.43
Two-way interactions				
form. x rate	0.58	0.47	0.46	0.12
form. x moist.	0.52	0.58	0.81	0.24
form. x irrig.	0.05	0.06	0.04	0.33
rate x moist.	0.63	0.58	0.90	0.26
rate x irrig.	1.00	0.73	0.62	0.44

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

[y] WAS=weeks after seeding. Additional counts were taken at 1, 3, 4, 5, 7, 8 and 9 WAS. However, results were equivalent to the data presented.

[x] F.W.=fresh weight of bittercress at 10 WAS.

Table 6. Response of hairy bittercress (*Cardamine hirsuta* L.) to the interaction of formulation and post-irrigation ^{z}. (Experiment 1)

Experimental variables		Weed counts (WAS^{y})			F.W.^{x}(g/pot)
Fomulation	Irrigation (cm)	2	6	10	(% control^{u})
spray^{w}	0.6	0.0a^{v}	0.0a	0.0a	0.0 (100.0)a
spray	1.3	0.0a	0.0a	0.0a	0.0 (100.0)a
spray	2.5	0.0a	0.3a	0.3a	0.6 (99.5)a
spray	5.1	0.0a	0.0a	0.0a	0.0 (100.0)a
	Mean	0.0A	0.0A	0.0A	0.2 (99.9)A
gran.	0.6	0.8a	0.4a	0.5a	8.6 (92.4)b
gran.	1.3	0.2b	0.1a	0.1a	3.8 (96.6)a
gran.	2.5	0.3b	0.1a	0.1a	3.6 (96.8)a
gran.	5.1	0.2b	0.4a	0.5a	9.8 (91.3)b
	Mean	0.4B	0.2B	0.3B	6.45(94.3)B
Non-treated control		11.2	15.7	16.5	113.2 (0.0)

^{z} Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

^{y} WAS=weeks after seeding. Additional counts were taken at 1, 3, 4, 5, 7, 8 and 9 WAS. However, results were equivalent to the data presented.

^{x} F.W.=fresh weight of bittercress at 10 WAS.

^{w} spray= SureGuard; gran.= granular= BroadStar.

^{v} Means separated using Duncan's Multiple Range Test at P = 0.05; lower cases within formulation; upper cases mean comparison.

^{u} % control = 100- (weed fresh weight/ control fresh weight) x 100.

Table 7. Response of hairy bittercress (*Cardamine hirsuta* L.) to the main effects of all experimental variables and their two-way interactions [z]. (Experiment 2)

	Weed counts /pot (WAS[y])			
Source of variation	2	5	8	F.W.[x]
Main effects	------------------------------	probability	--------------------------	
Formulation (form.)	<0.01	<0.01	<0.01	<0.01
Rate	0.07	0.01	0.02	0.03
Moisture (moist.)	0.77	0.66	0.68	0.61
Irrigation (irrig.)	0.07	0.70	0.12	0.57
Two-way interactions				
form. x rate	0.06	0.01	0.03	0.03
form. x moist.	0.77	0.66	0.72	0.61
form. x irrig.	0.07	0.70	0.15	0.57
rate x moist.	0.77	0.55	0.81	0.37
rate x irrig.	0.54	0.74	0.99	0.78

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

[y] WAS=weeks after seeding. Additional counts were taken at 1, 3, 4, 6 and 7 WAS. However, results were equivalent to the data presented.

[x] F.W.=fresh weight of bittercress at 8 WAS.

Table 8. Response of hairy bittercress (*Cardamine hirsuta* L.) to the interaction of formulation and rate [z]. (Experiment 2)

Experimental variables		Weed counts /pot (WAS[y])			F.W.[x] (g/pot)
Fomulation	Rate (kg ha^{-1})	2	5	8	(% control[u])
Spray[w]	0.28	0.0a[v]	0.0a	0.0a	0.0 (99.9)a
spray	0.42	0.0a	0.0a	0.0a	0.0 (100.0)a
	Mean	0.0A	0.0A	0.0A	0.0 (100.0)A
gran.	0.28	0.6a	0.9a	1.6a	12.7 (69.7)a
gran.	0.42	0.3b	0.4b	0.8b	6.9(83.5)b
	Mean	0.4B	1.7B	1.2B	9.8 (76.6)B
Non-treated control		5.8	8.7	8.7	42.0 (0.0)

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if P ≤ 0.05.

[y] WAS=weeks after seeding. Additional counts were taken at 1, 3, 4, 6 and 7 WAS. However, results were equivalent to the data presented.

[x] F.W.=fresh weight of bittercress at 8 WAS.

[w] spray= SureGuard; gran.= granular= BroadStar.

[v] Means separated using Duncan's Multiple Range Test at P = 0.05; lower cases within formulation; upper cases mean comparison.

[u] % control = 100- (weed fresh weight/ control fresh weight) x 100.

Table 9. Response of hairy bittercress (*Cardamine hirsuta* L.) to the main effects of all experimental variables and their two-way interactions [z]. (Experiment 3)

	Weed count/pot (WAS[y])			
Source of variation	2	6	11	F.W.[x]
<u>Main effects</u>	---------------------------------probability---------------------------------			
Formulation (form.)	<0.01	<0.01	<0.01	<0.01
Rate	0.09	<0.01	<0.01	<0.01
Moisture (moist.)	0.82	0.56	0.80	0.36
Irrigation (irrig.)	0.25	0.35	<0.01	0.59
<u>Two-way interactions</u>				
form. x rate	0.09	<0.01	<0.01	<0.01
form. x moist.	0.81	0.47	0.84	0.37
form. x irrig.	0.24	0.30	<0.01	0.58
rate x moist.	0.34	0.94	0.56	0.88
rate x irrig.	0.40	0.01	0.05	0.17

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

[y] WAS=weeks after seeding. Additional counts were taken at 1, 3, 4, 5, 7, 8, 9 and 10 WAS. However, results were equivalent to the data presented.

[x] F.W.=fresh weight of bittercress at 11 WAS.

Table 10. Response of hairy bittercress (*Cardamine hirsuta* L.) to formulation, rate and post-irrigation [z]. (Experiment 3)

Experimental variables			Weed counts/pot (WAS[y])			F.W.[x] (g/pot)
Formulation	Rate (kg ha^{-1})	Irrigation (cm)	2	6	11	(% control[u])
spray[w]	0.28	0.6	0.0a[v]	0.0a	0.1a	0.0 (100.0)a
spray	0.28	1.3	0.0a	0.3a	0.0a	0.0 (100.0)a
spray	0.28	2.5	0.0a	0.0a	0.1a	0.0 (100.0)a
spray	0.28	5.1	0.0a	0.0a	0.2a	0.0 (100.0)a
Mean			0.0B	0.1C	0.1C	0.0 (100.0)C
spray	0.42	0.6	0.0a	0.0a	0.0a	0.0 (100.0)a
spray	0.42	1.3	0.0a	0.0a	0.0a	0.0 (100.0)a
spray	0.42	2.5	0.0a	0.1a	0.0a	0.0 (100.0)a
spray	0.42	5.1	0.0a	0.0a	0.2a	0.0 (100.0)a
Mean			0.0B	0.0C	0.1C	0.0 (100.0)C
gran.	0.28	0.6	0.1a	5.9a	6.3a	27.9 (72.1)a
gran.	0.28	1.3	0.6a	6.6a	4.9a	26.2 (65.1)a
gran.	0.28	2.5	0.4a	7.2a	6.1a	34.2 (54.4)a
gran.	0.28	5.1	0.1a	7.1a	5.6a	29.7 (60.4)a
Mean			0.3A	6.7A	5.7A	29.5 (60.7)A
gran.	0.42	0.6	0.1a	7.2a	6.6a	27.4 (63.5)a
gran.	0.42	1.3	0.1a	4.1b	2.5b	20.4 (72.8)ab
gran.	0.42	2.5	0.1a	2.4b	2.1b	11.8 (84.3)ab
gran.	0.42	5.1	0.1a	3.7b	2.4b	8.8 (88.3)b
Mean			0.1B	4.3B	3.4B	16.9 (77.5)B
Control			0.3	12.5	11.2	75.0 (0.0)

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

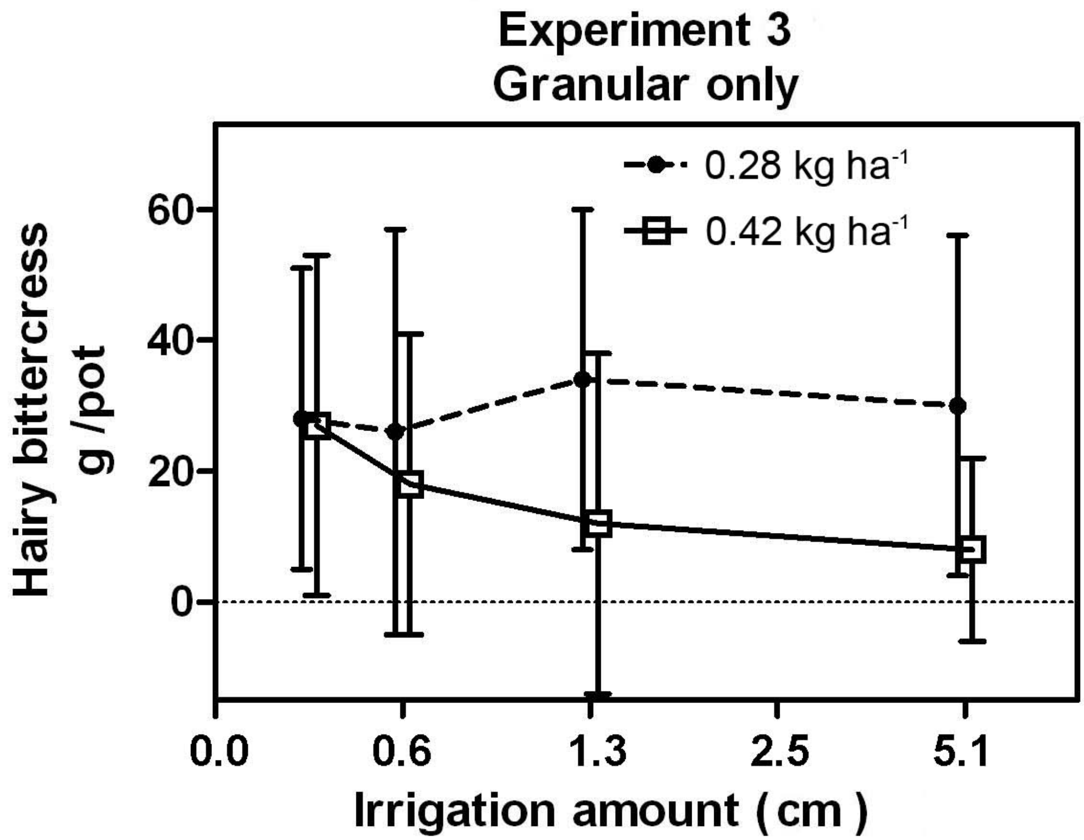
[y] WAS=weeks after seeding. Additional counts were taken at 1, 3, 4, 5, 7, 8, 9 and 10 WAS. However, results were equivalent to the data presented.

[x] F.W.=fresh weight of bittercress at 11 WAS.

[w] spray= SureGuard; gran.= granular= BroadStar.

[v] Means separated using Duncan's multiple range test at $P = 0.05$; lower cases within formulation; upper cases mean comparison.

Figure 5. Response of hairy bittercress (*Cardamine hirsuta* L.) to granular formulation of flumioxazin, error bars equivalent to standard errors. (Experiment 3)



Chapter IV: Effect of Pre and Post Moisture Level and Formulation on Preemergence Control of Spotted Spurge (*Chamaesyce maculata* L.) with Flumioxazin

Abstract

Flumioxazin is a commonly used herbicide in nursery production for preemergence weed control. Moisture is an important component to activate preemergence herbicides; however, this aspect had not been investigated in soilless substrate. The objective of this study was to evaluate the influence of both pre-application moisture levels and post-application irrigation levels in the preemergence control of spotted spurge (*Chamaesyce maculata* L.) with flumioxazin in pine bark substrate. Two similar experiments were conducted. Treatments were a factorial arrangement: three pre-application moisture levels (dry, medium and wet), two flumioxazin formulations (granular and spray), two flumioxazin rates [0.28 and 0.42 kg ha^{-1} (0.250 and 0.375 lb ai A^{-1})] and four post-application irrigation levels [0.6, 1.3, 2.5 and 5.1 cm (0.25, 0.50, 1.00 and 2.00 in)]. Treated pots were overseeded with 25 spotted spurge 1 day after herbicide application. Weed germination was counted weekly, and shoot fresh weights were taken after the last weed count. Results showed pre-application moisture did not affect the flumioxazin efficacy. The spray formulation provided maximum reduction of weed counts, regardless of rate, pre-moisture level or post-irrigation level. Conversely, the granular formulation was less effective, and the higher rate was generally more effective than lower rate. The efficacy of granular formulation at 0.42 kg ha^{-1} tended to be improved by additional post-irrigation. For granular formulation at 0.28 kg ha^{-1},

post-irrigation ranged from 1.3 cm to 2.5 cm provided higher control of spotted spurge, and over watering can reduce the efficacy of flumioxazin.

Index word: pine bark substrate, irrigation, moisture

Species used in this study: spotted spurge (*Chamaesyce maculata* L.).

Chemical used in this study: flumioxazin (BroadStar®, SureGuard®).

Significance to the Nursery Industry

Moisture is important to activate preemergence herbicides and transfer the herbicides into the substrate. Growers are generally instructed to apply irrigation after application of preemergence herbicides. However, little or no research has been conducted in soilless substrates evaluating effects of moisture levels. More data is needed to guide growers about how to best manage moisture levels for the best weed control. Therefore, this research evaluated the effects of pre-application moisture levels, post-application irrigation levels and flumioxazin rates in two different formulations: granular - BroadStar 0.25G® and spray - SureGuard 51WDG® on preemergence control of spotted spurge. The data showed more irrigation could improve the efficacy of granular formulation, while spray formulation provided excellent control of spotted spurge regardless of any variables.

Introduction

Preemergence herbicide application is the most popular method of weed control in nursery production (Everest et al., 1998). Weed control is one of the biggest problems for nursery managers. With increasing labor cost, hand-weeding cost is becoming more and more expensive.

Darden and Neal (1999) reported that hand weeding 1,000 pots cost as much as $1,376 over a four month period based on the minimum wage ($5.15), which had increased to $1,937 based on the minimum wage in 2011 ($7.25). Growers are becoming increasingly aware of the labor saved by the application of preemergence herbicide, and typically make 3-6 preemergence herbicides applications annually (Gilliam et al., 1990). Spotted spurge (*Chamaesyce maculata* L.) is one of top 10 noxious weeds in Southeast container nursery production (Ryan, 1977). It is an annual broadleaf (dicot) weed, which germinates within a temperature range of 60 to 100 F, and can flower and produce seed within 5 weeks.

Soil moisture is an important factor affecting the absorption of herbicides by germinating weeds (Menges, 1963), because water can dissolve granular herbicides, move the herbicides into substrate to enhance herbicide-substrate contact and allow herbicides to contact the roots of target weed plants. Previous research in 1960's showed irrigation volume affected effectiveness of preemergence herbicides with different ingredients and volatility (Knake et al., 1967). As pointed out by Audus (1964), the relationship between soil moisture and absorption of herbicides into the soil exchange complex may affect the availability of herbicides for uptake by the plant. Other research with diuron on cotton (*Gossypium hirsutum* L.) showed that diuron was more effective under high post-moisture conditions than under low moisture condition (Upchurch, 1957). In a study on foxtail control with 25, 31 and 37% soil moisture (Stickler et al., 1969), the effectiveness of atrazine and EPTC (ethyl N, N-dipropylthiocarbamate) increased with increasing soil moisture. In a more recent study with pronamide, 5 cm (2 in) of preplant irrigation reduced weed density compared with the no preplant irrigation (Shem-tov et al., 2006).

Flumioxazin inhibits protoporphyrinogen oxidase, which is an enzyme involved in chlorophyll synthesis (Scalla and Matringe, 1994). Flumioxazin is absorbed by both roots and foliage of targeted weeds, and has both preemergence and postemergence activity (Kelly et al., 2006), and has been reported to control many broadleaf weed species when applied preemergence in many crops (Cranmer et al., 2000). Over 95% spotted spurge control was obtained in pine bark substrate with flumioxazin at 0.11-0.43 kg ha^{-1} 6 weeks after treatment (Wehtje et al., 2010). The herbicide products used in this research were BroadStar 0.25G® (Anonymous, 2010) and SureGuard 51WDG® (Anonymous, 2009). BroadStar is a granular formulation with 0.25% active ingredient, first registered in 2003 for use in container and field grown woody shrubs, trees and groundcovers, and provides 8 to 12 weeks of preemergence control. Because many ornamentals were moderately or highly sensitive to flumioxazin, especially if any moisture is on the foliage, a new coating was added in 2009 to BroadStar® to prevent foliar damage from over-top application. Some growers have expressed dissatisfaction with the weed control efficacy of the new formulation. SureGuard is a water dispersible granular formulation containing 51% active ingredient. This product was registered for directed application in container and field-grown conifers and deciduous trees. In nursery situations, weed control provided by flumioxazin often lasts longer than reported in soil; however results showed no spotted spurge control was evident after 8 weeks in pine bark and sand substrate (Wehtje et al., 2012).

Previous research about the effect of moisture in weed control was conducted in field studies. Pine bark the primary commercial substrate used for container production of nursery crops after 1972. Both aged and fresh pine bark are available and economical. Pine bark substrates offer an excellent balance of water retention and drainage; is relatively sanitary; its light weight compared to soil substrate minimizes transportation cost (Davidson et al., 2000). However, little research has been conducted in soilless substrate to look at moisture levels effect for preemergence weed control in nursery production. Therefore, the objective of this study was to evaluate the influence of flumioxazin formulation, pre-application moisture and post-application irrigation on preemergence spotted spurge control in pine bark substrate.

Materials and Methods

Experiment 1.

Pots were filled with a commercial pine bark substrate with a 6:1 (volume: volume) ratio of pine bark to sand, which had been previously mixed with 9.3 kg m^{-3} (15 lb yd^{-3}) of Polyon® (17-5-11) control-released (7-8 months) fertilizer, 3.1 kg m^{-3} (5 lb yd^{-3}) of dolomitic limestone and 0.9 kg m^{-3} (1.5 lb yd^{-3}) Micromax. Weights of pots and container volumetric water contents for each moisture level were measured with 10 samples for each moisture level before herbicides were applied. A Decagon® Soil Moisture Sensor was used to measure volumetric water content. Three pre-application moisture levels were conducted:

For low moisture, pots were watered to saturation 4 days before treatment, then no water applied until herbicide application; average pot weight was 1.18 kg, and volumetric water content was 20%.

For medium moisture, pots were watered to saturation 1 day before treatment, then no water until herbicide application; average pot weight was 1.36 kg, and volumetric water content was 26%.

For high moisture, pots were watered to saturation imsubstratetely before treatment; average pot weight was 1.60 kg, and water content was 34%.

Flumioxazin treatments were applied on 7 September 2010. Treatments included BroadStar

0.25G at 0.28 and 0.42 kg ai ha^{-1} and SureGuard 51WDG at 0.28 and 0.42 kg ai ha^{-1}. BroadStar was applied with a hand-shaker. SureGuard was applied by an enclosed-cabinet sprayer, which had been calibrated to deliver at 30 GPA (gallon per acre) with a Teejet 8002 flat fan nozzle.

This experiment was conducted as a factorial treatment arrangement: three pre-application moisture levels (dry, medium and wet), two flumioxazin formulations (granular and spray), two flumioxazin rates (0.28 and 0.42 kg ha^{-1}) and four post-application irrigation levels (0.6, 1.3, 2.5 and 5.1 cm). With an additional non-treated control treatment, there were 49 treatments in total. Each treatment was replicated six times. Pots were maintained in a retractable roof greenhouse. A completely random experimental design was observed. After herbicides application and 1 day after completion of the single-event irrigation, a 1.3 cm per day irrigation schedule was started. This schedule was maintained for the duration of the experiment. Pots were seeded with 25 spotted spurge seeds 1 day after completion (8 September 2010) of the single-event irrigation. Number of spotted spurge seedlings was counted weekly for 9 weeks after seeding. Spotted spurge fresh weight was collected after final weed count (10 November 2010).

Experiment 2.

Experiment 2 was similar to experiment 1. Pots were filled on 23 August 2011. Container weights and container volumetric water content were measured before herbicides were applied on 26 August 2011: low pre-moisture-1.17 kg and 11%; medium pre-moisture- 1.48 kg and 13%; high pre-moisture- 1.61 kg and 21%. Spotted spurge was overseeded with 25 seeds per pot at 1 day after treatment (27 August 2011). Weed number was counted weekly until 10 weeks after treatment (4 November 2011). Fresh weight was collected after the final count.

Data were pooled over both experiment 1 and experiment 2 and subjected to analysis of variance (ANOVA), which reflected the factorial treatment arrangement. Data were pooled over non-significant experimental variables. Treatment means for experimental variables that were significant as either main effects or two-way interactions were separated by Duncan's multiple range test at the 0.05 level.

Results and Discussion

Both weed counts and fresh weight were influenced by the main effect of formulation and rate (Table 11). Conversely, the main effects of pre-application moisture and post-application irrigation were not significant for both weed counts and fresh weight. None of the two-way interactions were significant for fresh weight. The two-way interaction of formulation and rate was significant for weed counts at 3 and 6 weeks after seeding, but not significant at 9 weeks. Meanwhile, the two-way interaction of formulation and irrigation was significant at 6 and 9 weeks after seeding. Data were pooled over the pre-application moisture level in order to better examine the effects of the significant variables, i.e. formulation, rate and irrigation (Table 12).

At 3 weeks after seeding, the spotted spurge count was 0 with the spray application, and the count with the spray was significantly lower than with the granular formulation (Table 2). The weed count mean with the granular formulation at 0.42 kg ha^{-1} was lower than 0.28 kg ha^{-1}. Within each formulation-rate combination, irrigation level had no effect (Table 12).

Results at 6 weeks after seeding were similar to 3 weeks, except irrigation had an effect on granular formulation with lower rate. Within this group, the highest weed count was obtained by irrigation at 5.1 cm (2.00 in), and followed by irrigation at 0.6 cm. Irrigation level from 1.3 to 2.5 cm had same weed count number, but the number was significantly lower than irrigation at 5.1 cm.

At 9 weeks after seeding, the efficacy of spray formulation was still higher than granular formulation (Table 12). Spray treatments with higher rate resulted in lower spotted spurge counts, and irrigation had no effect within this group. Conversely, irrigation had an effect on the spray treatments at the lower rate. In this case, the lowest count was obtained with the lowest irrigation. Within the granular formulation, treatments with the higher rate also had lower weed counts. Irrigation was not significant in granular treatments with higher rate, but the weed count tended to decrease with increasing irrigation. Conversely, irrigation had an effect on the granular treatments with lower rate. Both 0.6 and 5.1 cm had higher counts than the other two levels. Irrigation at 2.5 cm provided the lowest numerical weed count in this group, which is similar to highest rate 0.42 kg ha^{-1}.

Weed count data reflected the length of treatment duration, but fresh weight reflected the control over the whole period. Because early germinated spotted spurge usually weighed more than newly germinated spotted spurge, the weight data did not reflect the final (9 weeks after seeding) weed count at. All spray formulation obtained almost 100% fresh weight control regardless of rate and post-irrigation level. Within the granular formulation, the high rate reduced the weight more than the low rate; 3.9 g per pot at 0.28 kg ha^{-1} versus 6.1 g per pot at 0.42 kg ha^{-1}. Irrigation had no effect on either combination of formulation or rate. Within granular treatments, the highest control was provided by irrigation at 1.3 cm of both lower rate (81.4%) and higher rate (92.3%) at 9 weeks after seeding. Wehtje (2010) reported over 90% spotted spurge control was obtained with flumioxazin at 0.11 to 0.43 kg ha^{-1} within at least 6 weeks after treatment, and no spotted spurge control was evident after about 8 weeks in pine bark and sand substrate (2012).

In summary, the spray formulation of flumioxazin provided maximum reduction of spotted spurge counts, regardless of rate, pre-moisture level or post-irrigation level. Conversely, the granular formulation was less effective, and the higher rate generally provided more effective spotted spurge control than the lower rate. Pre-application moisture at dry, medium and wet level did not affect the flumioxazin efficacy in either formulation. The efficacy of granular formulation tended to be improved by additional post-irrigation. However for granular formulation at 0.28 kg ha^{-1}, post-irrigation ranged from 1.3 cm to 2.5 cm, and over watering can reduce the efficacy of flumioxazin.

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Tabel 11. Response of spotted spurge (*Chamaesyce maculata* L.) to the main effects of all experimental variables and their two-way interactions (Data pooled over two runs of the experiment, i.e. Sept. 2010 and Aug. 2011)[z].

	Weed counts /pot (WAS[y])			
Sourse of variation	3	6	9	Fresh weight
Main effect	--	----------probability----------	--------------------------------	
Formulation (form.)	<0.01	<0.01	<0.01	<0.01
Rate	0.01	<0.01	<0.01	0.05
Moisture (moist.)	0.94	0.99	0.74	0.47
Irrigation (irrig.)	0.17	0.09	0.17	0.68
Two-way interactions				
form. x rate	0.01	0.01	0.85	0.07
form. x moist.	0.94	0.97	0.28	0.49
form. x irrig.	0.17	0.03	<0.01	0.65
rate x moist.	0.99	0.62	0.33	0.90
rate x irrig.	0.72	0.13	0.54	0.84

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

[y] WAS= weeks after seeding. Addition counts were taken at 1, 2, 4, 5, 7, 8 and 10 WAS. However, results were equivalent to the data presented.

Table 12. Response of spotted spurge (*Chamaesyce maculata* L.) to formulation, rate and post-irrigation[z].

Experimental variables			Weed counts/pot (WAS[y])			
Formulation	Rate (kg ai ha^{-1})	Irrigation (cm)	3	6	9	F.W.[x] (g/pot) (% control[w])
spray[v]	0.28	0.6	0.0a[u]	0.0a	0.5b	0.0 (100.0)a
spray	0.28	1.3	0.0a	0.1a	1.6a	0.1 (99.6)a
spray	0.28	2.5	0.0a	0.1a	0.8ab	0.1 (99.6)a
spray	0.28	5.1	0.0a	0.0a	0.7ab	0.1 (99.6)a
Mean			0.0C	0.1C	0.9C	0.1 (99.6)C
spray	0.42	0.6	0.0a	0.0a	0.1a	0.0 (100.0)a
spray	0.42	1.3	0.0a	0.0a	0.4a	0.0 (100.0)a
spray	0.42	2.5	0.0a	0.0a	0.5a	0.0 (100.0)a
spray	0.42	5.1	0.0a	0.0a	0.4a	0.0 (100.0)a
Mean			0.0C	0.0C	0.4D	0.0 (100.0)C
gran.	0.28	0.6	0.8a	1.4ab	2.8a	6.0 (78.9)a
gran.	0.28	1.3	0.6a	0.8b	1.9ab	5.3 (81.4)a
gran.	0.28	2.5	0.4a	0.8b	1.3b	6.0 (78.9)a
gran.	0.28	5.1	0.7a	1.9a	2.6a	6.8 (76.1)a
Mean			0.6A	1.2A	2.2A	6.1 (78.6)A
gran.	0.42	0.6	0.5a	0.9a	2.2a	5.2 (81.8)a
gran.	0.42	1.3	0.2a	0.6a	1.7a	2.2 (92.3)a
gran.	0.42	2.5	0.3a	0.7a	1.2a	4.5 (84.2)a
gran.	0.42	5.1	0.2a	0.7a	1.3a	3.7 (87.0)a
Mean			0.3B	0.7B	1.6B	3.9 (86.3)B
Non-treated control			5.3	9.3	9.9	28.5 (0.0)

[z] Analysis of variance performed using general linear model of SAS; effects are considered significant if $P \leq 0.05$.

[y] WAS= weeks after seeding. Additional counts were taken at 1, 2, 4, 5, 7, 8 and 10 WAS. However, results were equivalent to the data presented.

[x] F.W.= fresh weight of spotted spurge after last count.

[w] % control was determined by 100-(treated fresh weight/non-treated control fresh weight)x00.

[v] spray= SureGuard; gran.=granular= BroadStar.

[u] Means separated using Duncan's multiple range test at P= 0.05; lower cases within formulation and rate; upper cases mean comparison.