This is to certify that the
thesis entitled

WEED CONTROL WITH HERBICIDES AS ALTERNATIVES
TO METHYL BROMIDE IN HERBACEOUS PERENNIAL AND
CONIFER SEEDLING PRODUCTION

presented by

Daniel Alan Little

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Horticulture

Bernard H. Zandstra
Major Professor's Signature

May 3, 2007
Date

WEED CONTROL WITH HERBICIDES AS ALTERNATIVES TO METHYL BROMIDE IN HERBACEOUS PERENNIAL AND CONIFER SEEDLING PRODUCTION

By

Daniel Alan Little

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

2007

ABSTRACT

WEED CONTROL WITH HERBICIDES AS ALTERNATIVES TO METHYL BROMIDE IN HERBACEOUS PERENNIAL AND CONIFER SEEDLING PRODUCTION

By

Daniel Alan Little

Methyl bromide (MeBr) has been used in agriculture for many years to control nematodes, soil-borne pathogens, and weeds. In 1992, MeBr was declared a stratospheric ozone depleting substance and 180 countries signed a treaty to discontinue its use by 2005, except for import and export shipments and critical and emergency use. Michigan growers have relied on MeBr for control of pests in herbaceous perennial and conifer seedling beds. The removal of MeBr from the market has made it difficult for growers to control weeds. In this project, we examined 12 herbicide treatments and one alternative fumigant that may be used as alternatives to MeBr for weed control in five ornamental herbaceous perennial species and 12 herbicide treatments and one alternative fumigant that may be used as alternatives to MeBr for weed control in five conifer species seedling beds. Research was conducted in two fields over two years in Benton Harbor, MI and one field for one year in Holt, MI. Project goals were to: 1) determine alternative weed control treatments that are safe on the crops, and 2) determine treatments that provide weed control similar to MeBr. Each herbaceous perennial species responded differently to the treatments. Weed control in the herbaceous perennials varied from year to year with the treatments and was less than MeBr. The conifer seedlings were tolerant of most of the treatments tested. Weed control in the conifer seedlings was consistent from year to year, and many treatments provided similar weed control as MeBr.

ACKNOWLEDGMENTS

I would like to thank Dr. Bernard Zandstra and Dr. Robert Richardson for their guidance throughout this project. I would also like to thank my committee members Dr. Bert Cregg and Dr. Christy Sprague for their guidance. I am highly appreciative of Brian Walters, Caitlin Asman, and Tim Asher who spent many hours in the field with me and also Dr. Zandstra's entire lab: Dr. Michael Marshall, Michael Particka, Eric Ott, Sylvia Morse, Rebecca Baughan, Vijay Pandian, and Robert Uhlig, who were available when I needed help and also for making the last three years more enjoyable. Thanks to Dave Francis, Bill Chase, and their crews for helping to establish my plots. A special thanks to Dr. Sam Wang who assisted me with my statistics. I would like to thank the USDA for funding my project. And most of all, thanks to my family, fiancée, and friends for their support and understanding throughout this endeavor.

TABLE OF CONTENTS

LIST OF TABLES vi

CHAPTER ONE
LITERATURE REVIEW AND INTRODUCTION
- The Methyl Bromide Phaseout 2
- MeBr Use in Agriculture 3
- Ornamental Production in Michigan 4
- Herbicide Trials Containing Bugleweed, Daylily, Hosta, Lupine, and Periwinkle 5
- Christmas Tree Production in Michigan 7
- Weed Control in Conifer Seedlings 8
- Weed Control as a Problem with Alternative Fumigants 9
- Plan of Research 11
- References 13

CHAPTER TWO
ALTERNATIVE TREATMENTS TO METHYL BROMIDE FOR WEED CONTROL IN HERBACEOUS PERENNIAL PRODUCTION
- Abstract 17
- Introduction 18
- Materials and Methods 19
  - Field Studies 19
  - Greenhouse Studies 22
- Results and Discussion 23
  - Field Studies: Crop Injury 23
  - Field Studies: Weed Control 26
  - Greenhouse Studies: Crop Injury 30
- Conclusions 31
- References 48

CHAPTER THREE
ALTERNATIVE TREATMENTS TO METHYL BROMIDE FOR WEED CONTROL IN CONIFER SEEDLING PRODUCTION
- Abstract 50
- Introduction 51
- Materials and Methods 52
  - Field Studies 52
  - Greenhouse Studies 56
- Results and Discussion 57
  - Field Studies: Crop Injury 57
  - Field Studies: Weed Control 60
  - Greenhouse Studies: Crop Injury 65

Conclusion 66
References 87

CHAPTER FOUR
CONTROL OF FIELD HORSETAIL USING VARIOUS HERBICIDES
Abstract 89
Introduction 89
Materials and Methods 92
Field Studies 92
Greenhouse Studies 95
Results and Discussion 96
Field Studies: Site 1 96
Field Studies: Site 2 96
Field Studies: Site 3 2004 97
Field Studies: Site 3 2005 97
Field Studies: Site 4 98
Greenhouse Studies: Study 1 99
Greenhouse Studies: Studies 2 and 3 99
Greenhouse Studies: Study 4 99
Conclusions 100
References 109

LIST OF TABLES

TABLE PAGE

CHAPTER TWO

2.1 Herbicides, rates, and crops labeled for the treatments used in Field 1 in 2004 and 2005 on bugleweed (AR), periwinkle (VM), daylily (HS), and lupine (LS) and in Field 2 in 2005 and 2006 on AR, VM, HS, LS, and hosta (HT). 34

2.2 Herbicides, rates, and crops labeled for the treatments used in Field 3 in 2006 on bugleweed (AR), periwinkle (VM), daylily (HS), lupine (LS) and hosta (HT). 35

2.3 Percent visual injury and the end of season plant size (length multiplied by width) (cm^2) for bugleweed in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006 treated with potential alternatives to MeBr for weed control. 36

2.4 Percent visual injury and the end of season plant size (length multiplied by width) (cm^2) for periwinkle in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006 treated with potential alternatives to MeBr for weed control. 37

2.5 Percent visual injury and end of season height (cm) for daylily in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006 treated with potential alternatives to MeBr for weed control. 38

2.6 Percent visual injury and end of season shoot count and crop height for hosta in Fields 2 and 3 in 2006 and lupine in Field 3 in 2006 treated with potential alternatives to MeBr for weed control. 38

2.7 Percent control of large crabgrass in Fields 1 and 2 and percent control of stinkgrass in Field 3 using MeBr and various potential alternative treatments for weed control in herbaceous perennials. 40

2.8 Percent control of common ragweed in Fields 1 and 2 using MeBr and potential alternative treatments for weed control in herbaceous perennials. 41

2.9 Percent control of common lambsquarters in Fields 1, 2, and 3 using MeBr and various potential alternative treatments for weed control in herbaceous perennials. 42

2.10 Percent control of wild buckwheat in Fields 1 and 2 and percent.. 43
control of carpetweed in Fields 1, 2, and 3 using MeBr and
various potential alternatives for weed control in herbaceous
perennials.

2.11 Percent control of pigweed spp. in Fields 2 and 3 in 2006 and..... 44
percent control of vetch spp. in Field 1 in 2004 using MeBr and
various potential alternative treatments for weed control in
herbaceous perennials.

2.12 Percent injury and the final minus initial plant size for bugleweed............45
and periwinkle in two greenhouse studies to determine the
toxicity of nine potential herbicide treatments as replacements
for MeBr for weed control in herbaceous perennials.

2.13 Percent injury and final minus initial plant measurements for...... 46
daylily and lupine in two greenhouse studies to determine the
toxicity of nine potential herbicide treatments as replacements
for MeBr for weed control in herbaceous perennials.

2.14 Subjective summary of crop tolerance and weed control results... 47
of Field 1 and Field 2 on Bugleweed, Periwinkle, and_Daylily.

CHAPTER THREE

3.1 Herbicides, rates, and crops labeled for the treatments used in..... 69
Field 1 in 2004 and 2005 on Eastern White Pine (WP) and Fraser
Fir (FF) and in Field 2 in 2005 and 2006 on WP, FF, Douglas-Fir
(DF), and Colorado Blue Spruce (BS).

3.2 Herbicides, rates, and crops labeled for the treatments used in.... 70
Field 3 in 2006 on Fraser Fir (FF), Eastern White Pine (WP),
Douglas-Fir (DF), Colorado Blue Spruce (BS), and Balsam Fir
(BF).

3.3 Herbicides, rates, and crops labeled for the treatments used in.... 71
Greenhouse Study 1 in 2005 on seven conifer and three
deciduous species.

3.4 Herbicides, rates, and crops labeled for the treatments used in.... 72
Greenhouse Study 2 in 2006 on six conifer and three deciduous
species.

3.5 Visual injury on Fraser Fir in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006, tree heights for Field 1 in 2004-05 and Field 3 in 2006, and the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006. 73

3.6 Visual injury on Eastern White Pine in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006, tree heights for Field 1 in 2004-05 and Field 3 in 2006, and the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006. 74

3.7 Visual injury on Colorado Blue Spruce in Field 2 in 2005-06 and Field 3 in 2006, the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006, and tree heights in Field 3 in 2006. 75

3.8 Visual injury on Douglas-Fir in Field 2 in 2005-06 and Field 3 in 2006, the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006, and tree heights for Field 3 in 2006. Visual injury and tree heights of Balsam Fir in Field 3 in 2006. 76

3.9 Percent control of large crabgrass in Fields1 and 2 and control of stinkgrass in Field 3 using MeBr and various alternative fumigant and herbicide treatments for weed control in conifer seedlings. 77

3.10 Percent control of common ragweed in Fields 1 and 2 using MeBr and various herbicide alternative treatments for weed control in conifer seedlings. 78

3.11 Percent control of common lambsquarters in Fields 1, 2, and 3 using MeBr and various alternative fumigant and herbicide treatments for weed control in conifer seedlings. 79

3.12 Percent control of wild buckwheat and carpetweed in Fields 1 and 2 using MeBr and various alternative herbicide treatments for weed control in conifer seedlings. 80

3.13 Percent control of pigweed spp. in Field 3, horsenettle and vetch. in Field 1, and hairy nightshade in Field 2 using MeBr and various alternative fumigant and herbicide treatments for weed control in conifer seedlings. 81

3.14 Greenhouse Study 1: Percent injury to three deciduous and seven conifer tree species caused by 10 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds. 82

3.15 Greenhouse Study 1: Average length of new growth on three...... 83
stems in three deciduous and seven conifer tree species treated with 10 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds.

3.16 Greenhouse Study 2: Percent injury to three deciduous and six................84
conifer tree species caused by 13 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds.

3.17 Greenhouse Study 2: Average length of new growth on three...... 85
random stems in three deciduous and six conifer tree species treated with 13 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds.

3.18 Subjective summary of crop tolerance and weed control results................86
of Field 1 and Field 2 on Fraser Fir, Eastern White Pine, Colorado Blue Spruce, and Douglas-Fir.

CHAPTER FOUR

4.1 The rates, formulations, and mode of action of the herbicides...... 103
used in the field horsetail control studies.

4.2 Treatments used for the control of field horsetail present at the...............104
four field sites and four greenhouse studies are marked "X".

4.3 Percent control of field horsetail from various herbicides at...... 105
Manistee (Site 1) in 2003 and Flint (Site 2) in 2004.

4.4 Percent control of field horsetail from various herbicides at the... 106
West Olive site (Site 3) in 2004 and 2005.

4.5 Percent control of field horsetail from various herbicides at the... 107
Holt site (Site 4) in 2005 and 2006.

4.6 Percent control and dry weights of potted field horsetail plants...............108
six weeks after various herbicide treatments (WAT) and plant dry weights six and 10 WAT in four greenhouse studies.

CHAPTER ONE

LITERATURE REVIEW AND INTRODUCTION

LITERATURE REVIEW AND INTRODUCTION

The Methyl Bromide Phaseout

Methyl bromide (MeBr) has been used as a soil fumigant for the effective control of insects, nematodes, weeds, and soil-borne pathogens in agriculture for many years. In 1992, MeBr was determined to be a stratospheric ozone depleting substance, which caused an amendment to be made to the Montreal Protocol of 1991. The Montreal Protocol is an international treaty signed by over 180 countries, which protects the environment from ozone depleting substances (Anonymous, 2003). The treaty used the amount of MeBr produced for agricultural use in 1991 as a baseline for the phaseout process. The phaseout schedule was agreed upon in 1997 and began in 1999 for developed countries. The schedule stated that production would be reduced by 25 percent of baseline in 1999, 50 percent by 2001, 70 percent by 2003, and 100 percent by 2005. The phaseout dates were delayed for developing countries, with phaseout to be completed by 2015 (Osteen, 2000). The use of MeBr for quarantine of import and export shipments and critical and emergency use are currently exempt from the phaseout (Vick, 2001).

The Montreal Protocol assigned ratings, called the ozone depleting potential (ODP), to chemicals based on their impact on the ozone compared to chloroflurocarbon-11, which was given a rating of 1.0. MeBr was originally assigned an ODP of 0.7 in 1992, but was later reduced to 0.4 in 1998 after further research. The Montreal Protocol states that any chemicals having an ODP higher than 0.2 will be phased out. Methyl bromide easily reaches the stratosphere and has a very high mixing rate with ozone. The Agricultural Research Service estimates that 20 to 30 percent of the MeBr released into the atmosphere is from agricultural use, which accounts for 3 to 10 percent of the stratospheric ozone depletion (Vick, 2001). Most studies show that between 30 and 60% of the soil applied MeBr can escape into the atmosphere. The amount of MeBr that can escape is highly dependant on soil pH, organic matter, moisture, injection depth, injection method, and tarp material (Butler and Rodriguez, 1996).

MeBr Use in Agriculture

Over the years, many compounds have been used as soil fumigants. MeBr has been the most widely used fumigant because it is the most efficient, reliable, and cost effective way to control a wide range of soil-borne pests (Klein, 1996). In 2001, MeBr was used in over 100 crops. On average, the United States used approximately 27,000 MT of MeBr per year, with roughly 75 percent being used for preplant soil fumigation. The treatment of storage facilities and processing plants, and the fumigation of exports and imports account for the remaining portion (Ragsdale, 2004).

MeBr's broad spectrum of activity allows it to control weeds, nematodes, soil-borne insects, fungi, and some soil-borne bacteria. MeBr is able to penetrate deep into the soil rapidly at high concentrations, allowing it to control pests that may be missed by other fumigants that do not penetrate the soil as deeply. It is the only known fumigant that can penetrate plant residues from previous crops that can serve as hosts of pathogens. Control of pests can be completed in 1 to 2 days which is less time than other fumigants. The aeration time for other fumigants can take weeks, whereas MeBr dissipates in a few days so planting can be completed earlier (Klein, 1996).

Roughly 80 percent of the preplant MeBr is used in the production of strawberries (*Fragaria* spp.), tomatoes (*Lycopersicum esculentum*), peppers (*Capsicumannuum* spp.), ornamentals, and in seedling beds (Vick, 2002). Tomato producers in Florida and strawberry growers in California use the largest amounts of MeBr. About 24 percent of preplant MeBr is used in tomato production. Growers of strawberries and tomatoes produce their plants in seedling beds before transplanting them into the fields. Growers, therefore, treat both the seedling beds and the fields (Vick, 2002).

Fumigating seedling beds benefits growers. Benefits include reaching the transplant stage earlier, less crop injury due to weed competition, lower cost in manual weed control, less area needed to grow the same number of seedlings, prevention of large field contamination, and healthier seedlings that have a better chance of surviving transplanting. Strawberry growers in California increased their average yield from 7.5-12.5 tons/ha to 62.5-75 tons/ha when they began using MeBr (Klein, 1996).

Most of the cut flower acreage in the United States is fumigated with MeBr. California is the largest cut flower producer, while Michigan is ranked fourth with over $10 million in wholesale sales in 1997 (Carpenter et al., 2000).

Ornamental Production in Michigan

The nursery industry is an important part of Michigan's economy. Greenhouse and nursery crops ranked fourth, behind dairy, corn, and cattle, in cash receipts among farm products in 1990 in Michigan (Schutzki and Peterson, 1998). Wholesale and retail sales of all nursery and ornamental crops totaled $261 million in 2004, with about $110 million of that being sold wholesale outside of Michigan. Wholesale and retail sales of herbaceous plants accounted for $108 million of the $261 million. There were over 1,200 grower operations that have more than 0.04 ha in the production of ornamentals in 2004. In 2004, over 7,100 ha were used in the production of woody ornamentals and about

1,200 ha in herbaceous ornamentals. Of the 1,200 ha in herbaceous production, 1,050 ha were used for field grown production at 216 operations. The remaining 150 ha were used in container grown production at 385 operations. The number of ha of field grown ornamentals has increased from about 650 ha in 1999 to 1,050 ha in 2004 (Kleweno and Matthews, 2005). Michigan nursery stock is shipped for sale in 35 other states and to foreign markets (Rauscher, 2005).

Herbicide Trials Containing Bugleweed, Daylily, Hosta, Lupine, and Periwinkle

Czarnota et al. (1998) examined the use of thiazopyr, thiazopyr plus oxyfluorfen, dithiopyr, oxyfluorfen plus pendimethalin, isoxaben, and *s*-metolachlor in field-grown daylily (*Hemerocallis* spp.), hosta (*Hosta* spp.), bugleweed (*Ajuga reptans)*, and periwinkle (*Vinca minor*). Treatments containing oxyfluorfen caused the most injury to daylily, hosta, bugleweed, and periwinkle. Periwinkle injury was minimal with the other treatments. Exact injury by each treatment was not listed.

Salihu et al. (1999) looked at different applications of isoxaben to bugleweed. They did a hydroponics study examining the effects on shoot and root growth when isoxaben concentrations of 0, 0.5, 1.0, 2.0, and 4.0 ppm were applied to the roots and 0.84, 1.69, and 3.39 kg/ha were applied to the foliage. Root and shoot injury did not vary with the different concentrations of root applied isoxaben. At six weeks after treatment (WAT), root-applied isoxaben caused 30% injury to the shoots, a 20% reduction in shoot fresh weight and a 40% reduction in root weight. In the foliar study, increasing the rate of isoxaben did not increase the injury to the roots and shoots. As in the root applied study, injury from foliar applied isoxaben to the bugleweed shoots at six WAT also was 30%. There was a 17% reduction in the fresh weight of shoots with 0.84 and 1.69 kg/ha of isoxaben and a reduction of 48% when 3.39 kg/ha of isoxaben was foliar applied. Root weight was reduced 17, 12, and 32% when 0.84, 1.69, and 3.39 kg/ha of isoxaben were foliar applied, respectively. They also applied 0.84, 1.69, and 3.39 kg/ha of isoxaben to the roots only, shoots only, and shoot plus root on bugleweed planted in silica sand. At four WAT, root-applied isoxaben at 0.84, 1.69, and 3.39 kg/ha caused 12, 14, and 18% injury to the shoots, respectively, and at eight WAT, injury increased to 20, 33, and 35%, respectively. At four WAT, shoot-applied isoxaben at 0.84, 1.69, and 3.39 kg/ha caused 28, 31, and 32% injury to the shoots, respectively, and at eight WAT, injury increased to 42, 41, and 42%, respectively. At four WAT, root and shoot-applied isoxaben at 0.84, 1.69, and 3.39 kg/ha caused 32, 35, and 36% injury to the shoots, respectively, and at eight WAT, injury increased to 38, 41, and 49%, respectively. Plants treated with 0.84, 1.69, and 3.39 kg/ha of isoxaben applied to the shoots and roots had 48, 53, and 65% reduction in root weight and 32, 35, and 45% reduction in shoot weight, respectively.

Derr (1994) examined the tolerance of bugleweed and periwinkle treated with isoxaben, oryzalin, trifluralin plus isoxaben, oxadiazon, pendimethalin, prodiamine, dithiopyr, norflurazon, and simazine plus *s*-metolachlor. He found that trifluralin plus isoxaben and isoxaben alone caused visual injury to bugleweed. He also found that oxadiazon and norflurazon were the only treatments that did not reduce the fresh weight of the shoots of bugleweed. Pendimethalin, dithiopyr, prodiamine, and oxadiazon caused little or no injury to bugleweed and periwinkle.

Neal and Wooten (1998) examined the use of non-selective herbicides in dormant container grown daylily and hosta. They tested diquat, pelargonic acid, glufosinate, and glyphosate. They found no significant injury from any of the treatments. It was noted that diquat caused some tip burn if the daylily plants had emerged before treatment. Porter (1993) saw no injury to daylily when oxadiazon, oxyfluorfen plus pendimethalin, *s*-metolachlor, prodiamine, isoxaben, isoxaben plus trifluralin, isoxaben plus oryzalin, oxyfluorfen, dithiopyr, oryzalin, and trifluralin were applied to dormant daylily.

Murphy and Fare (1998) tested prodiamine, isoxaben, *s*-metolachlor, trifluralin plus isoxaben, and pendimethalin in container grown daylilies. They observed some foliar injury at 15 days after treatment by all treatments, but no injury was observed 30 days after treatments. Marshall and Zandstra (2006) applied sulfentrazone and flumioxazin to actively growing field-grown daylily and hosta. They found that both sulfentrazone and flumioxazin caused visual injury and significant reductions in daylily growth. Little injury was observed on hosta treated with sulfentrazone; however, growth was reduced. Flumioxazin caused significant injury and stunting to hosta. Richardson and Zandstra (2003a) observed significant injury and stunting to container-grown hosta treated with flumioxazin.

Lupine (*Lupinus* spp.) is a poor competitor with weeds. Only two herbicides, pendimethlin and *s*-metolachlor, are labeled for the use in lupine. Putnam et al. (1989) recommended avoiding planting lupine in fields with large number of perennial and late germinating annual broadleaf weeds. Nichols et al. (2001) found that late summer or early fall applications of glyphosate, glyphosate plus sulfometuron methyl, and glyphosate plus triclopyr did not affect the percent cover of blue lupine (*Lupinus perrennis*) in a restoration area in Wisconsin for the Karner Blue Butterfly (*Lycaeides* *melissa samuelis*). The Karner Blue Butterfly uses blue lupine as a food source and the females lay their eggs on the undersides of the leaves.

Christmas Tree Production in Michigan

Adequate precipitation, mild summers, cold winters, and a variety of soil types allow several conifer species to be produced in Michigan. Michigan accounts for about 15% of the national supply of Christmas trees. About 75% of the Christmas trees harvested are sold outside of Michigan (Koelling et al., 1998). Michigan growers harvested about three million Christmas trees in 2005 (Kleweno and Matthews, 2005).

The Christmas tree industry is an important part of Michigan's economy. Wholesale and retail sales totaled $41.5 million in 2004, plus an additional $1.3 million in sales of wreaths, cut boughs, garlands, and other cut greens. There were over 780 operations that have more than 2 ha in the production of Christmas trees. In 2004, about 17,000 ha were planted to Christmas trees in Michigan. About 21% of the total Christmas tree hectares was planted to Scotch pine (*Pinus sylvestris)* in 2005, which was down from 35% in 2000. The four leading species produced in Michigan are Scotch pine, Douglas-fir (*Psuedotsuga menziesii*), Fraser fir (*Abies fraseri*), and Colorado blue spruce (*Picea pungens*) which were produced on about 3600, 3100, 3100 and 2800 ha, respectively (Kleweno and Matthews, 2005).

Weed Control in Conifer Seedlings

Weeds compete with Christmas trees for light, water, and nutrients. Excessive weeds can be detrimental to conifer seedlings. High-resource-demanding species like spruces (*Picea* spp.), true firs (*Abies* spp.), and Douglas-fir are more susceptible to weed competition. Weeds growing near Christmas trees can cause injury to the trees by physical abrasions or shading of the branches (Brown et al., 1991).

Richardson and Zandstra (2003b) saw no injury to Colorado blue spruce seedlings when flumioxazin, flumioxazin plus *s*-metolachlor, flumioxazin plus oryzalin, simazine, simazine plus *s*-metolachlor, imazaquin, and imazaquin plus *s*-metolachlor were applied for the control of knawel (*Scleranthus perennis* L).

Most of the research related to weed control in conifer seedlings is in forest reestablishment. In forest reestablishment, weed control is critical in the first three years after transplanting. Rose and Ketchum (2003) found five-year old Douglas-fir had a 217% increase in stem size when a three year weed control program was implemented. They used sulfometuron methyl plus clopyralid with a spot treatment of glyphosate the first year, a spot treatment of triclopyr in year two, and sulfometuron methyl plus hexazinone in year three. Only an additional 18% increase in stem size resulted from a four year herbicide program.

Conifer species can vary in sensitivity to weed competition. White spruce (*Picea glauca)* and Colorado blue spruce can obtain optimal growth with 60% or more weed control (Grover, 1967). Scotch pine could reach its optimal growth with as little as 40% weed control. Chlorpropham, diuron, norea, and simazine provided 80% or more control of weeds for the whole season in Canada. An accumulation from yearly applications of simazine in the soil can cause complications for new transplants. Chlorpropham severely injured all three species tested. EPTC and endothall provided control only until about mid-season. Pyrazon caused browning of the needles of Colorado blue spruce and white spruce and also reduced growth. Norea and diuron reduced growth in Colorado blue spruce and Scotch pine (Grover, 1967).

Weed Control as a Problem with Alternative Fumigants

MeBr provided effective control of numerous weeds such as pigweed spp. (*Amaranthus* spp.), lambsquarters (*Chenopodium* spp.), oxalis (*Oxalis* spp.), hairy nightshade (*Solanum sarrachoides*), and others. In California strawberry production, most of the research performed on alternative fumigants has been concerned with the control of soil-borne pathogens. Plots are generally hand-weeded on a regular basis, so data on weed control is not generally recorded. If a fumigant does not control weeds as effectively as MeBr, the amount of labor needed for hand-weeding would increase. Growers in California are using herbicides for added weed control; however, only a few herbicides are labeled for use in strawberries. California researchers are screening new herbicides as a part of the IR-4 project (Carpenter et al., 2000).

In Florida, alternative fumigants do not fully control hard-seeded winter annual weeds and purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) in strawberry production. Researchers and growers are looking towards the use of herbicides for weed control. Researchers examined 12 herbicides applied preplant incorporated or preemergence in plastic mulched strawberries. The herbicides tested were: clopyralid, *s*-metolachlor, napropamide, prodiamine, simazine, terbacil, EPTC, norflurazon, trifluralin, oxyfluorfen, pendimethalin, and oryzalin. Oryzalin was the only herbicide that reduced plant vigor. Three treatments, simazine, oxyfluorfen, and a high rate of terbacil, provided season long control of two major weeds: Carolina geranium

(*Geranium carolinianum)* and cut-leaf evening primrose (*Oenothera laciniata)* (Carpenter et al., 2000). EPTC can be applied to dry soil and incorporated immediately for the control of nutsedge. Two applications may be required to control heavy infestations of nutsedge (McGiffen et al. 1997).

About two-thirds of the total acreage in caladium (*Caladium* spp.), an ornamental grown from tubers, production is fumigated with MeBr. Most of the world's caladium production occurs around Sebring, Florida. Growers have been experimenting with 1,3-D and metam sodium as alternatives to MeBr; however, weed control has become a problem. Growers currently are using oryzalin and *s*-metolachlor for weed control, but weed control can be inconsistent with these products (Carpenter et al., 2000).

Plan of Research

Most of the research on MeBr alternatives has been done with alternative soil fumigants in strawberries and tomatoes in Florida and California. Most of the research is on the control of soil-borne pathogens and nematodes and little has been done on weed control. It has been stated that the alternative fumigants are not as effective for weed control as MeBr. Most of the weed control studies have been conducted on container grown ornamentals and little research has been done on weed control for field grown herbaceous perennials. When growers start using alternative fumigants for ornamentals production it is likely that they will be supplementing the treatment with an herbicide program for weed control.

Most of the research done on weed control in conifer seedlings is in forest establishment. This research may be irrelevant to Michigan Christmas tree growers where tree quality is very important. Since nematodes are not a major problem in

Christmas tree production, growers can use a fungicide and herbicide program to control pathogens and weeds if proper alternatives are identified.

The objectives of this study were to 1) identify herbicide treatments that are safe on herbaceous perennials and conifer seedlings, 2) identify herbicide treatments that provide weed control similar to MeBr, and 3) make recommendations to growers on herbicide treatments that are safe on crops and provide good weed control. This study also evaluated the efficacy of various herbicides for control of field horsetail (*Equisetum arvense*) a hard to control perennial weed common in Christmas tree plantations and landscapes.

References

Anonymous. 2003. "Definition of Montreal Protocol." Available www.wordiq.com/definition/Montreal_Protocol.

Brown, J.H., W.F. Cowen Jr, and R.B. Heiligmann. 1991. "Ohio Christmas Tree Producers Manual." The Ohio State University Extension Bulletin 670.

Butler, J.H. and J.M Rodriguez. 1996. "Methyl Bromide in the Atmosphere." In: C.H. Bell et al., (eds.) The Methyl Bromide Issue, Vol. 1. Wiley. Chichester, England.

Carpenter, J., L. Gianessi, and L. Lynch. 2000. "The Economic Impact of the Scheduled U.S. Phaseout of Methyl Bromide." National Center for Food and Agricultural Policy. Washington, D.C.

Czarnota, M., J. Barney, K. Collins, R. Harmon, and R. McNiel. 1998. "Weed Control in Commercial Nurseries with EC and Granule Formulations of Thiazopyr." Proc. South. Nursery Assoc. Res. Conf. 43:411-418.

Derr, J. 1994. "Tolerance of Groundcovers to Preemergence Herbicides." Proc. South. Nursery Assoc. Res. Conf. 39:303-304.

Grover, R. 1967. "Effects of Chemical Weed Control on the Growth Patterns of Conifer Transplants." Weed Res. 7:155-163.

Klein, L. 1996. "Methyl Bromide as a Soil Fumigant." In: C.H. Bell et al., (eds.) The Methyl Bromide Issue, Vol. 1. Wiley. Chichester, England.

Kleweno, D.D. and V. Mathews. 2005. "Nursery and Christmas Tree Inventory 2004-2005." Michigan Rotational Survey. USDA, NASS, Michigan Field Office. Lansing, MI.

Koelling, M.R., J.B. Hart, and L. Leefers. 1998. "Christmas Tree Production in Michigan." Michigan State University Extension Ag Experiment Station Special Reports – SR619201.

Marshall, M.W. and B.H. Zandstra. 2006. "Evaluation of Ornamental Crop Tolerance to Sureguard and Sulfentrazone Herbicides." Michigan State University Extension Annual Report – SWMREC. Available www.maes.msu.edu/swmrec/publicationsfolder/Annualreports/06annualrpt/report index06.htm

McGiffen Jr., M.E., D.W. Cudney, E.J. Ogbuchiekwe, A. Baameur, and C.E. Bell. 1997. "Alternatives for Purple and Yellow Nutsedge Management." Proc. West. Soc. of Weed Science.

Murphy, T.R. and D.C. Fare. 1998. "Effects of Herbicides on Selected Perennials." Proc. South. Nursery Assoc. Res. Conf. 43:392-395.

Neal, J.C. and R.E. Wooten. 1998. "Postemergence Weed Control in Dormant Herbaceous Perennials." Proc. South. Nursery Assoc. Res. Conf. 43:366-369.

Nichols, T., E. Sucoff, C. Meehl, M. Lackey-Olsen, and A. Singsaas. 2001. "Herbicide Effects on Host Plants of Karner Blue Butterfly and on Butterfly Development from Egg to Adult." University of Wisconsin Water Resources Institute. DATCP Contract #96.02.

Osteen, C. 2000. "Economic Implications of the Methyl Bromide Phaseout." Economic Research Service, U.S. Department of Agriculture. Agriculture Information Bulletin No. 756 (AIB-756).

Porter, W.C. 1993. "Herbicides for Weed Control in Dormant Daylily." Proc. South. Nursery Assoc. Res. Conf. 38:319-321.

Putnam, D.H., E.S. Oplinger, L.L. Hardman, and J.D. Doll. 1989. "Lupine." Alternative Field Crops Manual. University of Wisconsin-Extension.

Ragsdale, N.N. 2004. "ARS Methyl Bromide Research." Methyl Bromide Home Page. Available www.ars.usda.gov/is/mb/mebrweb.htm.

Rauscher, K.J. 2005. "Pesticide & Plant Pest Management Division Annual Report." Michigan Department of Agriculture. Lansing, MI.

Richardson, R.J. and B.H. Zandstra. 2003a. "Liverwort and Hosta Response to Selected Herbicides." In Brown-Rytlewski, D. and J. O'Donnell Nursery, Landscape, and Christmas Tree Research Projects and Educational Programs. Michigan State University. Dec. 2003:9-11.

Richardson, R.J. and B.H. Zandstra. 2003b. "Knawel Control in Seedling Conifers." In Brown-Rytlewski, D. and J. O'Donnell Nursery, Landscape, and Christmas Tree Research Projects and Educational Programs. Michigan State University. Dec. 2003:9-11.

Rose, R. and J.S. Ketchum. 2003. "Interaction of initial seedling diameter, fertilization and weed control on Douglas-fir growth over the first four years after planting." Ann. For. Sci. 60:625-635.

Salihu, S., J.F. Derr, and K.K. Hatzios. 1999. "Differential Response of Ajuga (*Ajuga reptans)*, Wintercreeper (*Euonymus fortunei*), and Dwarf Burning Bush (*Euonymus alatus* 'Compacta') to Root- and Shoot-Applied Isoxaben." Weed Technology. 13:685-690.

Schutzki, R.E. and C. Peterson. 1998. "Status and Potential of Michigan Argriculture Phase II Report Nursery and Landscape." Michigan State University Extension Ag Experiment Station Special Reports – SR609201.

Vick, K.W. 2001. "Atmospheric Impact of Agricultural Use of MeBr." Agricultural Research Service. Newsletter Vol. 7, No. 2. Beltsville, MD.

Vick, K.W. 2002. "The Status of MeBr Alternatives." Agricultural Research Service. Newsletter Vol. 8, No. 1. Beltsville, MD.

CHAPTER TWO

ALTERNATIVE TREATMENTS TO METHYL BROMIDE FOR WEED CONTROL IN HERBACEOUS PERENNIAL PRODUCTION

ALTERNATIVE TREATMENTS TO METHYL BROMIDE FOR WEED CONTROL IN HERBACEOUS PERENNIAL PRODUCTION

Abstract

Ornamental growers have relied on methyl bromide (MeBr) for the control of nematodes, soil-borne pathogens, and weeds for many years. The removal of MeBr from the market has made it difficult for growers to control weeds adequately. Three field studies and two greenhouse studies were conducted in 2004, 2005, and 2006 to determine potential herbicide treatments as alternatives to MeBr for weed control. Field studies were initiated at the Southwest Michigan Research and Extension Center near Benton Harbor in 2004 and 2005. The third field study was established at Michigan State University in 2006. MeBr was applied in late May or early June of each year. Bugleweed (*Ajuga reptans* 'Gaiety'), periwinkle (*Vinca minor* 'Bowles'), daylily (*Hemerocallis* 'Stella D'Oro'), lupine (*Lupinus polyphyllus* 'Russell'), and hosta (*Hosta* spp.) were transplanted approximately 10 days after the MeBr applications. Herbicide treatments were applied over the top of the crops two days after planting. Herbicides tested included flumioxazin, oxyfluorfen, *s*-metolachlor, oxadiazon, dithiopyr, isoxaben, oryzalin, pendimethalin, and prodiamine. Herbicides were used alone or in tank mixes. The major weeds present included common ragweed (*Ambrosia artemisiifolia*), common lambsquarters (*Chenopodium album*), large crabgrass (*Digitaria sanguinalis*), and wild buckwheat (*Polygonum convolvulus*). Crop injury and weed control were visually rated on a 0-100% scale, with 0% equaling no crop injury or weed control and 100% equaling complete crop death or weed control. Measurements of the length and widths of bugleweed and periwinkle, the number of shoots and height of hosta and lupine, and the height and base width of daylily were taken at the end of each growing season. All treatments caused less

than 10% injury on periwinkle. Isoxaben (1.12 kg ai/ha), dithiopyr (0.28 kg ai/ha), and a combination of the two were safe on all the crops. Isoxaben plus oryzalin (3.36 kg ai/ha) and flumioxazin alone (0.28 kg ai/ha) provided the most consistent weed control but these treatments were injurious to some of the crops. No treatment controlled weeds as well or was as safe on the crops as MeBr.

Introduction

The nursery industry is an important part of Michigan's economy. Greenhouse and nursery crops ranked fourth behind dairy, corn, and cattle in cash receipts among farm products in 1990 (Schutzki and Peterson, 1998). Wholesale and retail sales of all nursery and ornamental crops totaled $261 million in 2004, with about $110 million of that being sold wholesale outside of Michigan. Wholesale and retail sales of herbaceous plants accounted for $108 million of the $261 million. There were over 1,200 grower operations that had more than 0.04 ha in ornamental production in 2004. In 2004, over 7,100 ha were used in the production of woody ornamentals and about 1,200 ha in herbaceous ornamentals. Of the 1,200 ha in herbaceous production, 1,050 ha were used for field grown production at 216 operations. The remaining 150 ha were used for container grown production at 385 operations. The number of ha of field grown ornamentals has increased from about 650 ha in 1999 to 1,050 ha in 2004 (Kleweno and Matthews, 2005). Michigan nursery stock is shipped for sale in 35 other states and to foreign markets (Rauscher, 2005).

Michigan growers have used methyl bromide (MeBr) to control weeds, nematodes, and soil-borne pathogens in their nursery beds. In 2000, Michigan growers applied approximately 221,000 kg of MeBr in herbaceous perennial ornamental, woody seedlings, and vegetable production. More than 90% of the total acreage in herbaceous perennial production was fumigated with MeBr in 2000 (Bird, 2004). Growers are seeking alternatives for MeBr to control their nursery pests. Growers report that nematodes and weeds are the greatest problems caused by the loss of MeBr (Dudek, personal communication).

Alternative fumigants do not provide the weed control that MeBr provided. Growers now must rely on hand-weeding, mulches, or herbicides for weed control. Oryzalin and *s*-metolachlor are labeled for most ornamentals; however, weed control has been inconsistent with these products (Carpenter et al., 2000). The purpose of this study was to identify herbicide treatments that can be alternatives to MeBr for weed control in herbaceous perennial crops.

Materials and Methods

Field Studies:

Field studies were established at the Southwest Michigan Research and Extension Center (SWMREC) near Benton Harbor, Michigan and the Horticulture Teaching and Research Center (HTRC) in Holt, Michigan. SWMREC is in a 6a and the HTRC is in a 5b USDA Hardiness Zone (www.usna.usda.gov/Hardzone/ushzmap.html). The soil classification for SWMREC is a Selfridge loamy sand, containing 87% sand, 12% silt and 1% clay with 1% organic matter, with a pH of 6.1. The soil classification for HTRC is Spinks loamy sand, containing 89% sand, 8% silt, and 3% clay with 1% organic matter, with a pH of 8.1.

In 2004, the first field study (Field 1) was established at SWMREC in early June. Methyl bromide:chloropicrin 98:2 (MeBr) was shank applied on June 2, 2004 at a rate of

392 kg/ha with a soil temperature of 21° C under moist soil conditions. The MeBr plots were tarped immediately after the application with a 3 m wide, 6 mil thick high density polyethylene plastic (HDPE). The tarps were removed after one week. Perennial species, bugleweed, daylily, lupine, and periwinkle, were planted on June 11, 2004. Plant species were planted in individual rows at in-row spacing of 46 cm and between row spacing of 183 cm. None of the lupine survived the transplanting.

Plots were arranged in a randomized complete block design with a plot size of 3.4 by 10.6 m and crop rows were randomly assigned. Field 1 consisted of 11 treatments with three replications. The treatments, rate, and crop labeling for Field 1 are listed in Table 2.1. All the treatments, except MeBr, were applied over the top of the crop on June 17, 2004. The liquid treatments were applied with a CO_2 backpack sprayer with four TeeJet® 8002 nozzles (Spraying Systems Co, Wheaton, Illinois) calibrated to apply 187 L/ha at 207 KPa of pressure and the granular herbicides were applied using a shaker bottle. Granular herbicides were not brushed off the crops. The 2004 treatments were applied when air and soil temperatures (5 cm deep) were approximately 26 and 24° C, respectively. The herbicide treatments were reapplied on June 9, 2005 when air and soil temperatures were 32 and 35° C, respectively. Overhead irrigation, 1.25 cm, was applied immediately after herbicide applications. Glufosinate was applied between rows before the 2005 re-application of herbicides to burn down emerged weeds.

In 2005, a second field study (Field 2) was established adjacent to Field 1, using the same design and treatments as in 2004, with the exception that MeBr 98:2 was replaced with MeBr 67:33 because MeBr 98:2 was not available. The treatments, rate, and crop labeling for Field 2 are listed in Table 2.1. The MeBr was shank applied on

May 24, 2005 with soil temperature of 19°C under dry soil conditions. The MeBr plots were tarped with HDPE immediately after application. The tarps were removed 10 days after application. Crops were planted on June 7, 2005 and the herbicide treatments were applied on June 9, 2005 with air and soil temperatures (5 cm deep) of 32 and 35°C, respectively. The lupine again did not survive transplanting. All treatments, including MeBr 67:33, were reapplied in 2006. MeBr was reapplied because of poor weed control in 2005. The crops were removed and MeBr was drip applied under HDPE on June 1, 2006 with soil temperature of 22°C under dry soil conditions. The tarps were removed on June 9, 2006. New bugleweed, periwinkle, and daylily plants were transplanted in the MeBr plots on June 12, 2006. Hosta was transplanted on June 12, 2006 as a replacement for lupine. The herbicides were reapplied on June 12, 2006 with air and soil temperatures of 18 and 24°C, respectively.

In mid-June 2006, a third field study (Field 3) was established at HTRC. The treatments, rates, and crops labeled for Field 3 are listed in Table 2.2. 1,3-dichloropropene: chloropicrin 65:35 (1,3-D) was shank applied on May 25, 2006 at a rate of 327 L/ha with a soil temperature of approximately 16°C under dry soil conditions. The 1,3-D plots were tarped with HDPE immediately after application. The MeBr was drip applied under HDPE on June 6, 2006 with soil temperature of 22°C under dry soil conditions. The tarps were removed on June 12, 2006. Five plants each of bugleweed, periwinkle, daylily, lupine, and hosta were planted in individual rows in the herbicide plots on June 13, 2006. The crops were transplanted into MeBr and 1,3-D plots on June 15, 2006. Herbicide treatments were applied on June 15, 2006 with air and soil temperatures of 26 and 27°C, respectively. Plot design and application methods were the same as Field 1.

To insure that crop injury was due to herbicide injury and not weed competition, an area of approximate 15 cm radius was hand weeded around the crop plants. Large crabgrass (*Digitaria sanguinalis)* and quackgrass (*Elytrigia repens)* were present in large numbers in 2005, so beginning one month after treatments, sethoxydim or clethodim were applied monthly to Fields 1 and 2 to control the grasses. The inter-row areas were mowed two months after treatments in 2004 and 2005.

Crop injury was measured on a visual scale from 0 (no injury) to 100% (plant death). Bugleweed and periwinkle length and width, daylily height, and lupine and hosta shoot count and height were measured at the end of each growing season. Weed control was measured on a visual scale from 0 (no control) to 100% (complete control). Each crop and weed species was rated individually. The untreated control plot was used as a standard for weed control and crop injury ratings. Ratings were recorded monthly throughout the growing season. The ratings at three MAT for crop injury and two MAT for most weed species are reported. Data were subjected to ANOVA and means were separated using Fisher's LSD at the p=0.05 level.

Greenhouse studies:

Two greenhouse studies were conducted during the summer of 2005, to evaluate herbicide toxicity to bugleweed, periwinkle, lupine, and daylily. Greenhouse Study 1 was initiated in mid-June and Greenhouse Study 2 was initiated in mid August. The crops were greenhouse grown in 10 X 10 X 15 cm plastic pots filled with Baccto® potting mix (Michigan Peat Co., Houston, TX). Four plants from each crop were picked at random per treatment. New plants were used in Greenhouse Study 2, but were planted at the same time as the plants in Greenhouse Study 1. The liquid herbicide treatments were applied in a moving track spray chamber (Allen Machine Works, Midland, MI) with a single Teejet® 8001 EVS nozzle (Spraying Systems Co, Wheaton, Illinois) calibrated to apply 187 L/ha at 207 KPa of pressure. The granular treatments were applied using a shaker bottle. The plants treated with granular herbicides were brushed off by hand to remove granules from the leaves. The treatment list is the same as field studies 1 and 2, with the exception of MeBr (Table 2.1). After treatment applications, the crops were returned to the greenhouse and irrigated.

Data were subjected to ANOVA and means were separated using Fisher's LSD at the $p=0.05$ level. Bugleweed and periwinkle widths, daylily heights, and lupine shoot counts were recorded before treatment application and 6 weeks after treatment. The difference between initial and final measurements was analyzed. Crop injury was measured on a visual scale from 0 (no injury) to 100% (plant death) at six weeks after treatment.

Results and Discussion

Field Studies: Crop Injury

Visual injury to bugleweed was less than 25% for all treatments at all rating dates (Table 2.3). Data for two months after treatment, instead of three months, are presented for Field 1 in 2005 because of plant dieback due to summer stress, which made it difficult to differentiate between plant stress and herbicide injury. Oxadiazon, flumioxazin, isoxaben plus oryzalin, oxadiazon plus pendimethalin, *s*-metolachlor, dithiopyr, and oxyfluorfen plus pendimethalin caused 10% or greater visual injury for one or more ratings. Oxadiazon plus pendimethalin caused the most injury with 23 and 15% in Field 3 in 2006 and Field 1 in 2005, respectively. Oxyfluorfen plus pendimethalin caused 15% injury in Field 3 in 2006. MeBr, 1,3-D, isoxaben plus prodiamine, and oxyfluorfen plus prodiamine caused no visual injury to bugleweed; however, isoxaben, isoxaben plus *s*-metolachlor, and isoxaben plus dithiopyr were not statistically ($p>0.05$) different from these treatments.

Flumioxazin and *s*-metolachlor consistently reduced growth in bugleweed plants compared to MeBr (Table 2.3). Oxadiazon, flumioxazin, isoxaben plus *s*-metolachlor, *s*-metolachlor, and the untreated control had bugleweed plants with reduced growth ($p<0.05$) compared toMeBr in Field 1 in 2004. Flumioxazin, isoxaben plus oryzalin, isoxaben plus *s*-metolachlor, *s*-metolachlor, dithiopyr, and the untreated control reduced growth ($p<0.05$) compared to MeBr in Field 1 in 2005. All treatments had plants with reduced growth compared to MeBr in Field 2 in 2005. MeBr plant sizes were not available in Field 2 in 2006 because the plants were removed and replaced at the beginning of the season. In Field 2 in 2006, isoxaben, isoxaben plus oryzalin, and *s*-metolachlor had the largest plants. Oxadiazon, flumioxazin, isoxaben, *s*-metolachlor, dithiopyr, oxyfluorfen plus pendimethalin, and oxyfluorfen plus prodiamine had bugleweed plants with reduced growth ($p<0.05$) compared to MeBr in Field 3 in 2006.

No visual injury ($p>0.05$) was observed on periwinkle (Table 2.4). The most injury was observed with flumioxazin (7% injury) three months after treatment in Field 1 in 2005. Field 1 in 2004 and Field 2 in 2005 and 2006 plant size measurements were not statistically different. Oxadiazon, isoxaben, isoxaben plus oryzalin, and isoxaben plus *s*-metolachlor had periwinkle plants with less growth ($p<0.05$) compared to MeBr in Field

1 in 2005. Isoxaben plus oryzalin, isoxaben plus dithiopyr, isoxaben plus *s*-metolachlor, oxyflurofen plus prodiamine, and oxyfluorfen plus pendimethalin had periwinkle plants with reduced growth ($p<0.05$) compared to MeBr in Field 3 in 2006.

Visual injury to daylily was less than 25% for all treatments for all rating dates (Table 2.5). Flumioxazin, isoxaben plus *s*-metolachlor, oxadiazon plus pendimethalin, *s*-metolachlor, oxyfluorfen plus pendimethalin, and oxyfluorfen plus prodiamine caused 10% or greater injury to daylily for one or more ratings. No visual injury ($p>0.05$) was observed in Field 1 in 2004. Flumioxazin caused visual injury ($p<0.05$) in Field 1 in 2005 and Fields 2 and 3 in 2006. Isoxaben plus *s*-metolachlor caused visual injury ($p<0.05$) in Field 1 in 2005. Oxadiazon plus pendimethalin caused visual injury ($p<0.05$) in Field 2 in both 2005 and 2006 and in Field 3 in 2006. *S*-metolachlor caused visual injury ($p<0.05$) in Field 2 in 2005. Oxyfluorfen plus pendimethalin and oxyfluorfen plus prodiamine caused visual injury ($p<0.05$) to daylily in Field 3 in 2006. Compared to MeBr, only flumioxazin in Field 1 in 2005 and oxadiazon plus pendimethalin and isoxaben plus prodiamine in Field 3 in 2006 had smaller daylily heights ($p<0.05$). Isoxaben plus dithiopyr, oxadiazon plus pendimethalin, *s*-metolachlor, and dithiopyr tended to have taller plants by the end of the second year of the field studies.

Granular herbicides tended to collect in the center of the daylily plants and cause injury. The plants would recover from most of the injury by the end of the year. "Drawstring" injury was observed on the leaves of daylilies treated with *s*-metolachlor, but the injury was seldom still visible by the end of the season.

In Field 3 in 2006, oxyfluorfen plus pendimethalin and oxadiazon plus pendimethalin caused 15 and 10% visual injury to hosta (Table 2.6). Oxadiazon caused

8% injury in Field 2 in 2006. Isoxaben plus dithiopyr was the only treatment that had a reduction ($p<0.05$) in the number of shoots in Field 2 in 2006 compared to MeBr. There was no difference ($p>0.05$) among all the treatments for plant height in Field 2 in 2006. The number of shoots in Field 3 in 2006 was similar ($p>0.05$) among treatments and plants in all treatments grew as well as plants treated with MeBr.

Oxadiazon, isoxaben plus prodiamine, oxyfluorfen plus pendimethalin, and oxyfluorfen plus prodiamine all caused visual injury ($p<0.05$) to lupine in Field 3 in 2006 (Table 2.6). Oxyfluorfen plus pendimethalin and oxadiazon caused the most visual injury at 37 and 27%, respectively. No injury was observed in the MeBr, isoxaben, dithiopyr, and 1,3-D plots. Oxadiazon, isoxaben plus *s*-metolachlor, *s*-metolachlor, oxyfluorfen plus pendimethalin, and the untreated control had fewer shoots ($p<0.05$) in Field 3 in 2006. There was no difference ($p>0.05$) among treatments in plant height.

Field studies: Weed Control

No treatments, including MeBr, provided greater than 80% control of large crabgrass (*Digitaria sanguinalis*) for all rating dates (Table 2.7). In 2004, flumioxazin, isoxaben plus oryzalin, and isoxaben plus *s*-metolachlor gave 80, 82, and 83% control. Oxadiazon was the only treatment that provided less large crabgrass control ($p<0.05$) than MeBr in 2004. Isoxaben plus dithiopyr and dithiopyr alone provided the best control in 2005 in both Fields 1 and 2. Isoxaben plus dithiopyr provided 68 and 87% control in Fields 1 and 2, respectively, while dithiopyr alone provided 85 and 83% control. In Field 1 in 2005, MeBr was not reapplied so no control was observed; however, isoxaben plus dithiopyr and dithiopyr alone were the only treatments to have better control ($p<0.05$) than MeBr. In Field 2 in 2005, isoxaben plus dithiopyr and dithiopyr alone provided control similar to MeBr. Field 2 was rated one month after treatment in 2005, because a postemergence grass herbicide was applied after the rating to control quackgrass (*Elytrigia repens).* In 2006 in Field 2, MeBr, dithiopyr, and isoxaben plus dithiopyr provided 90, 90, and 88% control. Large crabgrass control was poor for most treatments in 2005, compared with 2004 and 2006. Large crabgrass was not present in Field 3; however, stinkgrass (*Eragrostis cilianensis*) was present (Table 2.7). Isoxaben plus prodiamine and isoxaben plus oryzalin provided 93 and 92% control of stinkgrass, respectively. Oxadiazon did not control stinkgrass and isoxaben alone and oxyfluorfen plus pendimethalin provided less than 50% control.

MeBr was the only treatment to provide better than 80% control of common ragweed (*Ambrosia artemisiifolia)* at all rating dates (Table 2.8). Flumioxazin, MeBr, and isoxaben plus oryzalin provided the most consistent control, providing greater than 65% control for all rating dates. In 2004, all treatments except isoxaben provided greater than 60% control of common ragweed, with *s*-metolachlor, MeBr, and flumioxazin providing the best control at 98, 97, and 95%, respectively. In 2005 in Field 1, all treatments provided at least 60% control, with MeBr, isoxaben plus dithiopyr, and dithiopyr all providing 100% control. Isoxaben was the only treatment that did not control ($p<0.05$) common ragweed as well as MeBr for both years in Field 1. Common ragweed control was generally less for all treatments in Field 2 than Field 1 in 2005. MeBr, isoxaben plus oryzalin, and isoxaben alone provided the best control in Field 2 with 97, 77, and 67% control, respectively. Common ragweed control with oxadiazon, isoxaben plus *s*-metolachlor, isoxaben plus dithiopyr, oxadiazon plus pendimethalin, *s*-metolachlor, and dithiopyr was less ($p<0.05$) than MeBr in Field 2 in 2005. Common ragweed control in Field 2 was better in 2006 than in 2005. All treatments, except dithiopyr and oxadiazon, provided greater than 80% control of common ragweed in Field 2 in 2006.

Oxadiazon was the only treatment to provide greater than 80% control of common lambsquarters (*Chenopodium album*) for all rating dates (Table 2.9). Flumioxazin, oxadiazon, oxadiazon plus pendimethalin, isoxaben plus oryzalin and MeBr all provided 97% or greater control in Field 1 in 2004; however, treatments were not different from MeBr. Common lambsquarters control did not vary ($p>0.05$) among treatments for Field 1 in 2005. Oxadiazon, flumioxazin, MeBr, and isoxaben plus *s*-metolachlor all provided greater than 92% control in Field 2 in 2005. Common lambsquarters control was less ($p<0.05$) with isoxaben plus dithiopyr, *s*-metolachlor, and dithiopyr. In Field 2 in 2006, oxadiazon plus pendimethalin, oxadiazon, and isoxaben plus *s*-metolachlor provided 93, 83, and 83% control, respectively, which provided more control ($p<0.05$) of common lambsquarters than MeBr. Oxadiazon, flumioxazin, isoxaben, isoxaben plus oryzalin, isoxaben plus dithiopyr, oxadiazon plus pendimethalin, *s*-metolachlor, isoxaben plus prodiamine, and oxyfluorfen plus prodiamine all provided 90% or greater control of common lambsquarters in Field 3 in 2006. Dithiopyr and *s*-metolachlor were the only treatments that provided less control ($p<0.05$) of common lambsquarters than MeBr.

MeBr was the only treatment to control wild buckwheat (*Polygonum convolvulus*), consistently (Table 2.10). Wild buckwheat was not a major weed problem in 2004. Flumioxazin, MeBr, and isoxaben alone provided 98, 93, and 92% control in Field 1 in 2005, respectively. Isoxaben plus *s*-metolachlor and isoxaben plus dithiopyr were the only two treatments that provided less control ($p<0.05$) than MeBr. In Field 2 in

2005, isoxaben plus oryzalin and MeBr were the only treatments to have greater than 60% control, providing 68 and 97% control, respectively. All treatments, except isoxaben plus oryzalin, provided less control ($p<0.05$) than MeBr. Flumioxazin, isoxaben plus oryzalin, isoxaben, and MeBr provided the best control in Field 2 in 2006, providing 77, 77, 90 and 97% control, respectively. Isoxaben plus dithiopyr, *s*-metolachlor, and dithiopyr provided less control ($p<0.05$) of wild buckwheat than MeBr in Field 2 in 2006.

Oxadiazon, flumioxazin, isoxaben plus oryzalin, and oxadiazon plus pendimethalin provided greater than 80% control of carpetweed (*Mollugo verticillata)* for all rating dates (Table 2.10). Isoxaben plus oryzalin, oxadiazon plus pendimethalin, and flumioxazin provided 100, 100, and 98% control in Field 1 in 2004, respectively. Oxadiazon, flumioxazin, and MeBr all controlled carpetweed 100% in Field 2 in 2005. Isoxaben plus *s*-metolachlor and *s*-metolachlor alone provided less control ($p<0.05$) than MeBr in Field 2 in 2005. Flumioxazin, isoxaben plus oryzalin, isoxaben plus prodiamine, and oxyfluorfen plus pendimethalin all controlled carpetweed 100% in Field 3 in 2006. All treatments except *s*-metolachlor provided better ($p<0.05$) carpetweed control than MeBr in Field 3 in 2006.

Oxadiazon, isoxaben plus oryzalin, and isoxaben plus dithiopyr provided greater than 80% control of pigweed (*Amaranthus* spp.) for both rating dates (Table 2.11). Only redroot pigweed (*Amaranthus retroflexus*) was present in Field 2. Three species of pigweed were present in Field 3: tumble pigweed (*Amaranthus albus*), prostrate pigweed (*Amaranthus blitoides*), and redroot pigweed. All three pigweed species were rated together as one. Flumioxazin and oxadiazon plus pendimethalin provided 100% control and oxadiazon, isoxaben, isoxaben plus *s*-metolachlor, and dithiopyr each gave 93% control of pigweed in Field 2 in 2006. Oxyfluorfen plus pendimethalin, oxyfluorfen plus prodiamine, and isoxaben plus oryzalin provided 100, 98, and 95% control in Field 3 in 2006. Dithiopyr, in Field 3 in 2006, was the only treatment to provide less control ($p<0.05$) than MeBr for both fields.

Vetch (*Vicia* spp.) was a major weed problem in Field 1 in 2004 (Table 2.11). Dithiopyr, MeBr, and *s*-metolachlor did not control vetch. Flumioxazin provided the best control at 92%. No other treatment provided greater than 80% control.

Greenhouse studies: Crop Injury

Oxadiazon caused the most injury to bugleweed in both Greenhouse Study 1 (GS1) and Greenhouse Study 2 (GS2) (Table 2.12). Oxadiazon caused 54% injury in GS1. No other treatments caused visual injury ($p<0.05$) in GS1. There was no difference ($p>0.05$) among treatments in GS2; however, oxadiazon, isoxaben, isoxaben plus *s*-metolachlor, isoxaben plus dithiopyr, and *s*-metolachlor caused more than 10% injury. Oxadiazon was the only treatment that had a reduction ($p<0.05$) in plant size in GS1 compared to the untreated control. Plant size did not vary ($p>0.05$) in GS2.

The only treatment to cause injury to periwinkle in GS1 was *s*-metolachlor (Table 2.12). There was no difference ($p>0.05$) among treatments for periwinkle injury in GS2 and plant size in GS1 and GS2.

The most injury observed six weeks after treatment on daylily was 5% caused by oxadiazon in GS2 (Table 2.13). Injury to daylily did not vary ($p>0.05$) among all treatments in GS1. "Drawstring" injury was observed on daylily leaves treated with *s*-metolachlor but most injury was absent by six weeks after treatment. Compared to the untreated control, no treatments reduced height ($p<0.05$) in GS1. Daylily height did not vary ($p>0.05$) among treatments in GS2.

There was no difference ($p>0.05$) among treatments for injury or shoot counts in lupine in both GS1 and GS2 (Table 2.13). All treatments caused injury to lupine. Dithiopyr and *s*-metolachlor tended to cause the least amount of injury.

Conclusions

No treatments provided the broad spectrum weed control that was as safe on the crops as MeBr.

Isoxaben and isoxaben plus dithiopyr caused little or no injury on bugleweed for all the rating dates in the field studies. Injury did occur with these two treatments in GS2, but little injury was seen in GS1. Salihu et al. (1999) observed about 40% shoot injury from three different rates of isoxaben applied to bugleweed. They also observed 17, 17, and 48% reduction in fresh shoot weight and 17, 12, and 32% reduction in root fresh weight in bugleweed treated with 0.84, 1.69, and 3.39 kg ai/ha, respectively. Both treatments only provided poor to moderate control of weeds. Flumioxazin and isoxaben plus oryzalin provided the best weed control but caused significant injury to bugleweed. Isoxaben plus prodiamine and 1,3-D were safe on bugleweed and provided fair to good weed control; however more research is needed on these treatments. Isoxaben and isoxaben plus dithiopyr caused the least amount of injury to bugleweed; however the isoxaben label[1] warns about the use of isoxaben on bugleweed.

All treatments were fairly safe on periwinkle in the field and greenhouse studies. Flumioxazin caused 7% injury in the second year of Field 1, but only minor injury was

[1] Gallery® Dow Agroscience, Indianapolis, IN

observed on the other dates. Isoxaben plus oryzalin was the only treatment that produced small plants in the field studies. Flumioxazin is not currently labeled for use in periwinkle, but could be considered as a possible alternative if labeled. Flumioxazin provided good over all control except for large crabgrass. Further research should be conducted to test the use of flumioxazin plus dithiopyr for use in periwinkle. Isoxaben plus oryzalin provided good control with minimal visual injury; however, a reduction in plant size may occur.

Isoxaben plus dithiopyr, isoxaben plus oryzalin, and dithiopyr caused the least amount of visual injury to daylily. Dithiopyr alone provided good control of large crabgrass but provided poor or inconsistent control of the other weeds present. Isoxaben plus dithiopyr provided good control of large crabgrass and carpetweed, but was weak on common lambsquarters and wild buckwheat and provided inconsistent control of the other weeds. Isoxaben plus oryzalin provided good control of all weeds except large crabgrass. Some plant size reduction was seen in GS1, but not in any of the other studies. Isoxaben plus oryzalin might be a good option for weed control for growers; however, growers need to control large crabgrass with a postemergence herbicide or possibly by adding dithiopyr.

Isoxaben, isoxaben plus oryzalin, dithiopyr, and 1,3-D did not cause visual injury to hosta. No greenhouse study was performed on hosta. Dithiopyr was the only treatment that consistently had a low number of hosta shoots. No treatments resulted in consistently short plants. Since only one year of data is available, more research is needed to confirm these results on hosta.

Oxyfluorfen plus pendimethlin and *s*-metolachlor were the only treatments currently labeled for use in lupine; however, oxyfluorfen plus pendimethlin was not labeled for our species of lupine. Dithiopyr was one of the safest treatments in both the greenhouse and field studies. 1,3-D also did not cause injury in the field. Isoxaben alone was safe in the field but tended to injury lupine in the greenhouse. Dithiopyr and 1,3-D had acceptable crop safety but insufficient weed control. Since only one field and one year of data was collected, more research is needed to confirm these results.

Isoxaben plus oryzalin and flumioxazin provided the best weed control of the alternative treatments tested. Flumioxazin currently is not labeled for any of the crops tested, but did show potential for the use in periwinkle. Isoxaben plus oryzalin provided the best overall weed control and was safe on daylily and hosta. No visual injury was observed on periwinkle and isoxaben plus oryzalin is labeled for the use in periwinkle, but plant growth was reduced with this treatment. Isoxaben plus dithiopyr was the best treatment in bugleweed; however, the isoxaben label warns against the use in bugleweed, because of root and shoot injury.

Further research is needed on hosta and lupine and for the treatments 1,3-D, isoxaben plus prodiamine, oxyfluorfen plus prodiamine, and oxyfluorfen plus pendimethalin. New research should be conducted on the effects of using herbicide treatments in combination with 1,3-D for weed control in these crops.

Table 2.1: Herbicides, rates, and crops labeled for the treatments used in Field 1 in 2004 and 2005 on bugleweed (AR), periwinkle (VM), daylily (HS), and lupine (LS) and in Field 2 in 2005 and 2006 on AR, VM, HS, LS, and hosta (HT).

	Treatment[a]	Rate	Labeled[b]
1	MeBr:Chloropicrin[c]	392 kg/ha	AR/HS/VM/LS/HT
2	Dithiopyr 1EC	0.28 kg ai/ha	AR/HS/VM/HT
3	Flumioxazin 0.25G	0.28 kg ai/ha	NONE
4	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
5	Oxadiazon 2G	2.24kg ai/ha	AR/VM
6	*s*-Metolachlor 7.62EC	1.68 kg ai/ha	AR/HS/VM/LS/HT
7	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	Dithiopyr 1EC	0.28 kg ai/ha	
8	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	Oryzalin 4AS	3.36 kg/ha	
9	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
10	Oxadiazon 2G	2.24 kg ai/ha	AR/VM
	Pendimethalin 1.25G	1.40 kg ai/ha	
11	Untreated Control		

[a]G=granular, DF=dry flowable, AS=aqueous solution, EC=emulsifiable concentrate

[b]AR=bugleweed, VM=periwinkle, HS=daylily, LS=lupine, HT=hosta

[c]MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Field 2.

Table 2.2: Herbicides, rates, and crops labeled for the treatments used in Field 3 in 2006 on bugleweed (AR), periwinkle (VM), daylily (HS), lupine (LS), and hosta (HT).

	Treatment[a]	Rate	Labeled[b]
1	MeBr:Chloropicrin 67:33	392 kg/ha	AR/HS/VM/LS/HT
2	1,3-D:Chloropicrin 65:35	327 L/ha	AR/HS/VM/LS/HT
3	Dithiopyr 1EC	0.28 kg ai/ha	AR/HS/VM/HT
4	Flumioxazin 0.25G	0.28 kg ai/ha	NONE
5	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
6	Oxadiazon 2G	2.24kg ai/ha	AR/VM
7	*s*-Metolachlor 7.62EC	1.68 kg ai/ha	AR/HS/VM/LS/HT
8	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	Dithiopyr 1EC	0.28 kg ai/ha	
9	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	Prodiamine 4FL	1.68 kg ai/ha	
10	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	Oryzalin 4AS	3.36 kg/ha	
11	Isoxaben 75DF	1.12 kg ai/ha	HS/VM/HT
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
12	Oxadiazon 2G	2.24 kg ai/ha	AR/VM
	Pendimethalin 1.25G	1.40 kg ai/ha	
13	Oxyflourfen 2G	2.24 kg ai/ha	HS/VM/LS
	Pendimethalin 1G	1.12 kg ai/ha	
14	Oxyflourfen 4FL	0.28 kg ai/ha	NONE
	Prodiamine 4FL	1.68 kg ai/ha	
15	Untreated Control		

[a]G=Granular. DF=Dry flowable. AS=Aqueous solution. EC=Emulsifiable concentrate. FL=Flowable.

[b]AR=Bugleweed. VM=Periwinkle. HS=Daylily. LS=Lupine. HT=Hosta.

Table 2.3: Percent visual injury and the end of season plant size (length multiplied by width) (cm^2) for bugleweed in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006 treated with potential alternatives to MeBr for weed control.

Crop	Bugleweed									
Field	1	1	2	2	3	1	1	2	2	3
Year	2004	2005	2005	2006	2006	2004	2005	2005	2006	2006
MAT[a]	3	2[b]	3	3	3	4	4	4	4	4
Rating[c]	%Injury	%Injury	%Injury	%Injury	%Injury	Size(cm^2)	Size(cm^2)	Size(cm^2)	Size(cm^2)	Size(cm^2)
MeBr:Chloropicrin[d]	0	0	0	0	0	1100	3295	1010	NA[e]	1710
Dithiopyr	0	10*	0	0	0	1280	2250*	400*	1045	1180
Flumioxazin	10*	5*	8*	8*	10*	420*	1510*	500*	1380	870*
Isoxaben	3	0	0	0	0	835	2730	490*	1635	1060*
Oxadiazon	10*	7*	0	7*	5	655*	2920	575*	1480	845*
s-Metolachlor	5*	NA[f]	10*	2	0	710*	1590*	380*	1715	850*
Isoxaben + Dithiopyr	2	0	0	0	2	1190	2360	400*	910	1185
Isoxaben + Oryzalin	3	10*	0	3	0	810	1815*	440*	2100	1290
Isoxaben + *s*-Metolachlor	2	5*	5	0	0	685*	1580*	470*	1215	1215
Oxadiazon + Pendimethalin	2	15*	23*	7*	8*	1045	2520	330*	1270	800*
Isoxaben + Prodiamine	NP	NP	NP	NP	0	NP	NP	NP	NP	1285
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	15*	NP	NP	NP	NP	490*
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	0	NP	NP	NP	NP	740*
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	0	NP	NP	NP	NP	1700
Untreated	0	0	0	0	0	680*	1500*	420*	1445	1450
LSD (0.05)	4	3	7	6	7	344	1044	220	607	594
CV	64	71	100	148	162	62	66	58	65	72
p-value	<0.0001	0.0007	0.0003	0.0395	0.0018	<0.0001	0.0015	<0.0001	0.0108	0.0015

[a] Abreviations: MAT=Months after herbicide treatments. NA=Not available. NP=Treatment not present. LSD=Least significant difference.

[b] Plant dieback occurred 3MAT, 2MAT was used.

[c] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Size=average length multiplied by average width.

[d] MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Fields 2 and 3.

[e] Plants in MeBr plots were removed at the end 2005 and new plants were planted 2006.

[f] *s*-metolachlor was N/A because of plant dieback in two plots.

*Treatments statistically different from MeBr:Chloropicrin.

Table 2.4: Percent visual injury and the end of season plant size (length multiplied by width) (cm^2) for periwinkle in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006 treated with potential alternatives to MeBr for weed control.

Crop	Periwinkle									
Field	1	1	2	2	3	1	1	2	2	3
Year	2004	2005	2005	2006	2006	2004	2005	2005	2006	2006
MAT[a]	3	3	3	3	3	4	4	4	4	4
Rating[b]	%Injury	%Injury	%Injury	%Injury	%Injury	Size(cm^2)	Size(cm^2)	Size(cm^2)	Size(cm^2)	Size(cm^2)
MeBr:Chloropicrin[c]	0	0	0	0	0	1375	3800	740	NA[d]	2245
Dithiopyr	0	0	0	0	0	1440	3670	560	2405	1970
Flumioxazin	2	7	0	0	0	1130	3240	1025	2730	1650
Isoxaben	3	0	0	0	0	1370	2440*	370	2040	1500
Oxadiazon	2	3	0	0	0	1045	1830*	255	2660	2080
s-Metolachlor	3	3	0	0	2	1580	4420	370	2800	1835
Isoxaben + Dithiopyr	3	0	0	0	2	1300	3870	520	2295	1035*
Isoxaben + Oryzalin	2	2	0	0	0	930	2445*	285	1980	1320*
Isoxaben + *s*-Metolachlor	3	0	0	0	0	1045	2665*	1155	2360	835*
Oxadiazon + Pendimethalin	2	0	0	0	0	1590	4690	240	2375	1955
Isoxaben + Prodiamine	NP	NP	NP	NP	0	NP	NP	NP	NP	1040*
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	0	NP	NP	NP	NP	1600
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	3	NP	NP	NP	NP	1280*
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	0	NP	NP	NP	NP	1630
Untreated	0	0	0	0	0	1270	1760*	1000	1905	2190
LSD (0.05)	NS	NS	NS	NS	NS	NS	1085	NS	NS	784
CV	124	198	0	0	413	63	54	111	58	66
p-value	0.386	0.149	0	0	0.6252	0.155	<0.0001	0.398	0.528	0.0029

[a] Abreviations: MAT=Months after herbicide treatments. NA=Not available. NP=Treatment not present. NS=Not significant. LSD=Least significant difference. CV=Coefficient of variance.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Size=average length multiplied by average width.

[c] MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Fields 2 and 3.

[d] Plants in MeBr plots were removed at the end 2005 and new plants were planted 2006.

*Treatment statistically different from MeBr:Chloropicrin.

Table 2.5: Percent visual injury and end of season plant height (cm) for daylily in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006 treated with potential alternatives to MeBr for weed control.

Crop	Daylily									
Field	1	1	2	2	3	1	1	2	2	3
Year	2004	2005	2005	2006	2006	2004	2005	2005	2006	2006
MAT[a]	3	3	3	3	3	4	4	4	4	4
Rating[b]	%Injury	%Injury	%Injury	%Injury	%Injury	Height (cm)	Height (cm)	Height (cm)	Height (cm)	Height (cm)
MeBr:Chloropicrin[c]	0	0	0	0	0	26.0	34.7	28.6	NA[d]	29.2
Dithiopyr	5	0	0	0	0	30.5	45.4	25.8	49.1	31.4
Flumioxazin	3	13*	0	12*	10*	25.4	28.3*	27.5	47.0	28.3
Isoxaben	3	7	0	0	0	30.9	33.9	28.3	48.9	31.1
Oxadiazon	2	8	0	3	7	30.4	38.5	29.6	44.9	29.3
s-Metolachlor	3	8	10*	3	5	26.6	45.4	28.1	49.3	27.8
Isoxaben + Dithiopyr	3	2	0	0	0	28.1	44.8	27.6	49.3	28.9
Isoxaben + Oryzalin	5	3	0	3	0	28.6	38.6	26.4	44.4	28.7
Isoxaben + s-Metolachlor	3	15*	3	5	3	28.5	33.9	27.6	47.2	28.7
Oxadiazon + Pendimethalin	3	0	8*	8	15*	29.6	44.0	28.5	48.1	26.6*
Isoxaben + Prodiamine	NP	NP	NP	NP	7	NP	NP	NP	NP	26.7*
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	22*	NP	NP	NP	NP	27.8
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	10*	NP	NP	NP	NP	26.8
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	0	NP	NP	NP	NP	32.6
Untreated	0	0	0	0	0	26.6	33.3	28.2	45.8	30.0
LSD	NS	10	5	6	9	NS	5.3	NS	3.6	2.4
CV	80	112	130	118	101	22	20	17	12	11
p-value	0.1779	0.033	0.0005	0.0123	0.0003	0.125	<0.0001	0.5241	0.027	<0.0001

[a] Abreviations: MAT=Months after herbicide treatments. NP=Treatment not present. NS=Not significant. LSD=Least significant difference. CV=Coefficient of variance. NA=Not available.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height=distance from the ground to the tallest point.

[c] MeBr 98:2 in Field 1 and 67:33 in Fields 2 and 3.

[d] Plants in MeBr plots were removed at the end 2005 and new plants were planted 2006.

*Treatments with significant injury or reduction in height compared to MeBr:Chloropicrin.

Table 2.6: Percent visual injury and end of season shoot count and crop height for hosta in Fields 2 and 3 in 2006 and lupine in Field 3 in 2006 treated with potential alternatives to MeBr for weed control.

Crop	Hosta						Lupine		
Field	2	3	2	2	3	3	3	3	3
Year	2006	2006	2006	2006	2006	2006	2006	2006	2006
MAT[a]	3	3	4	4	4	4	3	4	4
Rating[b]	%Injury	%Injury	# Shoots	Height(cm)	# Shoots	Height(cm)	%Injury	# Shoots	Height(cm)
MeBr:Chloropicrin 67:33	0	0	11.7	14.2	8	11.6	0	58	19.8
Dithiopyr	0	0	9.6	15.6	6	11.8	0	40	17.8
Flumioxazin	2	7	10.8	11.5	12	11.5	5	41	13.8
Isoxaben	0	0	13.0	13.0	7	11.6	0	43	16.9
Oxadiazon	8*	3	14.3	16.4	8	10.8	27*	29*	14.1
s-Metolachlor	0	7	10.2	14.7	11	9.6	12	23*	13.9
Isoxaben + Dithiopyr	0	3	5.9*	12.6	12	11.8	5	47	15.5
Isoxaben + Oryzalin	0	0	8.2	11.3	9	12.7	3	53	19.6
Isoxaben + s-Metolachlor	2	7	9.8	12.4	11	14.1	13	36*	14.9
Oxadiazon + Pendimethalin	0	10*	12.5	12.5	9	11.8	5	38	14.6
Isoxaben + Prodiamine	NP	0	NP	NP	9	9.9	20*	41	15.4
Oxyfluorfen + Pendimethalin	NP	15*	NP	NP	11	10.4	37*	34*	15.5
Oxyfluorfen + Prodiamine	NP	8	NP	NP	10	10.1	18*	39	15.8
1,3-D:Chloropicrin 65:35	NP	0	NP	NP	9	15.1	0	56	18.5
Untreated	0	0	7.9	12.1	7	11.3	0	28*	14.0
LSD	3	8	4.4	NS	NS	2.5	15	22	NS
CV	147	116	53	33.8	56	25	91	63	35
p-value	<0.0001	0.0056	0.0084	0.067	0.3415	0.002	0.0002	0.0243	0.0747

[a] Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. NS=not significant. LSD=least significant difference. CV=coefficient of variance.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height=tallest part of each plant. #Shoots=shoot count.

*Treatments with significant injury or shoot number reduction compared to MeBr:Chloropicrin.

Table 2.7: Percent control of large crabgrass in Fields 1 and 2 and percent control of stinkgrass in Field 3 using MeBr and various potential alternative treatments for weed control in herbaceous perennials.

Weed	Large Crabgrass					Stinkgrass
Field	1	1	2	2		3
Year	2004	2005	2005	2006		2006
MAT[a]	2	1[c]	1[c]	2		2
Rating[b]	% Control	% Control	% Control	% Control		% Control
MeBr:Chloropicrin[d]	78	0	85	90		72
Dithiopyr	67	85	83	90		83
Flumioxazin	80	10	7*	40*		77
Isoxaben	60	0	3*	40*		43
Oxadiazon	20*	3	0*	23*		0*
s-Metolachlor	62	17	5*	40*		73
Isoxaben + Dithiopyr	77	68	87	88		75
Isoxaben + Oryzalin	82	20	3*	67		92
Isoxaben + *s*-Metolachlor	83	27	3*	63		78
Oxadiazon + Pendimethalin	57	23	0*	70		73
Isoxaben + Prodiamine	NP	NP	NP	NP		93
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP		47
Oxyfluorfen + Prodiamine	NP	NP	NP	NP		83
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP		77
Untreated	0*	0	0*	0*		0*
LSD(0.05)	43	27	11	40		33
CV	42	70	25	42		30
p-value	0.0089	<0.0001	<0.0001	0.0012		<0.0001

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[c]A post emergence grass herbicide was applied 1MAT, data at 2MAT was not available.

[d]MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Fields 2 and 3.

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 2.8: Percent control of common ragweed in Fields 1 and 2 using MeBr and potential alternative treatments for weed control in herbaceous perennials.

Weed	Common Ragweed			
Field	1	1	2	2
Year	2004	2005	2005	2006
MAT[a]	2	2	2	2
Rating[b]	% Control	% Control	% Control	% Control
MeBr:Chloropicrin[c]	97	100	97	100
Dithiopyr	65	100	0*	57*
Flumioxazin	95	97	65	92
Isoxaben	33*	67*	67	100
Oxadiazon	79	90	47*	60*
s-Metolachlor	98	83	7*	80
Isoxaben + Dithiopyr	62	100	3*	93
Isoxaben + Oryzalin	88	75	77	90
Isoxaben + *s*-Metolachlor	77	97	52*	95
Oxadiazon + Pendimethalin	88	78	15*	92
Untreated	0*	0*	0*	0*
LSD	44	25	35	30
CV	36	19	52	23
p-value	0.003	<0.0001	<0.0001	<0.0001

[a]Abbreviations: MAT=Months after herbicide treatments, LSD=Least significant difference, CV=Coefficient of variance.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[c]MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Field 2.

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 2.9: Percent control of common lambsquarters in Fields 1, 2, and 3 using MeBr and various potential alternative treatments for weed control in herbaceous perennials.

Weed	Common Lambsquarters				
Field	1	1	2	2	3
Year	2004	2005	2005	2006	2006
MAT[a]	2	2	2	2	2
Rating[b]	% Control	% Control	% Control	% Control	% Control
MeBr:Chloropicrin[c]	97	49	95	50	87
Dithiopyr	67	27	0*	0*	23*
Flumioxazin	100	62	93	78	97
Isoxaben	63	62	75	53	95
Oxadiazon	99	82	92	83	100
s-Metolachlor	84	32	7*	43	53*
Isoxaben + Dithiopyr	63	20	52*	47	90
Isoxaben + Oryzalin	99	80	88	77	100
Isoxaben + *s*-Metolachlor	73	32	95	83	87
Oxadiazon + Pendimethalin	98	72	83	93	95
Isoxaben + Prodiamine	NP	NP	NP	NP	100
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	85
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	93
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	63*
Untreated	0*	0	0*	0*	0*
LSD(0.05)	47	NS	25	29	23
CV	36	67	23	31	17
p-value	0.0088	0.0951	<0.0001	<0.0001	<0.0001

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance. NS=Not significant.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[c]MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Field 2.

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 2.10: Percent control of wild buckwheat in Fields 1 and 2 and percent control of carpetweed in Fields 1, 2, and 3 using MeBr and various potential alternative treatments for weed control in herbaceous perennials.

Weed	Wild Buckwheat				Carpetweed		
Field	1	2	2		1	2	3
Year	2005	2005	2006		2004	2005	2006
MAT[a]	1[b]	2	2		3[b]	3[b]	2
Rating[c]	% Control	% Control	% Control		% Control	% Control	% Control
MeBr:Chloropicrin[d]	93	97	97		66	100	33
Dithiopyr	75	0*	37*		72	70	43
Flumioxazin	98	48*	77		98	100	100
Isoxaben	92	18*	90		52	90	97
Oxadiazon	87	22*	67		93	100	83
s-Metolachlor	85	17*	33*		82	27*	33
Isoxaben + Dithiopyr	33*	7*	27*		70	70	82
Isoxaben + Oryzalin	88	68	77		100	93	100
Isoxaben + *s*-Metolachlor	55*	17*	57		52	60*	83
Oxadiazon + Pendimethalin	82	23*	55		100	87	92
Isoxaben + Prodiamine	NP	NP	NP		NP	NP	100
Oxyfluorfen + Pendimethalin	NP	NP	NP		NP	NP	100
Oxyfluorfen + Prodiamine	NP	NP	NP		NP	NP	95
1,3-D:Chloropicrin 65:35	NP	NP	NP		NP	NP	60
Untreated	0*	0*	0*		0*	0*	0
LSD	38	33	54		34	33	41
CV	31	67	57		28	27	34
p-value	0.0006	<0.0001	0.0338		0.0002	<0.0001	0.0002

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not available. LSD=Least significant difference. CV=Coefficient of variance.

[b]Wild buckwheat was only a major weed problem 1MAT in Field 1 in 2005. Carpetweed was only a major weed problem 3MAT in Fields 1 and 2.

[c]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[d]MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Fields 2 and 3.

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 2.11: Percent control of pigweed spp. in Fields 2 and 3 in 2006 and percent control of vetch spp. in Field 1 in 2004 using MeBr and various potential alternative treatments for weed control in herbaceous perennials.

Weed	Pigweed spp.			Vetch
Field	2	3		1
Year	2006	2006		2004
MAT[a]	2	2		2
Rating[b]	% Control	% Control		% Control
MeBr:Chloropicrin[c]	67	87		0
Dithiopyr	93	30*		0
Flumioxazin	100	77		92
Isoxaben	93	70		53
Oxadiazon	93	83		55
s-Metolachlor	67	60		0
Isoxaben + Dithiopyr	83	83		57
Isoxaben + Oryzalin	83	95		43
Isoxaben + *s*-Metolachlor	93	82		53
Oxadiazon + Pendimethalin	100	67		70
Isoxaben + Prodiamine	NP	90		NP
Oxyfluorfen + Pendimethalin	NP	100		NP
Oxyfluorfen + Prodiamine	NP	98		NP
1,3-D:Chloropicrin 65:35	NP	67		NP
Untreated	0*	0*		0
LSD (0.05)	49	48		40
CV	36	39		61
p-value	0.0178	0.0137		0.0004

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not available. LSD=Least significant difference. CV=Coefficient of

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[c]MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Fields 2 and 3.

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 2.12: **Percent injury and the final minus initial plant size for bugleweed and periwinkle in two greenhouse studies to** determine the toxicity of nine potential herbicide treatments as replacements for MeBr for weed control in herbaceous perennials.

Crop	Bugleweed					Periwinkle			
Greenhouse Study	1	2	1	2		1	2	1	2
Year	2005	2005	2005	2005		2005	2005	2005	2005
WAT[a]	6	6	6	6		6	6	6	6
Rating[b]	%Injury	%Injury	Size (cm^2)	Size (cm^2)		%Injury	%Injury	Size (cm^2)	Size (cm^2)
Dithiopyr	0	0	4	1		0	0	32	32
Flumioxazin	3	3	7	4		0	2	28	26
Isoxaben	1	13	5	1		0	1	39	37
Oxadiazon	54*	49	-5*	-3		0	0	34	40
s-Metolachlor	4	25	4	2		3*	0	31	54
Isoxaben + Dithiopyr	1	25	5	-4		0	0	28	28
Isoxaben + Oryzalin	3	6	5	0		0	0	34	43
Isoxaben + *s*-Metolachlor	4	15	4	1		0	5	17	39
Oxadiazon + Pendimethalin	7	1	9	3		0	0	42	49
Untreated	0	0	4	0		0	0	36	48
LSD (0.05)	20	NS	5	NS		1	NS	NS	NS
CV	183	172	94	1123		365	363	54	57
p-value	0.0001	0.2097	0.0032	0.2787		0.0113	0.3008	0.7485	0.7165

[a] Abbreviations: WAT=Weeks after treatments. LSD=Least significant difference. CV=Coefficient of variance.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Size= Final length multiplied width minus initial length multiplied by width (cm^2)

*Treatments statistically different from the untreated control.

Table 2.13: Percent injury and final minus intial plant measurements for daylily and lupine in two greenhouse studies to determine the toxicity of nine potential herbicide treatments as replacements for MeBr for weed control in herbaceous perennials.

Crop	Daylily					Lupine			
Greenhouse Study	1	2	1	2		1	2	1	2
Year	2005	2005	2005	2005		2005	2005	2005	2005
WAT[a]	6	6	6	6		6	6	6	6
Rating[b]	%Injury	%Injury	Height (cm)	Height (cm)		%Injury	%Injury	# Shoots	# Shoots
Dithiopyr	1	0	-5	14		19	8	10	1
Flumioxazin	4	0	3*	10		25	9	3	6
Isoxaben	1	0	2	13		47	17	5	-1
Oxadiazon	3	5*	1	14		39	23	11	-2
s-Metolachlor	3	0	-8	14		23	3	9	4
Isoxaben + Dithiopyr	3	0	3*	10		38	5	15	6
Isoxaben + Oryzalin	2	0	-1	13		50	15	4	-1
Isoxaben + s-Metolachlor	2	0	4*	14		29	6	8	2
Oxadiazon + Pendimethalin	2	0	-5	12		25	27	12	0
Untreated	0	0	-4	6		0	0	14	13
LSD (0.05)	NS	3	6	NS		NS	NS	NS	NS
CV	101	365	-383	64		73	174	83	427
p-value	0.1493	0.0113	0.0019	0.3319		0.0934	0.6212	0.2655	0.89

[a] Abbreviations: WAT=Weeks after treatments. LSD=Least significant difference. CV=Coefficient of variance.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height= Final height minus initial height. # Shoots = Final shoot count minus initial shoot count.

*Treatments statistically different from the untreated control.

Table 2.14: Subjective summary of crop tolerance and weed control results of Field 1 and Field 2 on Bugleweed, Periwinkle, and Daylily.

	Crop Injury			Weed Control				
Crop/Weed	AR[a]	VM	HS	LC	CR	CL	WB	CW
MeBr:Chloropicrin	E	E	E	P	E	G	E	G
Dithiopyr	G	E	G	G	P	P	P	G
Flumioxazin	P	G	P	P	E	G	E	E
Isoxaben	G	G	G	P	P	P	P	G
Oxadiazon	P	G	P	P	P	E	P	E
s-Metolachlor	P	G	P	P	P	P	P	P
Isoxaben + Dithiopyr	G	G	G	G	P	P	P	G
Isoxaben + Oryzalin	G	G	G	P	G	E	G	E
Isoxaben + *s*-Metolachlor	P	G	P	P	G	G	P	P
Oxadiazon + Pendimethalin	P	G	P	P	P	E	P	E

[a] Abbreviations: AR=Bugleweed. VM=Periwinkle. HS=Daylily. LC=Large Crabgrass. CR=Common Ragweed. CL=Common Lambsquarters. WB=Wild Buckwheat. CW=Carpetweed.

*Scale: E=Excellent (No crop injury and growth reduction/>85% weed control). G=Good (Minimal crop injury and growth reduction/70-85% weed control). P=Poor (>5% crop injury or significant plant reduction/<70% weed control).

References

Anonymous. 2004. Gallery 75DF herbicide label. Dow Agroscience. Indianapolis, IN.

Bird, G.W. 2004. "Methyl Bromide Regulation Update with Special Reference to Michigan." Methyl Bromide Alternatives Task Force.. Available www.ent.msu.edu/Bird_Lab/Methyl_bromide_regulation_update.pdf.

Carpenter, J., L. Gianessi, and L. Lynch. 2000. "The Economic Impact of the Scheduled U.S. Phaseout of Methyl Bromide." National Center for Food and Agricultural Policy. Washington, D.C.

Dudek, T. 2006. Personal communication.

Kleweno, D.D. and V. Mathews. 2005. "Nursery and Christmas Tree Inventory 2004-2005." Michigan Rotational Survey. USDA, NASS, Michigan Field Office. Lansing, MI.

Rauscher, K.J. 2005. "Pesticide & Plant Pest Management Division Annual Report." Michigan Department of Agriculture. Lansing, MI.

Salihu, S., J.F. Derr, and K.K. Hatzios. 1999. "Differential Response of Ajuga (*Ajuga reptans)*, Wintercreeper (*Euonymus fortunei*), and Dwarf Burning Bush (*Euonymus alatus* 'Compacta') to Root- and Shoot-Applied Isoxaben." Weed Technology. 13:685-690.

Schutzki, R.E. and C. Peterson. 1998. "Status and Potential of Michigan Argriculture Phase II Report Nursery and Landscape." Michigan State University Extension Ag Experiment Station Special Reports – SR609201.

CHAPTER THREE

ALTERNATIVE TREATMENTS TO METHYL BROMIDE FOR WEED CONTROL IN CONIFER SEEDLING PRODUCTION

ALTERNATIVE TREATMENTS TO METHYL BROMIDE FOR WEED CONTROL IN CONIFER SEEDLING PRODUCTION

Abstract

There were approximately 17,000 ha planted with Christmas trees in Michigan in 2005. Michigan Christmas trees had a farmgate value of $41.5 million in 2004. Christmas tree growers have been using methyl bromide (MeBr) for the control of weeds in conifer seedling beds. The removal of MeBr from the market has made it difficult for growers to control weeds adequately. From 2004 to 2006, three field studies and two greenhouse studies were conducted to determine potential herbicide treatments as alternatives to MeBr for weed control in conifer seedlings. Two field studies, one in 2004 and one in 2005, were conducted at the Southwest Michigan Research and Extension Center near Benton Harbor. The third field study was established at Michigan State University in 2006. MeBr was applied in late May or early June of each year. Seedling Fraser fir (*Abies fraseri*), Eastern white pine (*Pinus strobes*), Colorado blue spruce (*Picea pungens*), Douglas-fir (*Psuedotsuga menziesii*), and Balsam fir (*Abies balsamea*) were planted approximately 10 days after the MeBr applications. Herbicide treatments were applied over top of seedlings two days after planting. Herbicides tested included flumioxazin, oxyfluorfen, *s*-metolachlor, oxadiazon, dithiopyr, mesotrione, trifloxysulfuron, rimsulfuron, pendimethalin, trifluralin, isoxaben, and prodiamine. Herbicides were used individually or in tank mixes. The major weeds present included common ragweed (*Ambrosia artemisiifolia*), common lambsquarters (*Chenopodium album*), large crabgrass (*Digitaria sanguinalis*), and wild buckwheat (*Polygonum convolvulus*). Crop injury and weed control were visually rated on a 0-100% scale, with 0% equaling no crop injury or weed control and 100% equaling complete crop death or

weed control. Tree heights or dry weights of the crops were measured at the end of the season. Oxyfluorfen (1.12 kg ai/ha) caused less than 10% injury to all of the crops tested. Oxyfluorfen provided good control of most of the weeds present; however, the addition of a preemergence grass herbicide, e.g. *s*-metolachlor, dithiopyr, pendimethalin, or prodiamine, was needed to control annual grasses. The addition of preemergence grass herbicides did not increase crop injury. Flumioxazin provided good control of most weeds except large crabgrass, and caused little injury to the crops if applied before bud break. Mesotrione plus *s*-metolachlor provided excellent weed control but injured most of the crops. Data indicates that oxyfluorfen plus *s*-metolachlor and oxyfluorfen plus dithiopyr are good alternatives to MeBr for weed control in conifer seedlings.

Introduction

Michigan is one of the leading Christmas tree producing states because adequate precipitation, mild summers, cold winters, and variety of soil types allow several varieties of conifer species to be produced in Michigan. Michigan produces about 15% of the national supply of Christmas trees. About 75% of the Christmas trees grown in Michigan are sold outside the state of Michigan (Koelling et al., 1998).

The Christmas tree industry is an important part of Michigan's economy. Michigan growers harvested about three million Christmas trees in 2005. Michigan wholesale and retail sales totaled $41.5 million in 2004, plus an additional $1.3 million in the sale of wreaths, cut boughs, garlands, and other cut greens. There were over 780 operations that have more than 2 ha in the production of Christmas trees in Michigan. In 2004, about 17,000 ha were used in the production of Michigan Christmas trees. About 21% of the total Michigan Christmas tree hectares were planted to Scotch pine (*Pinus* *sylvestris)* in 2005, which was down from 35% in 2000. The four leading species produced in Michigan are Scotch pine, Douglas-fir (*Psuedotsuga menziesii*), Fraser fir (*Abies fraseri*), and Colorado blue spruce (*Picea pungens*) which were produced on about 3600, 3100, 3100 and 2800 ha, respectively (Kleweno and Matthews, 2005).

Michigan growers have used methyl bromide (MeBr) to control weeds, nematodes, and soil-borne pathogens in their conifer seedling beds. In 2000, growers applied approximately 221,000 kg of MeBr in herbaceous perennial ornamental, woody seedlings, and vegetable production. More than 75% of the total acreage in woody ornamental seedling production was fumigated with MeBr in 2000 (Bird, 2004). The removal of MeBr from the market has left growers looking for alternatives to control their nursery pests. With the absence of MeBr, growers have indicated that weed control is their greatest concern, followed by soil-borne pathogens. Since nematodes are not a major concern for Christmas trees, growers may switch to herbicides and fungicides to control weeds and diseases if effective alternatives are available (Dudek, personal communication).

The purpose of this study was to evaluate herbicide treatments as alternatives to MeBr for weed control in conifer seedling beds.

Materials and Methods

Field Studies:

Field studies were established at the Southwest Michigan Research and Extension Center (SWMREC) near Benton Harbor, Michigan and the Horticulture Teaching and Research Center (HTRC) in Holt, Michigan. SWMREC is in a 6a and the HTRC is in a 5b USDA Hardiness Zone (www.usna.usda.gov/Hardzone/ushzmap.html). The soil classification for SWMREC is Selfridge loamy sand containing 87% sand, 12% silt and 1% clay with 1% organic matter and a pH of 6.1. The soil classification for HTRC is Spinks loamy sand containing 89% sand, 8% silt, and 3% clay with 1% organic matter and a pH of 8.1.

In 2004, the first field study (Field 1) was established at SWMREC in early June. Methyl bromide:chloropicrin 98:2 (MeBr) was shank applied on June 2, 2004 at a rate of 392 kg/ha with a soil temperature of 21° C under moist soil conditions. The MeBr plots were tarped immediately after the application with a 3 m wide, 6 mil thick high density polyethylene plastic (HDPE). The tarps were removed after one week. Two-year old Fraser fir (FF) (*Abies fraseri)* and Eastern white pine (WP) (*Pinus strobes)* were planted on June 11, 2004. Plant species were planted in individual rows at an in-row spacing of 25 cm and between-row spacing of 183 cm.

Plots were arranged in a randomized complete block design with a plot size of 3.4 by 6.1 m and crop rows were randomly assigned. The Field 1 study consisted of 11 treatments with three replications. The treatments, rates, and crops labeled for Fields 1 and 2 are listed in Table 3.1. All the treatments, except MeBr, were applied over top of the crop on June 17, 2004. The liquid treatments were applied with a CO_2 backpack sprayer with a four nozzle boom with TeeJet® (Spraying Systems Co, Wheaton, Illinois) 8002 nozzles calibrated to apply 187 L/ha at 207 KPa of pressure. The granular products were applied using a shaker bottle. Treatments were applied when air and soil temperatures (5 cm deep) were approximately 26 and 24° C, respectively. The herbicide treatments were reapplied on June 9, 2005 when air and soil temperatures were approximately 32 and 35° C, respectively. Overhead irrigation was applied immediately after herbicide applications. A burn down application of glufosinate was applied between rows before the 2005 re-application of herbicides.

In 2005, a second field study (Field 2) was established adjacent to Field 1. The same 11 treatments used in Field 1 were used in Field 2 with the exception that MeBr 98:2 was replaced with MeBr 67:33 because of product availability. The MeBr fumigation was shank applied on May 24, 2005 with soil temperature of 19°C under dry soil conditions. The MeBr plots were tarped under HDPE immediately after application. The tarps were removed 10 days after application. One-year old FF, WP, Douglas-fir (DF) (*Pseudotsuga menziesii)*, and Colorado blue spruce (BS) (*Picea pungens)* were planted on June 7, 2005. One-year old seedlings were used to better simulate grower seedling beds and the two additional species broadened the study.

The herbicide treatments were applied on June 9, 2005 with air and soil temperatures (5 cm deep) of 32 and 35°C, respectively. All treatments, including MeBr, were reapplied in 2006. MeBr was reapplied because of poor weed control in 2005. The crops were removed and MeBr was hot gas applied under HDPE on June 1, 2006 with soil temperature of 22°C under dry soil conditions. The tarps were removed on June 9, 2006. New one-year old FF, WP, DF, and BS were transplanted in the MeBr plots on June 12, 2006. Approximately 50% of each of the conifer species did not survive the first year, so dead plants were replaced with new one-year old seedlings on June 12, 2006. The herbicides were reapplied on June 12, 2006 with air and soil temperatures being approximately 18 and 24°C, respectively.

In late May 2006, a third field study (Field 3) was established at HTRC. The treatments, rates, and crops labeled for Field 3 are given in Table 3.2. 1,3-

dichloropropene: chloropicrin 65:35 (1,3-D) was shank applied on May 15, 2006 at a rate of 327 L/ha with a soil temperature of approximately 16°C under dry soil conditions. The 1,3-D plots were tarped under HDPE immediately after application. The MeBr was hot gas applied under HDPE on June 6, 2006 with a soil temperature of 22°C under dry soil conditions. The tarps were removed on June 12, 2006. One-year old FF, WP, DF, BS, and Balsam fir (BF) (*Abies balsamea)* were transplanted in individual rows in the herbicide plots on June 13, 2006. The crops were transplanted into MeBr and 1,3-D plots on June 15, 2006. Herbicide treatments were applied on June 15, 2006 with air and soil temperatures of 26 and 27°C, respectively. Plants were planted in individual rows at an in row spacing of 25 cm and between row spacing of 183 cm. Plots were arranged in a randomized complete block design with a plot size of 3.4 m by 10.6 m and crop rows were randomly assigned. Herbicide treatment parameters were the same as Field 1.

To insure that crop injury was due to herbicide injury and not weed competition, an approximate 15 cm radius area was hand weeded around the crops. Due to favorable conditions in 2005, large crabgrass (*Digitaria sanguinalis)* and quackgrass (*Elytrigia repens)* were present in large numbers, so one month after treatments monthly applications of sethoxydim or clethodim were applied to Fields 1 and 2. Two months after treatments in 2004 and 2005, the between row areas were mowed.

Crop injury was measured on a visual scale from 0 (no injury) to 100% (plant death). Tree heights were measured four months after treatments in Field 1 in 2004 and 2005 and in Field 3 in 2006. Since approximately 50% of the conifers died in 2005 in Field 2, tree heights were not measured. In 2006, the dry weights of above ground biomass were measured for both the conifers planted in 2005 (two-year old) and in 2006 (one-year old). Where applicable, five one-year old and two-year old seedlings were randomly removed from each plot and the roots were removed. The above ground biomass was placed in a paper bag and oven dried at 41°C for 10 days and the average weight per tree for each category was recorded. Weed control was measured on a visual scale from 0 (no control) to 100% (complete control). Each crop species and weed species was rated individually. Weed species were rated when they were most prevalent. The untreated control plot was used as a standard for weed control and crop injury ratings. Ratings were recorded monthly throughout the growing season. For this report, only the three months after treatment (MAT) rating is reported for crop injury and the two MAT control rating is report for most weed species.

Data were subjected to ANOVA and means were separated using Fisher's LSD at the p=0.05 level.

Greenhouse studies:

Two greenhouse studies were established to test herbicides for weed control in deciduous and conifer seedling beds. Greenhouse Study 1 was established in 2005 to observe the phytotoxicity of 10 herbicide treatments on two-year old sugar maple (SM) (*Acer saccharum*), red oak (RO) (*Quercus rubra*), white oak (WO) (*Quercus alba*), FF, BF, WP, Scotch pine (SP) (*Pinus sylvestris*), DF, BS, and white spruce (WS) (*Picea glauca*) seedlings. Treatments for Greenhouse Study 1 are listed in Table 3.3. Greenhouse Study 2 was established in 2006 to observe the phytotoxicity of 13 herbicide treatments on two-year old SM, RO, WO, BF, WP, SP, DF, BS, and WS seedlings. FF seedlings were not available in 2006. Treatments for Greenhouse Study 2 are listed in

Table 3.4. Seedlings were planted in 15 by 15 by 41 cm pots (Stuewe and Sons, Inc., Corvallis, OR) filled with a sandy loam soil.

Four plants from each crop were picked at random per treatment. The liquid herbicide treatments were applied in a moving track spray chamber (Allen Machine Works, Midland, MI) with a single Teejet® (Spraying Systems Co, Wheaton, Illinois) 8001 EVS nozzle calibrated to apply 187 L/ha at 207 KPa of pressure. The granular treatments were applied using a shaker bottle. After treatment applications, the plants were returned to the greenhouse.

Crop injury was measured on a visual scale from 0 (no injury) to 100% (plant death) at three months after treatment. Plant growth measurements were taken three months after treatments by measuring the new growth of three shoots of each plant. The average of the three growth measurements was recorded. Data for crop injury and crop growth were subjected to ANOVA and means were separated using Fisher's LSD at the p=0.05 level.

Results and Discussion

Field Studies: Crop Injury

Visual injury to FF was less than 30% for all treatments for all rating dates (Table 3.5). The most injury occurred from flumioxazin in the second year of both Fields 1 and 2. This injury occurred because bud break had occurred before the application. All other treatments caused less than 20% injury. In 2005, mesotrione plus *s*-metolachlor and trifloxysulfuron plus *s*-metolachlor each caused 18% injury in Field 1 and 15 and 10% injury in Field 2, respectively. Oxyfluorfen plus dithiopyr caused 15% injury in 2005 in Field 2, but injury was 5% or less for the other ratings. Rimsulfuron plus *s*-metolachlor caused 13% injury in 2006 in Field 3, which was the only treatment to cause injury ($p<0.05$) in Field 3. Trifloxysulfuron and rimsulfuron caused chlorosis of the needle tips. There was no difference ($p>0.05$) among treatments in tree heights in Field 1 in 2004 and 2005. There was no difference ($p>0.05$) among treatments for the dry weights for both one-year old and two-year old seedlings in Field 2. In Field 3, no treatments were different ($p<0.05$) from MeBr in tree heights. In Field 3, 1,3-D and trifluralin plus isoxaben plus oxyfluorfen had the tallest trees and flumioxazin had the smallest trees.

Visual injury to WP was less than 25% for all the treatments among all rating dates (Table 3.6). In 2004 in Field 1, mesotrione plus *s*-metolachlor, rimsulfuron plus *s*-metolachlor, trifloxysulfuron plus *s*-metolachlor, oxyfluorfen plus *s*-metolachlor, oxyfluorfen, oxyfluorfen plus dithiopyr, and mesotrione caused visual injury ($p<0.05$) to WP. Irrigation was not applied until two hours after herbicide applications in Field 1 in 2004, and increased injury may have occurred because the EC formulated herbicides were not washed off the plants. Injury ($p>0.05$) was not observed in Field 1 in 2005 and Field 2 in 2005 and 2006. Mesotrione plus *s*-metolachlor and trifloxysulfuron plus *s*-metolachlor caused 23% injury in Field 3 in 2006. Mesotrione caused needle fusion in some of the new buds in the early months of the studies. In most cases the injury was absent by the end of the season. *S*-metolachlor can cause some needle twisting in the new buds in the early months; however, injury was usually absent by the end of the season. In Field 1 in 2004, no treatments had trees smaller ($p<0.05$) than MeBr. Flumioxazin, oxyfluorfen, and mesotrione had the tallest trees and MeBr and mesotrione plus *s*-metolachlor had the smallest trees. In Field 1 in 2005, mesotrione plus *s*-metolachlor had smaller ($p<0.05$) trees than MeBr and oxyfluorfen and mesotrione had trees taller ($p<0.05$) than MeBr. In 2006 in Field 3, the tallest trees were in the trifloxysulfuron plus *s*-metolachlor and mesotrione plus *s*-metolachlor plots. These were the only two treatments to cause visual injury in Field 3. This might indicate that the injury was only superficial; however, mesotrione plus *s*-metolachlor reduced height ($p<0.05$) in Field 1 in 2004 and 2005. *S*-metolachlor tended to cause needle twisting after application and may have affected crop growth. WP treated with oxyfluorfen, mesotrione plus *s*-metolachlor, trifloxysulfuron plus *s*-metolachlor, rimsulfuron plus *s*-metolachlor, oxyfluorfen plus pendimethalin, and oxyfluorfen plus prodiamine were taller ($p<0.05$) than WP treated with MeBr in Field 3. The smallest trees were in the 1,3-D and the mesotrione plots; however, they were not different ($p<0.05$) from MeBr. Flumioxazin was the only treatment that had one-year old seedlings with dry weights less ($p<0.05$) than MeBr. There was no difference ($p>0.05$) among treatments for the dry weights of the two-year old seedlings.

In BS, mesotrione and mesotrione plus *s*-metolachlor caused visual injury ($p<0.05$) in Fields 2 and 3 (Table 3.7). In Field 2, mesotrione and mesotrione plus *s*-metolachlor caused 23 and 15% injury, respectively, in 2005, and 18 and 7% injury, respectively, in 2006. In Field 3, mesotrione alone and mesotrione plus *s*-metolachlor caused 47 and 40% injury, respectively. The mesotrione in the mesotrione plus *s*-metolachlor treatment probably caused the injury to the BS. There was no difference ($p>0.05$) among all treatments for dry weights for both the one and two-year old seedlings in Field 2. In Field 3, the tallest trees were in the 1,3-D and MeBr plots. There was height reduction ($p<0.05$) in BS treated with flumioxazin, mesotrione, mesotrione plus *s*-metolachlor, trifloxysulfuron plus *s*-metolachlor, and trifluralin plus isoxaben plus oxyfluorfen.

In DF, mesotrione and mesotrione plus *s*-metolachlor caused the most injury in Fields 2 and 3 (Table 3.8). In Field 2, mesotrione and mesotrione plus *s*-metolachlor caused 23 and 17% injury, respectively in 2005, and 22 and 8% injury, respectively in 2006. In Field 3, mesotrione and mesotrione plus *s*-metolachlor caused 50 and 43% injury, respectively. The mesotrione in the mesotrione plus *s*-metolachlor treatment probably caused the injury to the DF. The only other injury ($p<0.05$) observed was from flumioxazin in Field 2 in 2006. There was no difference ($p>0.05$) among all treatments for dry weights for both the one and two-year old seedlings in Field 2. Similar to BS, the tallest DF trees were in the MeBr and the 1,3-D plots in Field 3. All treatments, except oxyfluorfen plus pendimethalin and 1,3-D, had smaller ($p<0.05$) DF trees than MeBr in Field 3.

Injury to BF was 5% or less for all treatments in Field 3 (Table 3.8). Mesotrione and trifloxysulfuron plus *s*-metolachlor each caused 5% injury. There was no difference ($p>0.05$) among treatments in tree heights.

Field Studies: Weed Control

Oxyfluorfen plus *s*-metolachlor and mesotrione plus *s*-metolachlor were the only treatments that provided greater than 80% control of large crabgrass (*Digitaria sanguinalis*) for all rating dates (Table 3.9). In 2004, all treatments except flumioxazin, oxadiazon, MeBr, and oxyfluorfen provided greater than 90% control in Field 1. Oxadiazon did not control large crabgrass. MeBr and flumioxazin provided only 33 and 52% control, respectively. Due to favorable growing conditions, large crabgrass pressure was high in 2005. Crabgrass control was not rated in Field 1 because a postemergence grass herbicide was applied to suppress quackgrass (*Elytrigia repens*) prior to the rating dates and applications continued monthly throughout the growing season. One rating of large crabgrass control was made one month after treatments prior to monthly postemergence grass herbicide applications in Field 2 in 2005. Oxyfluorfen plus *s*-metolachlor and mesotrione plus *s*-metolachlor each provided 87% control in Field 2 in 2005, one month after treatments. All other treatments provided 80% or less control. Oxadiazon and flumioxazin did not control large crabgrass. Oxyfluorfen plus dithiopyr, oxyfluorfen plus *s*-metolachlor, and mesotrione plus *s*-metolachlor provided 90, 90, and 80% control in Field 2 in 2006, respectively. All other treatments provided less than 70% control. Once again oxadiazon did not control large crabgrass. MeBr and flumioxazin only provided 23 and 40% control respectively. Large crabgrass was not present in Field 3; however, stinkgrass (*Eragrostis cilianensis*) was present (Table 3.9). Trifloxysulfuron plus *s*-metolachlor, oxyfluorfen plus dithiopyr, mesotrione plus *s*-metolachlor, and MeBr provided 95, 87, 83, and 83% control of stinkgrass, respectively. All other treatments provided less than 80% control. Oxadiazon, rimsulfuron plus *s*-metolachlor, oxyfluorfen plus pendimethalin and 1,3-D provided only10, 32, 37, and 40% control.

All treatments, except oxadiazon and rimsulfuron plus *s*-metolachlor, provided greater than 90% control of common ragweed (*Ambrosia artemisiifolia*) for all rating dates (Table 3.10). Oxyfluorfen plus dithiopyr, oxyfluorfen plus *s*-metolachlor, mesotrione, and mesotrione plus *s*-metolachlor provided 100% control in Field 1 in 2004 and 2005 and in Field 2 in 2006. Oxyfluorfen alone provide 100% control in Field 1 in 2005 and trifloxysulfuron plus *s*-metolachlor provided 100% control in Field 1 in 2005 and Field 2 in 2006. MeBr was the only treatment to provide 100% control in Field 2 in 2005. MeBr and flumioxazin also provided 100% control in Field 2 in 2006. Oxadiazon was the only treatment that consistently provided poor control. Rimsulfuron plus *s*-metolachlor provided greater than 90% control in all ratings except in 2005 in Field 2 where it only provided 43% control. Common ragweed was not present in Field 3.

In 2004, all treatments, except rimsulfuron plus *s*-metolachlor (99%) and MeBr (66%), provided 100% control of common lambsquarters (*Chenopodium album*) (Table 3.11). In Field 1 in 2005, mesotrione plus *s*-metolachlor and trifloxysulfuron plus *s*-metolachlor provided 100% control. Oxadiazon, MeBr, and rimsulfuron plus *s*-metolachlor provided less than 90% control. In Field 2 in 2005, flumioxazin (98%), oxadiazon (68%), MeBr (85%), and oxyfluorfen plus dithiopyr (99%) did not provide complete control of common lambsquarters. Flumioxazin, oxyfluorfen plus dithiopyr, mesotrione, mesotrione plus *s*-metolachlor, and trifloxysulfuron plus *s*-metolachlor provided 100% control of common lambsquarters in Field 2 in 2006. All treatments except MeBr (73%) provided greater than 90% control. No treatment provided 100% control of common lambsquarters in Field 3. Oxadiazon, trifloxysulfuron plus *s*-metolachlor, MeBr, trifluralin plus isoxaben plus oxyfluorfen, and oxyfluorfen plus pendimethalin provided 97, 95, 93, 90, and 90% control, respectively. Flumioxazin, 1,3-D, and rimsulfuron plus *s*-metolachlor provided only 53, 33, and 32% control, respectively.

Oxyfluorfen plus dithiopyr provided 100% control of wild buckwheat (*Polygonum convolvulus*) for all rating dates (Table 3.12). Wild buckwheat was not a major weed problem in 2004. Flumioxazin, oxyfluorfen, oxyfluorfen plus dithiopyr, oxyfluorfen plus *s*-metolachlor, and mesotrione plus *s*-metolachlor provided 100% control in Field 1 in 2005. Oxadiazon, MeBr, and rimsulfuron plus *s*-metolachlor provided only 40, 37, and 23% control, respectively. Flumioxazin, oxyfluorfen plus dithiopyr, and oxyfluorfen plus *s*-metolachlor provided 100% control in 2005 in Field 2. Oxadiazon (65%), mesotrione (73%), mesotrione plus *s*-metolachlor (77%), and rimsulfuron plus *s*-metolachlor (77%) provided less than 80% control. Unlike in 2005, oxadiazon provided 100% control in 2006. Oxyfluorfen plus dithiopyr and mesotrione plus *s*-metolachlor also provided 100% control of wild buckwheat. Flumioxazin, oxyfluorfen, and oxyfluorfen plus *s*-metolachlor provided greater than 80% control. Wild buckwheat was not present in Field 3. Oxyfluorfen and oxyfluorfen tank mixes provided good control of wild buckwheat.

Oxyfluorfen, oxyfluorfen plus dithiopyr, oxyfluorfen plus *s*-metolachlor, mesotrione, and mesotrione plus *s*-metolachlor all provided 100% control of carpetweed (*Mollugo verticillata*) for all rating dates (Table 3.12). MeBr and rimsulfuron plus *s*-metolachlor were the only treatments that provided less 80% control for all of the rating dates. Flumioxazin also provided 100% control in Field 1 in 2005 and Field 2 in 2006. Rimsulfuron plus *s*-metolachlor did not control carpetweed in Field 1 in 2005. Oxadiazon and trifloxysulfuron plus *s*-metolachlor also provided 100% control in Field 2 in 2006. Carpetweed was not a major weed problem in Field 2 in 2005 or Field 3 in 2006.

Three species of pigweed (*Amaranthus* spp.) were present in Field 3: tumble pigweed (*Amaranthus albus*), prostrate pigweed (*Amaranthus blitoides*), and redroot pigweed (*Amaranthus retroflexus*). All three pigweed species reacted similarly to the treatments and were rated together as one (Table 3.13). Trifloxysulfuron plus *s*-metolachlor, trifluralin plus isoxaben plus oxyfluorfen, and oxyfluorfen plus pendimethalin provided 100% control of pigweed. The only treatments that provided less than 80% control were flumioxazin, oxadiazon, oxyfluorfen, mesotrione, and 1,3-D.

Horsenettle (*Solanum carolinense*) was a major weed problem only in Field 1 in 2005 (Table 3.13). MeBr was the only treatment that provided 100% control of horsenettle. The herbicide treatments that provided the best control were oxyfluorfen and mesotrione plus *s*-metolachlor providing 98 and 97% control, respectively. Flumioxazin, oxyfluorfen plus dithiopyr, trifloxysulfuron plus *s*-metolachlor, and rimsulfuron plus *s*-metolachlor provided less than 80% control of horsenettle.

Hairy nightshade (*Solanum sarrachoides*) was present only in Field 2. Oxyfluorfen plus *s*-metolachlor provided 100% control in 2005 and 2006 (Table 3.13). Flumioxazin and oxyfluorfen plus dithiopyr also provided 100% control in 2005. Oxadiazon, trifloxysulfuron plus *s*-metolachlor, and rimsulfuron plus *s*-metolachlor provided less than 80% control in 2005. Trifloxysulfuron plus *s*-metolachlor and rimsulfuron plus *s*-metolachlor did not provide any hairy nightshade control. Oxyfluorfen also provided 100% control in 2006. MeBr, mesotrione, trifloxysulfuron plus *s*-metolachlor, and rimsulfuron plus *s*-metolachlor provided less than 80% control in 2006. Rimsulfuron plus *s*-metolachlor did not provide any control again in 2006.

Vetch (*Vicia* spp.) was a major weed problem only in Field 1 in 2004. Vetch has a hard seed coat and is not controlled by MeBr (Table 3.13). Flumioxazin and oxyfluorfen plus *s*-metolachlor provided 100% control of vetch. All treatments, except oxadiazon, which provided 87% control and MeBr which did not control vetch, provided more than 90% control.

Greenhouse studies: Crop Injury

In Greenhouse Study 1 (GS1), there was no statistical difference in crop injury among all treatments in all tree species (Table 3.14). However, oxyfluorfen plus *s*-metolachlor, mesotrione, mesotrione plus *s*-metolachlor, oxadiazon plus pendimethalin, and rimsulfuron plus *s*-metolachlor caused more than 10% injury to SM. Mesotrione plus *s*-metolachlor was the only treatment to cause more than 10% injury to WO. None of the treatments for any of the tree species were different ($p>0.05$) for new growth in GS1 (Table 3.15).

Since leaf eating insects consumed most of the leaf tissue on SM, WO, and RO, no herbicide injury ratings were taken in Greenhouse Study 2 (GS2) (Table 3.16). FF plants were unavailable at the time of the study. Treatments were not different ($p>0.05$) for crop injury in BF; however, prodiamine plus oxyfluorfen and prodiamine plus norflurazon caused more than 10% injury. The only treatment to cause injury ($p<0.05$) in WP was oxyfluorfen plus norflurazon at 38% injury. Prodiamine plus norflurazon and oxyfluorfen plus norflurazon caused 19 and 33% injury, respectively, to SP. Mesotrione, mesotrione plus *s*-metolachlor, prodiamine plus norflurazon, and oxyfluorfen plus norflurazon caused injury ($p<0.05$) to both DF and BS. The mesotrione in the mesotrione plus *s*-metolachlor treatment probably caused the injury to DF and BS. Mesotrione and oxyfluorfen plus norflurazon caused 23 and 21% injury in WS, respectively. The treatments containing norflurazon caused injury to all the conifer species.

Growth measurements in GS2 did not vary among treatments in all species except in SM and BS (Table 3.17). Rimsulfuron plus *s*-metolachlor and prodiamine plus norflurazon had more growth ($p<0.05$) than the other treatments in SM; however, no conclusions can be drawn because none of the untreated SM broke bud. Oxyfluorfen and oxyfluorfen plus norflurazon treatments had less new growth ($p<0.05$) than the untreated control.

Conclusion

Oxyfluorfen plus *s*-metolachlor and mesotrione plus *s*-metolachlor provided the best control of large crabgrass. All treatments except oxadiazon and rimsulfuron plus *s*-metolachlor provided good control of common ragweed. Trifloxysulfuron plus *s*-metolachlor, oxyfluorfen plus dithiopyr, and mesotrione plus *s*-metolachlor provided the most consistent control of common lambsquarters. Flumioxazin, oxyfluorfen, oxyfluorfen plus dithiopyr, and oxyfluorfen plus *s*-metolachlor provided good control of wild buckwheat. The oxyfluorfen in the oxyfluorfen plus dithiopyr and oxyfluorfen plus *s*-metolachlor tank mixes probably provided the control of wild buckwheat. All herbicide treatments except trifloxysulfuron plus *s*-metolachlor and rimsulfuron plus *s*-metolachlor provided good control of carpetweed. Flumioxazin, oxyfluorfen, oxyfluorfen plus dithiopyr, oxyfluorfen plus *s*-metolachlor and mesotrione plus *s*-metolachlor provided the best control of hairy nightshade. After one year of research, trifluralin plus isoxaben plus oxyfluorfen shows promise for overall weed control. 1,3-D did not provide good control of weeds. Oxyfluorfen plus *s*-metolachlor provided the best overall weed control. Mesotrione plus *s*-metolachlor and oxyfluorfen plus dithiopyr are also good options for good overall weed control.

Oxyfluorfen and oxyfluorfen plus *s*-metolachlor were the only treatments that caused less than 10% injury consistently in FF. Flumioxazin did not cause injury during the first year of each field study in FF. In the second year of each field study, flumioxazin caused injury because the applications were made after bud break. More research is needed to observe injury when treatments are applied in the second year before bud break. After one year of research, trifluralin plus isoxaben plus oxyfluorfen, oxyfluorfen plus pendimethalin, oxyfluorfen plus prodiamine, and 1,3-D show promise for being safe on FF. Oxyfluorfen plus *s*-metolachlor could be used as an alternative for weed control in FF seedlings.

Mesotrione plus *s*-metolachlor and trifloxysulfuron plus *s*-metolachlor caused the most injury to WP. All other treatments were fairly safe on WP. Flumioxazin and oxadiazon were the safest herbicide treatments. Oxyfluorfen plus *s*-metolachlor caused 11% injury in Field 1 in 2004, but no injury was observed on any of the other rating dates. Oxyfluorfen plus *s*-metolachlor did not cause injury in the greenhouse studies. Treatments containing *s*-metolachlor had some needle twisting early after applications, but measurements of the treatments, other than mesotrione plus *s*-metolachlor, do not indicate a negative growth response. Needle fusion and twisting was observed using mesotrione and *s*-metolachlor early after applications. Height measurements in Field 1 indicate that mesotrione plus *s*-metolachlor might decrease the growth of WP. Oxyfluorfen plus *s*-metolachlor and oxyfluorfen plus dithiopyr are good options as alternatives to MeBr for weed control in WP seedlings.

Herbicide treatments containing mesotrione caused serious injury to BS and DF. All other treatments tended to be safe on BS and DF. Oxyfluorfen plus dithiopyr and oxyfluorfen plus *s*-metolachlor are good options as alternatives to MeBr for weed control in BS and DF seedlings. Only one year of data was available for BF. No treatments caused serious injury to BF.

Oxyfluorfen plus *s*-metolachlor provided good overall weed control and was safe on the crops and could be considered as an alternative to MeBr for weed control in conifer seedling production. Oxyfluorfen plus dithiopyr also could be another alternative for weed control but caused significant injury to FF in one rating.

Table 3.1: Herbicides, rates, and crops labeled for the treatments used in Field 1 in 2004 and 2005 on Eastern White Pine (WP) and Fraser Fir (FF) and in Field 2 in 2005 and 2006 on WP, FF, Douglas-Fir (DF), and Colorado Blue Spruce (BS).

#	Treatment[a]	Rate	Labeled[b]
1	MeBr:Chloropicrin[c]	392 kg/ha	FF/WP/DF/BS
2	Flumioxazin 51WG	0.28 kg ai/ha	FF/WP/DF/BS
3	Mesotrione 4SC	0.28 kg ai/ha	None
4	Oxadiazon 2G	2.24 kg ai/ha	WP/DF/BS
5	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF/BS
6	Mesotrione 4SC	0.28 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
7	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF/BS
	Dithiopyr 1EC	0.28 kg ai/ha	
8	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF/BS
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
9	Rimsulfuron 25DG	0.03 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
10	Trifloxysulfuron 75DF	0.008 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
11	Untreated Control		

[a]WG=Wettable granules. G=Granular. EC=Emulsifiable concentrate. SC=Soluable concentrate. DF=Dry flowable. DG=Dispersible granules.

[b]FF=Fraser Fir. WP=Eastern White Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce.

[c]MeBr:Chloropicrin 98:2 was used in Field 1 in 2004 and 67:33 in Field 2 in 2005 and 2006.

Table 3.2: Herbicides, rates, and crops labeled for the treatments used in Field 3 in 2006 on Fraser Fir (FF), Eastern White Pine (WP), Douglas-Fir (DF), Colorado Blue Spruce (BS), and Balsam Fir (BF).

#	Treatment[a]	Rate	Labeled[b]
1	MeBr:Chloropicrin 67:33	392 kg/ha	FF/WP/DF/BS/BF
2	1,3-D/Chloropicrin 65:35	327 L/ha	FF/WP/DF/BS/BF
3	Flumioxazin 51WG	0.28 kg ai/ha	FF/WP/DF/BS
4	Mesotrione 4SC	0.28 kg ai/ha	None
5	Oxadiazon 2G	2.24 kg ai/ha	WP/DF/BS
6	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF/BS
7	Isoxaben 0.25G	0.56 kg ai/ha	WP/BS
	Oxyfluorfen 0.25G	0.56 kg ai/ha	
	Trifluralin 2G	4.48 kg ai/ha	
8	Mesotrione 4SC	0.28 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
9	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF
	Dithiopyr 1EC	0.28 kg ai/ha	
10	Oxyfluorfen 2G	2.24 kg ai/ha	None
	Pendimethalin 1G	1.12 kg ai/ha	
11	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF/BS
	Prodiamine 4FL	1.68 kg ai/ha	
12	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/DF/BS
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
13	Rimsulfuron 25DG	0.03 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
14	Trifloxysulfuron 75DF	0.008 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
15	Untreated Control		

[a]WG=Wettable granules. G=Granular. EC=Emulsifiable concentrate. SC=Soluable concentrate. DF=Dry flowable. DG=Dispersible granules. FL=Flowable.

[b]FF=Fraser Fir. WP=Eastern White Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. BF=Balsam Fir.

Table 3.3: Herbicides, rates, and crops labeled for the treatments used in Greenhouse Study 1 in 2005 on seven conifer and three deciduous species.

#	Treatment[a]	Rate	Labeled[b]
1	Flumioxazin 51WG	0.28 kg ai/ha	FF/WP/SP/DF/BS/WS/RO/WO/SM
2	Mesotrione 4SC	0.28 kg ai/ha	None
3	Oxadiazon 2G	2.24 kg ai/ha	WP/SP/DF/BS/WS/SM/RO/WO
4	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/SP/DF/BS/SM/RO
5	Mesotrione 4SC	0.28 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
6	Oxadiazon 2G	2.24 kg ai/ha	DF/SM/WO/RO/BS/WS
	Pendimethalin 1.25G	1.4 kg ai/ha	
7	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/SP/DF/BS/SM/RO
	Dithiopyr 1EC	0.28 kg ai/ha	
8	Oxyfluorfen 2EC	1.12 kg ai/ha	FF/WP/SP/DF/BS/SM/RO
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
9	Rimsulfuron 25DG	0.03 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
10	Trifloxysulfuron 75DF	0.008 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
11	Untreated Control		

[a]WG=Wettable granules. G=Granular. EC=Emulsifiable concentrate. SC=Soluable concentrate. DF=Dry flowable. DG=Dispersible granules.

[b]FF=Fraser Fir. BF=Balsam Fir. WP=Eastern White Pine. SP=Scotch Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. WS=White Spruce. RO=Red Oak. WO=White Oak. SM=Sugar Maple.

Table 3.4: Herbicides, rates, and crops labeled for the treatments used in Greenhouse Study 2 in 2006 on six conifer and three deciduous species.

#	Treatment[a]	Rate	Labeled[b]
1	Flumioxazin 51WG	0.28 kg ai/ha	WP/DF/BS/WS/RO/WO/SM/SP
2	Mesotrione 4SC	0.28 kg ai/ha	None
3	Oxadiazon 2G	2.24 kg ai/ha	WP/SP/DF/BS/WS/SM/RO/WO
4	Oxyfluorfen 2EC	1.12 kg ai/ha	WP/SP/DF/BS/SM/RO
5	Norflurazon 80WG	2.69 kg ai/ha	None
	Oxyfluorfen 2EC	1.12 kg ai/ha	
6	Norflurazon 80WG	2.69 kg ai/ha	None
	Prodiamine 4FL	1.68 kg ai/ha	
7	Mesotrione 4SC	0.28 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
8	Oxadiazon 2G	2.24 kg ai/ha	DF/SM/WO/RO/BS/WS
	Pendimethalin 1.25G	1.4 kg ai/ha	
9	Oxyfluorfen 2EC	1.12 kg ai/ha	WP/SP/DF/BS/SM/RO
	Dithiopyr 1EC	0.28 kg ai/ha	
10	Oxyfluorfen 2EC	1.12 kg ai/ha	WP/SP/DF/BS/RO
	Prodiamine 4FL	1.68 kg ai/ha	
11	Oxyfluorfen 2EC	1.12 kg ai/ha	WP/SP/DF/BS/SM/RO
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
12	Rimsulfuron 25DG	0.03 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
13	Trifloxysulfuron 75DF	0.008 kg ai/ha	None
	s-Metolachlor 7.62EC	1.68 kg ai/ha	
14	Untreated Control		

[a]WG=Wettable granules. G=Granular. EC=Emulsifiable concentrate. SC=Soluable concentrate. DF=Dry flowable. DG=Dispersible granules. FL=Flowable.

[b]BF=Balsam Fir. WP=Eastern White Pine. SP=Scotch Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. WS=White Spruce. RO=Red Oak. WO=White Oak. SM=Sugar Maple.

Table 3.5: Visual injury on Fraser Fir in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006, tree heights for Field 1 in 2004-05 and Field 3 in 2006, and the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006.

Crop	Fraser Fir									
Field	1	1	2	2	3	1	1	2	2	3
Year	2004	2005	2005	2006	2006	2004	2005	2006	2006	2006
MAT[a]	3	3	3	3	3	4	4	4	4	4
Rating[b]	%Injury	%Injury	%Injury	%Injury	%Injury	Height(cm)	Height(cm)	1YO[c] DW(g)	2YO[c] DW(g)	Height(cm)
MeBr:Chloropicrin[d]	0	0	0	0	0	22.8	35.1	5.0	NA[e]	16.5
Flumioxazin	0	25*	0	27	0	24.5	29.5	2.9	5.4	14.9
Mesotrione	8	8	10	7	0	26.5	33.3	4.1	6.1	16.9
Oxadiazon	0	10	0	3	0	24.7	32.9	3.9	11.1	17.7
Oxyfluorfen	4	3	7	2	2	24.2	34.3	3.8	9.7	18.1
Mesotrione + *s*-Metolachlor	0	18*	15*	0	3	25.0	34.9	3.8	4.9	15.9
Oxyfluorfen + Dithiopyr	5	3	15*	0	0	24.2	35.0	4.0	5.4	16.1
Oxyfluorfen + *s*-Metolachlor	2	5	0	0	2	24.7	33.2	3.7	5.0	18.2
Rimsulfuron + *s*-Metolachlor	5	8	2	7	13*	24.6	31.5	3.9	6.8	16.1
Trifloxysulfuron + *s*-Metolachlor	2	18*	10	8	2	25.2	33.8	3.6	6.2	16.8
Isoxaben + Oxyfluorfen + Trifluralin	NP	NP	NP	NP	0	NP	NP	NP	NP	19.0
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	0	NP	NP	NP	NP	18.1
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	2	NP	NP	NP	NP	18.5
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	0	NP	NP	NP	NP	19.8
Untreated	0	0	0	0	0	26.1	32.7	4.7	7.3	17.2
LSD (0.05)	NS	14	11	12	5	NS	NS	NS	NS	2.5
CV	121	75	63	143	160	17	17	24	68	26
p-value	0.0712	0.0275	0.0408	0.0058	0.0007	0.0533	0.1334	0.5099	0.7861	0.0051

[a] Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance. DW=Dry weight. YO=Year old. NS=Not significant. NA=Not available.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height is based on the total height of the plant in cm. Dry weight is the average of up to five seedlings in g.

[c] 1YO were seedlings planted in 2006. 2YO were seedlings planted in 2005.

[d] MeBr:Chloropicrin 98:2 used in Field 1 in 2004 and 67:33 used in Field 2 in 2005 and 2006 and Field 3 in 2006.

[e] Plants in MeBr plots were removed at the end 2005 and new one-year old plants were planted 2006.

*Treatments statisically different from MeBr:Chloropicrin.

Table 3.6: Visual injury on Eastern White Pine in Field 1 in 2004-05, Field 2 in 2005-06, and Field 3 in 2006, tree heights for Field 1 in 2004-05 and Field 3 in 2006, and the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006.

Crop	Eastern White Pine									
Field	1	1	2	2	3	1	1	2	2	3
Year	2004	2005	2005	2006	2006	2004	2005	2006	2006	2006
MAT[a]	3	3	3	3	3	4	4	4	4	4
Rating[b]	%Injury	%Injury	%Injury	%Injury	%Injury	Height(cm)	Height(cm)	1YO[c] DW(g)	2YO[c] DW(g)	Height(cm)
MeBr:Chloropicrin[d]	0	0	0	0	0	23.6	51.2	8.9	NA[e]	17.7
Flumioxazin	0	0	0	2	0	27.9	50.2	4.2*	15.8	19.6
Mesotrione	8*	3	5	0	0	27.3	58.2	5.7	26.4	16.4
Oxadiazon	0	3	5	0	0	25.6	48.2	6.0	17.3	19.2
Oxyfluorfen	8*	0	0	0	0	27.3	58.7	7.6	29.8	20.3
Mesotrione + *s*-Metolachlor	13*	3	3	0	23*	23.4	43.9*	5.6	28.1	21.7
Oxyfluorfen + Dithiopyr	8*	0	0	0	0	26.7	52.1	6.4	22.5	18.7
Oxyfluorfen + *s*-Metolachlor	11*	0	0	0	0	25.0	53.5	9.7	26.6	18.1
Rimsulfuron + *s*-Metolachlor	12*	0	0	3	0	27.2	52.1	5.7	19.6	20.1
Trifloxysulfuron + *s*-Metolachlor	11*	0	0	3	23*	26.9	56.0	7.9	23.1	22.5
Isoxaben + Oxyfluorfen + Trifluralin	NP	NP	NP	NP	0	NP	NP	NP	NP	17.6
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	0	NP	NP	NP	NP	21.1
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	0	NP	NP	NP	NP	20.8
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	0	NP	NP	NP	NP	16.7
Untreated	0	0	0	0	0	26.3	49.1	4.7*	32.9	19.7
LSD (0.05)	5	NS	NS	NS	5	2.8	6.3	3.3	NS	2.1
CV	113	297	201	337	106	22	25	29	31	21
p-value	<0.0001	0.4755	0.1211	0.5886	<0.0001	0.0098	<0.0001	0.0434	0.1741	<0.0001

[a] Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance. DW=Dry weight. YO=Year old. NS=Not significant. NA=Not available.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height is based on the total height of the plant in cm. Dry weight is the average of up to five seedlings in g.

[c] 1YO were seedlings planted in 2006. 2YO were seedlings planted in 2005.

[d] MeBr:Chloropicrin 98:2 used in Field 1 in 2004 and 67:33 used in Field 2 in 2005 and 2006 and Field 3 in 2006.

[e] Plants in MeBr plots were removed at the end 2005 and new one-year old plants were planted 2006.

*Treatments with significant injury or smaller plants compared to MeBr:Chloropicrin.

Table 3.7: Visual injury on Colorado Blue Spruce in Field 2 in 2005-06 and Field 3 in 2006, the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006, and tree heights in Field 3 in 2006.

Crop	Colorado Blue Spruce					
Field	2	2	3	2	2	3
Year	2005	2006	2006	2006	2006	2006
MAT[a]	3	3	3	4	4	4
Rating[b]	%Injury	%Injury	%Injury	1YO[c] DW(g)	2YO[c] DW(g)	Height(cm)
MeBr:Chloropicrin 67:33	0	0	0	7.8	NA[d]	29.3
Flumioxazin	5	0	0	7.2	17.5	25.0*
Mesotrione	23*	18*	47*	3.1	20.3	26.5*
Oxadiazon	0	0	0	4.3	14.3	28.5
Oxyfluorfen	0	0	0	5.6	19.5	28.5
Mesotrione + *s*-Metolachlor	15*	7*	40*	3.4	19.2	26.6*
Oxyfluorfen + Dithiopyr	0	0	0	3.0	18.9	28.5
Oxyfluorfen + *s*-Metolachlor	5	0	0	5.1	21.1	28.6
Rimsulfuron + *s*-Metolachlor	5	0	0	3.8	21.1	26.9*
Trifloxysulfuron + *s*-Metolachlor	0	0	0	3.5	13.2	26.9*
Isoxaben + Oxyfluorfen + Trifluralin	NP	NP	0	NP	NP	27.7*
Oxyfluorfen + Pendimethalin	NP	NP	0	NP	NP	28.1
Oxyfluorfen + Prodiamine	NP	NP	3	NP	NP	28.6
1,3-D:Chloropicrin 65:35	NP	NP	0	NP	NP	30.9
Untreated	0	0	0	2.8	28.0	28.3
LSD (0.05)	13	5	10	NS	NS	1.4
CV	105	132	98	66	45	10
p-value	0.0107	<0.0001	<0.0001	0.477	0.7285	<0.0001

[a] Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance. DW=Dry weight. YO=Year old. NS=Not significant. NA=Not available.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height is based on the total height of the plant in cm. Dry weight is the average of up to five seedlings in g.

[c] 1YO were seedlings planted in 2006. 2YO were seedlings planted in 2005.

[d] Plants in MeBr plots were removed at the end 2005 and new one-year old plants were planted 2006.

*Treatments with significant injury or smaller plants compared to MeBr:Chloropicrin.

Table 3.8: Visual injury on Douglas-Fir in Field 2 in 2005-06 and Field 3 in 2006, the dry weights of seedlings planted in 2005 and 2006 in Field 2 in 2006, and tree heights (cm) for Field 3 in 2006. Visual injury and tree heights of Balsam Fir in Field 3 in 2006.

Crop	Douglas-Fir							Balsam Fir	
Field	2	2	3	2	2	3		3	3
Year	2005	2006	2006	2006	2006	2006		2006	2006
MAT[a]	3	3	3	4	4	4		3	4
Rating[b]	%Injury	%Injury	%Injury	1YO[c] DW(g)	2YO[c] DW(g)	Height(cm)		%Injury	Height(cm)
MeBr:Chloropicrin 67:33	0	0	0	4.0	NA[d]	18.4		0	17.8
Flumioxazin	8	10*	0	1.9	19.4	14.5*		3	18.0
Oxadiazon	0	0	0	1.9	33.9	15.2*		0	18.3
Oxyfluorfen	0	0	0	2.2	26.8	16.4*		0	18.4
Oxyfluorfen + Dithiopyr	7	2	0	5.8	22.1	15.5*		0	19.7
Oxyfluorfen + *s*-Metolachlor	5	0	0	2.7	28.0	15.6*		0	16.2
Mesotrione	23*	22*	50*	6.8	26.6	14.2*		5*	18.0
Mesotrione + *s*-Metolachlor	17*	8	43*	3.8	25.7	12.3*		0	21.7
Trifloxysulfuron + *s*-Metolachlor	0	5	0	3.4	18.8	15.6*		0	19.0
Rimsulfuron + *s*-Metolachlor	5	0	8	3.1	19.5	15.3*		5*	16.9
Trifluralin + Isoxaben + Oxyfluorfen	NP	NP	5	NP	NP	16.1*		0	18.9
Oxyfluorfen + Pendimethalin	NP	NP	8	NP	NP	16.9		0	19.5
Oxyfluorfen + Prodiamine	NP	NP	0	NP	NP	14*		2	20.8
1,3-D:Chloropicrin 65:35	NP	NP	0	NP	NP	18.0		0	16.5
Untreated	0	0	0	4.0	35.7	16*		0	18.6
LSD (0.05)	13	9	8	NS	NS	1.8		3	NS
CV	93	128	62	51	38	21		197	24
p-value	0.0126	0.0015	<0.0001	0.1477	0.515	<0.0001		0.0161	0.0631

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance. DW=Dry weight. YO=Year old. NS=Not significant.

[b]Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death). Height is based on the total height of the plant in cm. Dry weight is the average of up to five seedlings in g.

[c]1YO were seedlings planted in 2006. 2YO were seedlings planted in 2005.

[d]Plants in MeBr plots were removed at the end 2005 and new one-year old plants were planted 2006.

*Treatments with significant injury or smaller plants than MeBr:Chloropicrin.

Table 3.9: Percent control of large crabgrass in Fields 1 and 2 and control of stinkgrass in Field 3 using MeBr and various alternative fumigant and herbicide treatments for weed control in conifer seedlings.

Weed	Large Crabgrass				Stinkgrass
Field	1	2	2		3
Year	2004	2005	2006		2006
MAT[a]	2	1[c]	2		2
Rating[b]	% Control	% Control	% Control		% Control
MeBr:Chloropicrin[d]	33	78	23		83
Flumioxazin	52	5*	40		73
Mesotrione	94	73	30		73
Oxadiazon	0*	3*	0		10*
Oxyfluorfen	80	43*	30		78
Mesotrione + *s*-Metolachlor	99	87	80		83
Oxyfluorfen + Dithiopyr	92	48*	90		87
Oxyfluorfen + *s*-Metolachlor	97	87	90		78
Rimsulfuron + *s*-Metolachlor	99	80	57		32*
Trifloxysulfuron + *s*-Metolachlor	94	23*	63		95
Isoxaben + Oxyfluorfen + Trifluralin	NP	NP	NP		72
Oxyfluorfen + Pendimethalin	NP	NP	NP		37*
Oxyfluorfen + Prodiamine	NP	NP	NP		77
1,3-D:Chloropicrin 65:35	NP	NP	NP		40*
Untreated	0*	0*	0		0*
LSD (0.05)	31	19	50		32
CV	27	24	64		32
p-value	<0.0001	<0.0001	0.0058		<0.0001

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[c]A post emergence grass herbicide was applied 1MAT, data at 2MAT was not available.

Table 3.10: Percent control of common ragweed in Fields 1 and 2 using MeBr and various herbicide alternative treatments for weed control in conifer seedlings.

Weed	Common Ragweed			
Field	1	1	2	2
Year	2004	2005	2005	2006
MAT[a]	2	2	2	2
Rating[b]	% Control	% Control	% Control	% Control
MeBr:Chloropicrin	92	97	100	100
Flumioxazin	99	100	98	100
Mesotrione	100	100	97	100
Oxadiazon	23*	30*	7*	80*
Oxyfluorfen	99	100	96	97
Mesotrione + *s*-Metolachlor	100	100	97	100
Oxyfluorfen + Dithiopyr	100	100	95	100
Oxyfluorfen + *s*-Metolachlor	100	100	99	100
Rimsulfuron + *s*-Metolachlor	94	93	43*	97
Trifloxysulfuron + *s*-Metolachlor	99	100	99	100
Untreated	0*	0*	0*	0*
LSD (0.05)	21	20	13	14
CV	15	14	10	9
p-value	<0.0001	<0.0001	<0.0001	<0.0001

[a]Abbreviations: MAT=Months after herbicide treatments. LSD=Least significant difference. CV=Coefficient of variance.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

*Treatments with statisically less control than MeBr:Chloropicrin.

Table 3.11: Percent control of common lambsquarters in Fields 1, 2, and 3 using MeBr and various alternative fumigant and herbicide treatments for weed control in conifer seedlings.

Weed	Common Lambsquarters				
Field	1	1	2	2	3
Year	2004	2005	2005	2006	2006
MAT[a]	2	2	2	2	2
Rating[b]	% Control	% Control	% Control	% Control	% Control
MeBr:Chloropicrin	66	47	85	73	93
Flumioxazin	100	98	98	100	53
Mesotrione	100	100	100	100	73
Oxadiazon	100	88	68	97	97
Oxyfluorfen	100	95	100	97	78
Mesotrione + *s*-Metolachlor	100	100	100	100	83
Oxyfluorfen + Dithiopyr	100	96	99	100	87
Oxyfluorfen + *s*-Metolachlor	100	96	100	97	78
Rimsulfuron + *s*-Metolachlor	99	53	100	93	32*
Trifloxysulfuron + *s*-Metolachlor	100	97	100	100	95
Isoxaben + Oxyfluorfen + Trifluralin	NP	NP	NP	NP	90
Oxyfluorfen + Pendimethalin	NP	NP	NP	NP	90
Oxyfluorfen + Prodiamine	NP	NP	NP	NP	58
1,3-D:Chloropicrin 65:35	NP	NP	NP	NP	33*
Untreated	0*	0*	0*	0*	0*
LSD (0.05)	29	33	21	12	43
CV	20	25	15	8	37
p-value	<0.0001	<0.0001	<0.0001	<0.0001	0.0015

[a]Abbreviations: MAT=Months after herbicide treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 3.12: Percent control of wild buckwheat and carpetweed in Fields 1 and 2 using MeBr and various alternative herbicide treatments for weed control in conifer seedlings.

Weed	Wild Buckwheat				Carpetweed		
Field	1	2	2		1	1	2
Year	2005	2005	2006		2004	2005	2006
MAT[a]	2	2	2		2	2	2
Rating[b]	% Control	% Control	% Control		% Control	% Control	% Control
MeBr:Chloropicrin	37	95	77		52	22	33
Flumioxazin	100	100	87		98	100	100
Mesotrione	93	73	60		100	100	100
Oxadiazon	40	65	100		87	97	100
Oxyfluorfen	100	98	97		100	100	100
Mesotrione + *s*-Metolachlor	100	77	100		100	100	100
Oxyfluorfen + Dithiopyr	100	100	100		100	100	100
Oxyfluorfen + *s*-Metolachlor	100	100	97		100	100	100
Rimsulfuron + *s*-Metolachlor	23	77	67		70	0*	53
Trifloxysulfuron + *s*-Metolachlor	85	98	73		91	73	100
Untreated	0	0*	0*		0*	0*	0*
LSD (0.05)	39	37	46		26	19	38
CV	32	27	35		19	15	28
p-value	<0.0001	0.0005	0.0073		<0.0001	<0.0001	<0.0001

[a]Abbreviations: MAT=Months after herbicide treatments. LSD=Least significant difference. CV=Coefficient of variance.

[b]Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

*Treatments with statistically less control than MeBr:Chloropicrin.

Table 3.13: Percent control of pigweed spp. in Field 3, horsenettle and vetch in Field 1, and hairy nightshade in Field 2 using MeBr and various alternative fumigant and herbicide treatments for weed control in conifer seedlings.

Weed	Pigweed spp.	Horsenettle	Hairy Nightshade		Vetch
Field	3	1	2	2	1
Year	2006	2005	2005	2006	2004
MAT[a]	2	2	2	2	2
Rating[b]	% Control	% Control	% Control	% Control	% Control
MeBr:Chloropicrin[c]	87	100	80	60	0
Flumioxazin	60	75	100	93	100
Mesotrione	57	93	98	67	92
Oxadiazon	53	80	32*	87	87
Oxyfluorfen	67	98	98	100	98
Mesotrione + *s*-Metolachlor	97	97	98	87	98
Oxyfluorfen + Dithiopyr	83	60	100	93	98
Oxyfluorfen + *s*-Metolachlor	93	90	100	100	100
Rimsulfuron + *s*-Metolachlor	93	70	0*	0*	92
Trifloxysulfuron + *s*-Metolachlor	100	53	0*	40	91
Isoxaben + Oxyfluorfen + Trifluralin	100	NP	NP	NP	NP
Oxyfluorfen + Pendimethlin	100	NP	NP	NP	NP
Oxyfluorfen + Prodiamine	90	NP	NP	NP	NP
1,3-D:Chloropicrin 65:35	67	NP	NP	NP	NP
Untreated	0*	0*	0*	0*	0
LSD (0.05)	43	54	30	27	9
CV	33	43	28	24	7
p-value	0.0028	0.0383	<0.0001	<0.0001	<0.0001

[a] Abreviations: MAT=Months after herbicide treatments. N/P=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

[b] Control based on a visual rating 0-100% (0%=no control, 100%=complete weed control).

[c] MeBr:Chloropicrin 98:2 in Field 1 and 67:33 in Fields 2 and 3

*Treatments with significantly less control than MeBr:Chloropicrin.

Table 3.14: Greenhouse Study 1: Percent injury to three deciduous and seven conifer tree species caused by 10 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds.

Crop	SM	WO	RO	FF	BF	WP	SP	DF	BS	WS
Greenhouse Study	1	1	1	1	1	1	1	1	1	1
Year	2005	2005	2005	2005	2005	2005	2005	2005	2005	2005
MAT[a]	3	3	3	3	3	3	3	3	3	3
Rating[b]	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury
Flumioxazin	2	0	0	0	0	0	0	1	3	1
Mesotrione	13	4	0	0	1	0	4	2	3	2
Oxadiazon	8	0	0	0	0	0	0	5	1	0
Oxyfluorfen	0	0	0	1	3	0	0	3	2	0
Mesotrione + *s*-Metolachlor	11	12	0	0	8	0	1	2	3	3
Oxyfluorfen + Dithiopyr	7	3	3	0	1	0	1	1	0	3
Oxyfluorfen + Pendimethalin	10	0	3	0	1	0	1	1	0	1
Oxyfluorfen + *s*-Metolachlor	13	8	0	1	1	0	0	1	5	6
Rimsulfuron + *s*-Metolachlor	15	0	0	0	3	0	7	2	0	0
Trifloxysulfuron + *s*-Metolachlor	8	0	4	0	4	0	0	3	0	0
Untreated	0	0	0	0	0	0	0	0	0	0
LSD (0.05)	NS	NS	NS	NS	NS	-	NS	NS	NS	NS
CV	119	260	343	462	187	-	261	201	219	316
p-value	0.2935	0.3573	0.4853	0.4654	0.1541	-	0.0786	0.8787	0.4965	0.665

[a] Abbreviations: MAT=Months after treatment. NS=Not significant. LSD=Least significant difference. CV=Coefficient of variance. FF=Fraser Fir. BF=Balsam Fir. WP=Eastern White Pine. SP=Scotch Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. WS=White Spruce. RO=Red Oak. WO=White Oak. SM=Sugar Maple.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death).

Table 3.15: Greenhouse Study 1: Average length of new growth on three stems in three deciduous and seven conifer tree species treated with 10 herbicide treatments that may be used as alternatives to MeBr for weed control in nursery beds.

Crop	SM	WO	RO	FF	BF	WP	SP	DF	BS	WS
Field	1	1	1	1	1	1	1	1	1	1
Year	2005	2005	2005	2005	2005	2005	2005	2005	2005	2005
MAT[a]	3	3	3	3	3	3	3	3	3	3
Measurement[b]	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)
Flumioxazin	22	8	11	8	5	10	5	5	5	5
Oxadiazon	15	8	14	7	5	9	6	10	7	5
Oxyfluorfen	10	13	24	6	3	7	4	6	5	3
Oxyfluorfen + Dithiopyr	15	8	15	8	4	5	4	4	4	5
Oxyfluorfen + *s*-Metolachlor	12	4	10	7	6	8	5	5	4	5
Mesotrione	19	5	13	8	5	9	4	5	6	5
Mesotrione + *s*-Metolachlor	15	4	24	8	5	8	6	4	6	3
Trifloxysulfuron + *s*- Metolachlor	14	8	6	6	3	8	6	8	4	3
Rimsulfuron + *s*-Metolachlor	3	6	17	6	2	11	4	6	7	6
Oxyfluorfen + Pendimethalin	21	9	12	7	3	9	5	6	5	3
Untreated	17	3	11	6	4	6	5	6	4	5
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV	58	94	95	37	77	32	59	71	64	43
p-value	0.1755	0.5851	0.7373	0.8802	0.691	0.1307	0.9584	0.6815	0.8898	0.1787

[a] Abbreviations: MAT=Months after treatment. NG=New growth. NS=Not significant. LSD=Least significant difference. CV=Coefficient of variance. FF=Fraser Fir. BF=Balsam Fir. WP=Eastern White Pine. SP=Scotch Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. WS=White Spruce. RO=Red Oak. WO=White Oak. SM=Sugar Maple.

[b] Growth measurements were made by measuring three random growing points on each plant.

Table 3.16: Greenhouse Study 2: Percent injury to three deciduous and six conifer tree species caused by 13 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds.

Crop	SM	WO	RO	FF	BF	WP	SP	DF	BS	WS
Greenhouse Study	2	2	2	2	2	2	2	2	2	2
Year	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006
MAT[a]	3	3	3	3	3	3	3	3	3	3
Rating[b]	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury	%Injury
Flumioxazin	NA[c]	NA	NA	NA	0	0	0	0	0	4
Mesotrione	NA	NA	NA	NA	0	0	0	24*	23*	18*
Oxadiazon	NA	NA	NA	NA	0	0	0	0	0	0
Oxyfluorfen	NA	NA	NA	NA	0	0	0	0	0	0
Mesotrione + *s*-Metolachlor	NA	NA	NA	NA	8	0	0	20*	30*	5
Norflurazon + Oxyfluorfen	NA	NA	NA	NA	5	38*	33*	33*	88*	19*
Norflurazon + Prodiamine	NA	NA	NA	NA	16	5	19*	20*	18*	9
Oxyfluorfen + Dithiopyr	NA	NA	NA	NA	0	3	3	0	0	0
Oxyfluorfen + Pendimethalin	NA	NA	NA	NA	0	0	0	0	0	0
Oxyfluorfen + Prodiamine	NA	NA	NA	NA	15	0	0	0	0	6
Oxyfluorfen + *s*-Metolachlor	NA	NA	NA	NA	0	0	6	0	5	0
Rimsulfuron + *s*-Metolachlor	NA	NA	NA	NA	0	0	0	0	0	0
Trifloxysulfuron + *s*-Metolachlor	NA	NA	NA	NA	3	0	0	4	0	9
Untreated	NA	NA	NA	NA	0	0	0	0	0	0
LSD (0.05)	NA	NA	NA	NA	NS	7	13	13	17	13
CV	NA	NA	NA	NA	261	147	210	130	92	151
p-value	NA	NA	NA	NA	0.0968	<0.0001	<0.0001	<0.0001	<0.0001	0.0038

[a] Abbreviations: MAT=Months after treatment. NS=Not significant. NA=Not available. LSD=Least significant difference. CV=Coefficient of variance. FF=Fraser Fir. BF=Balsam Fir. WP=Eastern White Pine. SP=Scotch Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. WS=White Spruce. RO=Red Oak. WO=White Oak. SM=Sugar Maple.

[b] Injury based on a visual rating 0-100% (0%=no injury, 100%=complete plant death).

[c] Injury to was NA for SM, RO, and WO because leaf eating insects caused injury to most of the leaves. FF was NA because the plants were unavailable at the time of the study.

*Treatments statistically different from the untreated control.

Table 3.17: Greenhouse Study 2: Average length of new growth on three random stems in three deciduous and six conifer tree species treated with 13 herbicide treatments that may be used as alternatives to MeBr for weed control in seedling beds.

Crop	SM	WO	RO	FF	BF	WP	SP	DF	BS	WS
Field	2	2	2	2	2	2	2	2	2	2
Year	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006
MAT[a]	3	3	3	3	3	3	3	3	3	3
Measurement[b]	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)	NG (cm)
Flumioxazin	3	10	7	NA[c]	6	11	7	5	5	3
Mesotrione	5	13	4	NA	7	14	8	5	5	4
Oxadiazon	7	11	11	NA	7	12	6	6	6	5
Oxyfluorfen	5	13	6	NA	6	12	11	6	3	5
Mesotrione + s-Metolachlor	4	10	7	NA	6	13	8	5	4	4
Norflurazon + Oxyfluorfen	6	9	4	NA	6	13	10	4	0*	4
Norflurazon + Prodiamine	20*	7	5	NA	6	16	7	6	5	3
Oxyfluorfen + Dithiopyr	3	10	9	NA	6	14	9	4	6	4
Oxyfluorfen + Pendimethalin	5	18	4	NA	7	18	8	5	6	4
Oxyfluorfen + Prodiamine	4	14	6	NA	6	10	7	8	5	4
Oxyfluorfen + s-Metolachlor	4	10	6	NA	6	9	8	6	4	3
Rimsulfuron + s-Metolachlor	16*	4	1	NA	6	9	6	5	4	5
Trifloxysulfuron + s-Metolachlor	5	7	4	NA	5	8	4	5	6	4
Untreated	0	12	9	NA	7	11	8	7	6	5
LSD (0.05)	7	NS	NS	NA	NS	NS	NS	NS	3	NS
CV	75	72	83	NA	30	33	43	31	31	30
p-value	0.0018	0.5882	0.3461	NA	0.9603	0.1145	0.4147	0.3388	0.0265	0.6126

[a] Abbreviations: MAT=Months after treatment. NG=New growth. NS=Not significant. LSD=Least significant difference. CV=Coefficient of variance. FF=Fraser Fir. BF=Balsam Fir. WP=Eastern White Pine. SP=Scotch Pine. DF=Douglas-Fir. BS=Colorado Blue Spruce. WS=White Spruce. RO=Red Oak. WO=White Oak. SM=Sugar Maple.

[b] Growth measurements were made by measuring three random growing points on each plant.

[c] FF was not available (NA) because the plants were unavailable at the time of the study.

*Treatments statisically different from the untreated control.

Table 3.18: Subjective summary of crop tolerance and weed control results of Field 1 and Field 2 on Fraser Fir, Eastern White Pine, Colorado Blue Spruce, and Douglas-Fir.

	Crop Injury				Weed Control				
Crop/Weed	FF[a]	WP	BS	DF	LC	CR	CL	WB	HN
MeBr:Chloropicrin	E	E	E	E	P	E	P	G	G
Flumioxazin	P	E	G	P	P	E	E	E	E
Mesotrione	P	P	P	P	P	E	E	G	G
Oxadiazon	G	G	E	E	P	P	E	P	P
Oxyfluorfen	G	G	E	E	P	E	E	E	E
Mesotrione + *s*-Metolachlor	P	P	P	P	E	E	E	E	E
Oxyfluorfen + Dithiopyr	P	G	E	G	G	E	E	E	E
Oxyfluorfen + *s*-Metolachlor	G	G	G	G	E	E	E	E	E
Rimsulfuron + *s*-Metolachlor	P	G	G	G	G	G	E	P	P
Trifloxysulfuron + *s*-Metolachlor	P	G	E	G	P	E	E	E	P

[a]Abbreviations: FF=Fraser Fir. WP=Eastern White Pine. BS=Colorado Blue Spruce. DF=Douglas-Fir. LC=Large Crabgrass. CR=Common Ragweed. CL=Common Lambsquarters. WB=Wild Buckwheat. HN=Hairy Nightshade.
*Scale: E=Excellent (No crop injury and growth reduction/>85% weed control). G=Good (Minimal crop injury and growth reduction/70-85% weed control). P=Poor (>5% crop injury or significant plant reduction/<70% weed control).

References

Bird, G.W. 2004. "Methyl Bromide Regulation Update with Special Reference to Michigan." Methyl Bromide Alternatives Task Force. Available www.ent.msu.edu/Bird_Lab/Methyl_bromide_regulation_update.pdf.

Dudek, T. 2006. Personal communication.

Kleweno, D.D. and V. Mathews. 2005. "Nursery and Christmas Tree Inventory 2004-2005." Michigan Rotational Survey. USDA, NASS, Michigan Field Office. Lansing, MI.

Koelling, M.R., J.B. Hart, and L. Leefers. 1998. "Christmas Tree Production in Michigan." Michigan State University Extension Ag Experiment Station Special Reports – SR619201.

CHAPTER FOUR

CONTROL OF FIELD HORSETAIL USING VARIOUS HERBICIDES

CONTROL OF FIELD HORSETAIL USING VARIOUS HERBICIDES

Abstract

Field horsetail *(Equisetum arvense* L.) is a perennial weed species that is tolerant of most herbicides used in agriculture. It is commonly found in landscapes, orchards, and ornamental nurseries. Field horsetail emerges in early spring and spreads by creeping rhizomes that produce tubers. From 2003 to 2006, six field and four greenhouse studies were conducted to determine potential herbicides for the control of field horsetail. Field trials were conducted at various nurseries in Michigan during the summer months. Visual ratings were taken monthly for up to four months. Several treatments consistently provided greater than 80% control during the growing season: MCPA (1.22 kg a.i./ha), triclopyr (1.12 kg a.i./ha), flumioxazin (0.27 kg a.i./ha) + oryzalin (3.36 kg a.i./ha) + glufosinate (1.12 kg a.i./ha), MCPA + clopyralid (0.22 kg a.i./ha), triclopyr + 2,4-D (1.12 kg a.i./ha), dichlobenil 4G (6.72 kg a.i./ha) and dichlobenil 4G + glufosinate, and dichlobenil CS (2.24 kg a.i./kg) + glufosinate. One year after treatment, dichlobenil 4G, triclopyr + 2,4-D, and dichlobenil 4G + glufosinate were the only treatments that provided control ($p<0.05$) with 70, 53, and 42% control, respectively. Greenhouse studies conducted at the Michigan State University research greenhouses had results similar to the field results, but control was generally better in the greenhouse.

Introduction

Field horsetail (*Equisetum arvense* L.) is a primitive perennial crytogam native to North America and Europe (Mitich, 1992; Sullivan, 1993). In North America, field horsetail is distributed from Canada to Alaska and southward throughout most of the United States (Mitich, 1992; Hauke, 1978; Rook, 2002). It is widespread throughout

Europe and the British Isles (Mitich, 1992). Other regions where field horsetail can be found are Greenland, Korea, Japan, and Asia as far south as Turkey, Iran, and the Himalayas, and all but the southeastern part of China (Hauke, 1978).

Field horsetail is best adapted to sandy soils that are neutral or slightly basic, but it will also grow in other soil types. It is a common weed in areas where the water table is high or the soil drainage is poor (Uva et.al., 1997), such as marshes, swamps, ditches, riverbanks, open fields, open woods, road sides, and railroad embankments (Hauke, 1978).

The primary mode of field horsetail reproduction is asexual, by its extensive rhizome system and tubers. Broken rhizome segments as short as 3 cm can sprout new shoots and tubers can also produce shoots if removed from the rhizome. Overwintering buds develop at the nodes of the rhizomes. Rhizomes can reach depths of over 1 m, with one report stating that rhizomes were found at depths of over 2 m deep. Sullivan (1993) reported that most of the rhizome mass is found in the top 48 cm of the soil, with 50% in the first 25 cm and 23% in the next 23 cm. The roots of the field horsetail plant have the ability to take up nutrients and various compounds from the soil. The deep root and rhizome system of field horsetail make it difficult to control (Mitich, 1992).

Field horsetail can also reproduce sexually. Fertile stems produce one spore cone per plant that releases millions of minute spores, which are disseminated by wind or water (Doll, 2002, Sullivan 1993). The spores are only viable for 48 hours after release (Doll, 2002). Spores produce two tiny gametophytes that bear male and female organs. Fertilization occurs off the plant and can only occur in water where the sperm can pass from the male to female organ. Once fertilization occurs, a zygote develops and the resulting embryo develops into both a fertile and a sterile stem the following year. Since water is needed for sexual reproduction, reproduction by spores usually does not occur in an agricultural system (Mitich, 1992).

Simulations estimate that field horsetail can infest 1 ha within six years after its first introduction in a tillage system. Its impact is highly correlated with crop type. In corn, soybeans, or small grains, field horsetail is seldom a problem; however, it is very competitive in slow growing and short stature vegetables and in landscape plantings (Doll, 2002). It is believed that due to its high concentration of alkaloids, FH is allelopathic. Researchers in Russia found that water extracts from field horsetail have an inhibitory effect on seed germination and seedling vigor of 30 species of meadowgrass (Burrill and Parker, 1994).

Practices like improving drainage, cleaning cultivation equipment, and increasing the crop's competitiveness can reduce field horsetail populations (Mitich, 2002). Removing the shoots every two weeks for three to four years can reduce field horsetail populations. In a landscape setting, geotextile fabrics can be used to suppress field horsetail because the field horsetail stems are not strong or sharp enough to penetrate the fabric. Organic mulches do not provide any control. Controlled flaming can provide temporary control (Burrill and Parker, 1994). The continued use of glyphosate on railroad embankments in Sweden has lead to an increase in field horsetail populations. Glyphosate has limited effects on field horsetail (Torstensson, 2001).

Primisulfuron can be used as a burn down control for horsetail in corn. Repeated applications of MCPA can reduce horsetail populations and are safe on perennial grasses (Doll, 2002). The Weed Control Manual 2002 (Curran, et al., 2002) lists six herbicides for the control or suppression of field horsetail in non-croplands: glufosinate, fluroxypyr, bromacil, diclobenil, chlorsulfuron, and sulfometuron. It also lists diclobenil and glufosinate for ornamentals and woody plantings, small fruits, and deciduous fruit trees.

The objective of the study was to evaluate herbicides for the control of field horsetail. Herbicides with different modes of action were included in the study. The four field sites were located in different areas of the state and were not in crop production at the time of the study.

Materials and Methods

Field Studies:

Field studies were conducted from 2003 to 2006 at four sites in Michigan. Three sites were located on Christmas tree plantations and the other site was a roadside right-of-way. Various herbicides and herbicide combinations were evaluated for field horsetail control. Weed control was rated on a visual scale from 0 (no control) to 100% (complete control). The herbicides, rates and formulations are given in Table 4.1. Liquid treatments were applied over top of field horsetail with a CO_2 backpack sprayer with four TeeJet® (Spraying Systems Company, Wheaton, IL) 8002 nozzles calibrated to apply 187 L/ha at 207 KPa of pressure. Granular treatments were applied using a shaker bottle. All herbicide applications were made postemergence with the exception of dichlobenil 4G alone, which was applied preemergence.

Site 1 was a non-cultivated lane located on a Christmas tree plantation in Manistee, Michigan. Data was recorded at one and two months after application (MAT) in 2003. The soil type is a sandy loam. Herbicide applications were made on June 24, 2003, with air and soil temperatures of 28 and 23°C, respectively. Treatments were applied when soil moisture was low, under clear skies and 54% relative humidity. The field horsetail plants were between 10 and 31 cm in height and had a density of approximately 90/m^2. Plots were arranged in a randomized complete block design with plot size of 1.6 by 1.5 m. The study consisted of 11 treatments with three replications. Treatments are listed in Table 4.2.

Site 2 was located in a pine under-story next to a two-track road at a Christmas tree plantation in Flint, Michigan. Data was recorded at one and two MAT in 2004. The soil type is a poorly drained clay loam. Herbicide applications were made on June 16, 2004, with both air and soil temperatures of 26°C. Treatments were applied when soil was moist, under cloudy conditions and 74% relative humidity. The field horsetail plants were between 30 and 45 cm in height with a density of approximately 165/ m^2. Plots were arranged in a randomized complete block design with plot size of 1.6 by 3.0 m. The study consisted of 12 treatments with three replications. Treatments are listed in Table 4.2.

Site 3 was in a nursery production area that was previously planted in Christmas trees in West Olive, Michigan. This site was used in 2004 and 2005. In 2004, data was recorded at one, two and four MAT. In 2005, data was recorded one, two and 12 MAT. Soil type was a sandy loam. A preemergence application of dichlobenil 4G was made on April 21, 2005. Postemergence herbicide applications were made on June 16, 2004 and May 18, 2005. In 2004, applications were made when the air temperature was 22°C, soil temperature of 23°C, with wet soil conditions, clear skies, and 45% relative humidity. In 2005, the preemergence application was made when the air temperature was 12°C, soil temperature of 17°C, with dry soil conditions, clear skies, and 42% relative humidity.

The postemergence applications were made when the air temperature was 19°C and soil temperature was 17°C, with dry soil conditions, partly cloudy skies, and 45% relative humidity. The field horsetail plants were between 5 and 15 cm in height with a density of approximately 110/m^2 in 2004 and 1 to 10 cm in height with a density of approximately 275/m^2 in 2005 at the time of postemergence applications. Plots were arranged in a randomized complete block design with plot size of 1.6 by 6.0 m in 2004 and 1.6 by 3.0 m in 2005. The study consisted of 13 and 19 treatments with three replications in 2004 and 2005, respectively. Treatments are listed in Table 4.2.

Site 4 was a roadside right-of-way in turf located at the Michigan State Horticulture Teaching and Research Center in Holt, Michigan. The site was used in 2005 and 2006. In 2005, data was recorded one and two MAT and one, two, and three MAT in 2006. Herbicide applications were made on June 20, 2005 and July 7, 2006. Soil type was a loam that contained gravel. In 2005, applications were made when the air temperature was 26°C, soil temperature was 21°C, with moist soil conditions, clear skies, and 45% relative humidity. In 2005, the applications were made when the air temperature was 23°C, soil temperature of 26°C, under dry soil conditions, under partly cloudy skies, and 55% relative humidity. The field horsetail plants were between 1 and 10 cm in height with a density of approximately 165/m^2 for both years. Plots were arranged in a randomized complete block design with plot size of 1.6 by 3.0 m. The study consisted of 5 and 10 treatments with three replications in 2005 and 2006, respectively. Treatments are listed in Table 4.2. Turf injury was not evaluated.

Greenhouse Studies:

Four greenhouse studies were established from 2003 to 2005. Two or three 2.5 cm rhizomes were planted in 10 X 10 X 15 cm plastic pots filled with Baccto® potting mix (Michigan Peat Co., Houston, TX). Rhizomes from Site 1 were used in greenhouse study 1. Site 3 rhizomes were used for greenhouse studies 2 and 3. Rhizomes from Site 4 were used in greenhouse study 4. Treatments were applied when the field horsetail plants were 10-20 cm in height. Four pots were chosen at random for each treatment. Treatments were applied in a moving track spray chamber (Allen Machine Works, Midland, MI) with a single Teejet® (Spraying Systems Co, Wheaton, Illinois) 8001 EVS nozzle calibrated to apply 187 L/ha at 207 KPa of pressure. Greenhouse studies 1, 2, and 3 were conducted in a glass greenhouse, while study 4 was conducted in a lathe house. Treatments are listed in Table 4.2.

Field horsetail control was rated six weeks after treatments on a visual scale form 0 (no control) to 100% (complete control) in greenhouse studies 1, 2, 3, and 4. In studies 1, 2, and 3, all above ground plant biomass, dead and living tissue, was removed, placed in paper bags, oven dried at 41°C for 3 to 5 days, and then weighed. In studies 2 and 3, field horsetail was allowed to regrow for four weeks after the first harvest and all new shoots were cut, placed in paper bags, oven dried at 41°C for 3 to 5 days, and then weighed. In study 4, all dead plant tissue was removed at 6 weeks after treatments and the field horsetail were allowed to grow for another four weeks. The above ground plant tissue was removed, placed in paper bags, oven dried at 41°C for 3 to 5 days, and then weighed. Data were subjected to ANOVA and means were separated using Fisher's LSD at the p=0.05 level.

Results and Discussion

Field Studies: Site 1

Glufosinate, flumioxazin plus glufosinate, flumioxazin plus glufosinate plus oryzalin, and clopyralid plus MCPA all gave greater than 90% control one month after treatments (MAT) (Table 4.3). Clopyralid plus MCPA provided the best control at 98%, followed by glufosinate and flumioxazin plus glufosinate at 94% each. By two MAT, clopyralid plus MCPA was the only treatment to provide greater than 90% control with 92% control. Since clopyralid alone was poor in controlling field horsetail, the MCPA in the MCPA plus clopyralid treatment is probably providing the control.

Halosulfuron, flumioxazin, halosulfuron plus clopyralid, and clopyralid provided the least control at one MAT, providing 38, 40, 40, and 43% control, respectively. By two MAT, flumioxazin and clopyralid were the only treatments to provide 50% or less control (Table 4.3).

Field Studies: Site 2

Clopyralid plus MCPA was the only treatment to provide greater than 90% control at site 2, one MAT (Table 4.3). Clopyralid plus MCPA, flumioxazin plus glufosinate, and flumioxazin plus glufosinate plus oryzalin provided the best control at 92, 86, and 84% control one MAT, respectively. No treatment provided greater than 90% control two MAT. Clopyralid plus MCPA, flumioxazin plus glufosinate, and flumioxazin plus glufosinate plus oryzalin still provided the best control two MAT providing 77, 71, and 78% control, respectively.

Halosulfuron plus clopyralid, halosulfuron alone, and clopyralid alone provided the least control at one MAT, providing 38, 46, and 45% control, respectively.

Halosulfuron plus clopyralid, flumioxazin plus halosulfuron, flumioxazin, clopyralid, and halosulfuron all provided less than 50% control by two MAT (Table 4.3).

Field Studies: Site 3 2004

MCPA provided 100% control at one, two, and four MAT (Table 4.4). Clopyralid plus MCPA provided 100% control at one and two MAT, but only gave 92% control by four MAT. Flumioxazin plus glufosinate and flumioxazin plus glufosinate plus oryzalin each gave 95% control one MAT, but only provided 74 and 80% control by four MAT, respectively. MCPA, clopyralid plus MCPA, flumioxazin plus glufosinate plus oryzalin, and glyphosate provided the best control four MAT at 100, 92, 80, and 80%, respectively. In the clopyralid plus MCPA treatment, the MCPA was providing the control since MCPA alone provided great control and clopyralid alone did not provide much control.

Flumioxazin, halosulfuron, clopyralid, halosulfuron plus clopyralid, and mesotrione all provided less than 50% control for all rating dates. Flumioxazin plus halosulfuron gave less than 50% control one and two MAT, but provided 55% control four MAT (Table 4.4).

Field Studies: Site 3 2005

Dichlobenil 4G, dichlobenil 4G plus glufosinate, and MCPA all provided 100% control one MAT (Table 4.4). Dichlobenil 4G alone was applied preemergence one month prior to postemergence treatments and the rating dates are in months after postemergence applications, so one MAT is two months after the Dichlobenil 4G treatment. Clopyralid plus MCPA, and triclopyr plus 2,4-D each gave 98% control one MAT. Dichlobenil CS plus glufosinate, flumioxazin plus glufosinate plus oryzalin, and glufosinate alone provided 97, 92, and 95% control, respectively. Dichlobenil 4G, dichlobenil CS plus glufosinate, and MCPA provided 100% control at two MAT. Dichlobenil 4G plus glufosinate, glufosinate, clopyralid, clopyralid plus MCPA, triclopyr, and triclopyr plus 2,4-D all provided greater than 90% control two MAT. One year after the treatments were applied, only two treatments reduced field horsetail populations by more than 50%, dichlobenil 4G and triclopyr plus 2,4-D. Dichlobenil 4G, reduced populations by 70%, while triclopyr plus 2,4-D reduced populations by approximately 55%.

Halosulfuron, clopyralid, halosulfuron plus clopyralid, glyphosate, and mesotrione all provided less than 50% control one MAT. By two MAT, all treatments gave at least 50% control (Table 4.4). Hot and dry environmental conditions may have influenced field horsetail control. By three MAT all field horsetail plants were dormant.

Field Studies: Site 4

Dichlobenil CS provided 94% control one MAT, which was the only treatment in 2005 with greater than 90% control (Table 4.5). Triclopyr, MCPA, and clopyralid plus MCPA gave 83, 77, and 65% control, respectively one MAT. No treatment provided greater than 90% control two MAT. Triclopyr provided 80% control, while clopyralid plus MCPA, MCPA, and dichlobenil CS provided 65, 60, and 48% control, respectively.

In 2006, triclopyr, triclopyr plus clopyralid, fluroxypyr, 2,4-D plus triclopyr, 2,4-D plus prodiamine, and quinclorac all provided greater than 90% control one MAT (Table 4.5). Quinclorac gave 100% control and 2,4-D plus triclopyr gave 99% control. All treatments gave at least 78% control one MAT. By two MAT, no treatments provided greater than 90% control. Triclopyr plus clopyralid, quinclorac, fluroxypyr, and triclopyr provided the best control at 89, 85, 82, and 82% control, respectively. Three MAT, triclopyr plus clopyralid provided 92% control and fluroxypyr gave 87% control. Triclopyr plus 2,4-D, 2,4-D alone and MCPA provided the least control at 58, 50, and 45% control, respectively.

Greenhouse Studies: Study 1

Glufosinate, flumioxazin plus glufosinate, flumioxazin plus glufosinate plus oryzalin, and clopyralid plus MCPA all provided greater than 90% control of field horsetail six weeks after treatments (WAT) (Table 4.6). No treatment provided 100% control. Clopyralid and mesotrione were the only treatments to provide less than 50% control, providing only 20 and 16% control, respectively. Flumioxazin plus glufosinate, clopyralid, halosulfuron plus clopyralid, and clopyralid plus MCPA were the only treatments that did not reduce ($p<0.05$) above ground biomass. Even though flumioxazin plus glufosinate and clopyralid plus MCPA provided good control of field horsetail, the remaining plant tissue was taller than the treatments that had less biomass measurements (data not presented).

Greenhouse Studies: Studies 2 and 3

Study by treatment interaction was not significant ($p>0.05$) so data from studies 2 and 3 were combined. All treatments except clopyralid provided greater than 95% control (Table 4.6). Clopyralid was also the only treatment that did not reduce ($p<0.05$) above ground biomass six WAT. All treatments reduced field horsetail shoot regrowth biomass four weeks after the first biomass harvest. Triclopyr was the only treatment that did not have any regrowth.

Greenhouse Studies: Study 4

Flumioxazin, flumioxazin plus glufosinate, flumioxazin plus glufosinate plus oryzalin, fluroxypyr, and triclopyr plus 2,4-D provided greater than 90% control six WAT (Table 4.6). Halosulfuron plus clopyralid provided no control and halosulfuron and clopyralid alone provided only 20 and 18% control, respectively. Halosulfuron plus clopyralid was the only treatment that did not reduce above ground dry weight biomass. Flumioxazin plus glufosinate plus oryzalin and triclopyr plus 2,4-D had the lowest above ground biomass at 0.02 and 0.1 g, respectively.

The greenhouse studies followed the same trends as the field studies, but control was generally better. Better control may have occurred because the field horsetail plants had under-developed cuticles when grown in a glass greenhouse. The field horsetail plants in Study 4 had thicker cuticles when grown in a lathe house, which had control similar to that of the field studies. The growth regulator herbicides, except clopyralid alone, and glufosinate treatments provided good control but regrowth of field horsetail shoots did occur. Triclopyr did not have regrowth 10 weeks after treatments in studies 2 and 3.

Conclusions

The growth regulator herbicides, except clopyralid alone, provided the best control early in the studies, but reemergence of field horsetail shoots was seen as early as two MAT. About 50% reduction in field horsetail populations was recorded one year after applications in the triclopyr plus 2,4-D plots at the West Olive site (Site 3) (Table 4.4). More research is needed for long term suppression of field horsetail using triclopyr plus 2,4-D.

Glufosinate provided good top growth suppression of field horsetail. Like the growth regulator herbicides, reemergence of field horsetail shoots also was observed as early as two MAT. Adding flumioxazin and flumioxazin plus oryzalin to glufosinate increased control but regrowth did occur. No reduction in field horsetail populations was recorded one year after applications with these three treatments (Table 4.5).

Dichlobenil treatments gave season long field horsetail control in 2005 at the West Olive site (Site 3); however, control by dichlobenil CS had decreased below 50% at the Holt site (Site 4) by two MAT. To preserve some turf cover, glufosinate was applied with dichlobenil CS at Site 4. The addition of glufosinate at West Olive may explain the increase in control. Applying dichlobenil 4G preemergence provided season long control and provided 70% reduction in FH population 12 MAT. Dichlobenil is listed in the Weed Control Manual (Curran et al, 2002) as a control of field horsetail; however, a rotational restriction of one year for non labeled crops is required. Dichlobenil has a half life of 1.5 to 12 months and can be effective from 2 to 6 months, or even up to one year under favorable conditions, depending on soil conditions (Duphar, 1985).

Field horsetail was fairly tolerant of glyphosate. Control by glyphosate tended to increase in the later months of the studies, but control never exceeded 80%. Reduction of field horsetail populations was not observed in the glyphosate plots one year after applications.

All the growth regulator herbicides tested except clopyralid (MCPA, triclopyr, fluroxypyr, 2,4-D, and quinclorac) and glufosinate are good treatment options for short term suppression of field horsetail. However, dichlobenil continues to be the best option to suppress field horsetail populations, but label restrictions limit the use of this product.

The granular formulation used preemergence provided the best long term results. Triclopyr plus 2,4-D showed promise of reducing field horstail populations one year after application, but more research is needed.

Table 4.1: The rates, formulations, and mode of action of the herbicides used in the field horsetail control studies.

Herbicide	Rate kg a.i./ha	Formulation[a]	Mode of Action
2,4-D	1.12	3.8SL	Growth Regulator
Clopyralid	0.22	3EC	Growth Regulator
Dichlobenil	2.24	1.38CS	Shoot and Root Inhibitor
Dichlobenil	6.72	4G	Shoot and Root Inhibitor
Flumioxazin	0.28	51WG	Cell Membrane Disruptor
Fluroxypyr	0.22	1.5EC	Growth Regulator
Glufosinate	1.12	1SL	Amino Acid Synthesis Inhibitor
Glyphosate	2.24	5.5SL	Amino Acid Synthesis Inhibitor
Halosulfuron[b]	0.07	75DF	Amino Acid Synthesis Inhibitor
MCPA	1.22	3.7SL	Growth Regulator
Mesotrione[c]	0.28	4SC	Pigment Inhibitor
Oryzalin	3.36	4AS	Root Inhibitor
Prodiamine	1.68	4FL	Root Inhibitor
Quinclorac[d]	1.12	75DF	Growth Regulator
Triclopyr	1.12	3EC	Growth Regulator

[a]CS= Capsule suspension. DF=Dry flowable. EC=Emulsifiable concentrate. FL=Flowable. G=Granular. SL= Soluble liquid. SC=Soluble concentrate. WG=Wettable granules. AS=Aqueous solution.

[b]0.25% v/v Non-ionic surfactant added

[c]1% v/v Crop oil concentrate added

[d]1% v/v Methylated seed oil added

Table 4.2: Treatments used for the control of field horsetail present at the four field sites and four greenhouse studies are marked "X".

Treatment[a]	FS[b] 1(03)[c]	FS 2(04)	FS 3(04)	FS 3(05)	FS 4(05)	FS 4(06)	GS 1(03)	GS 2 and 3(04)	GS 4(05)
2,4-D						X		X	
2,4-D + Prodiamine						X			
Clopyralid	X	X	X	X			X	X	X
Clopyralid + Halosulfuron	X	X	X	X			X		X
Clopyralid + MCPA	X	X	X	X	X	X	X	X	
Dichlobenil 4G				X					
Dichlobenil 4G + Glufosinate				X					
Dichlobenil CS + Glufosinate				X	X[d]				
Flumioxazin	X	X	X	X			X		X
Flumioxazin + Glufosinate	X	X	X	X			X		X
Flumioxazin + Glufosinate + Oryzalin	X	X	X	X			X		X
Flumioxazin + Halosulfuron	X	X	X	X			X		
Fluroxypyr				X		X		X	X
Glufosinate	X	X	X	X			X		X
Glyphosate	X	X	X	X			X		X
Halosulfuron	X	X	X	X			X		X
MCPA			X	X	X	X		X	
MCPA (0.56 kg ai/ha)							X	X	
Mesotrione		X	X	X					X
Quinclorac						X			
Triclopyr				X	X	X		X	
Triclopyr + 2,4-D				X		X		X	X
Triclopyr + Clopyralid						X		X	
Untreated Control	X	X	X	X	X	X	X	X	X

[a]Treatments marked "X" were present.

[b]Abbreviations: FS=Field Site. GS=Greenhouse Study. FS 1=Manistee Site. FS 2=Flint Site. FS 3=West Olive Site. FS 4=Holt Site.

[c](0X) indicates year of study: 200X

[d]Dichlobenil CS alone was used.

Table 4.3: Percent control of field horsetail from various herbicides at Manistee (Site 1) in 2003 and Flint (Site 2) in 2004.

	2003		2004	
	Site 1		Site 2	
Treatment	1 MAT[a]	2 MAT	1 MAT	2 MAT
Clopyralid	43	50	45	38
Clopyralid + Halosulfuron	40	57	38	33
Clopyralid + MCPA	98	92	92	77
Flumioxazin	40	47	53	37
Flumioxazin + Glufosinate	94	67	86	71
Flumioxazin + Glufosinate + Oryzalin	92	70	84	78
Flumioxazin + Halosulfuron	55	67	62	33
Glufosinate	94	67	77	57
Glyphosate	58	70	61	70
Halosulfuron	38	60	46	40
Mesotrione	NP	NP	62	65
Untreated Control	0	0	0	0
LSD (0.05)	**16**	**18**	**17**	**18**
CV	**14**	**16**	**16**	**22**
p-value	**<0.0001**	**0.0028**	**<0.0001**	**<0.0001**

[a]Abbreviations: MAT=Months after treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

Table 4.4: Percent control of field horsetail from various herbicides at the West Olive site (Site 3) in 2004 and 2005.

Treatment	2004 Site 3			2005 Site 3		
	1 MAT[a]	2 MAT	4 MAT	1 MAT	2 MAT	12 MAT
Clopyralid	0	5	5	28	95	5
Clopyralid + Halosulfuron	4	13	8	30	50	0
Clopyralid + MCPA	100	100	92	98	95	28
Dichlobenil 4G[b]	NP	NP	NP	100	100	70
Dichlobenil 4G + Glufosinate	NP	NP	NP	100	98	42
Dichlobenil CS + Glufosinate	NP	NP	NP	97	100	25
Flumioxazin	25	35	30	60	60	0
Flumioxazin + Glufosinate	95	86	74	88	73	7
Flumioxazin + Glufosinate + Oryzalin	95	91	80	92	83	0
Flumioxazin + Halosulfuron	17	25	55	69	87	10
Fluroxypyr	NP	NP	NP	65	82	33
Glufosinate	73	68	60	95	95	7
Glyphosate	67	75	80	43	80	12
Halosulfuron	17	30	28	27	65	7
MCPA	100	100	100	100	100	23
Mesotrione	8	30	37	42	82	3
Triclopyr	NP	NP	NP	88	98	7
Triclopyr + 2,4-D	NP	NP	NP	98	98	54
Untreated Control	0	0	0	0	0	0
LSD (0.05)	**36**	**31**	**26**	**19**	**30**	**31**
CV	**46**	**37**	**31**	**19**	**22**	**106**
p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0006**

[a]Abbreviations: MAT=Months after postemergence treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

[b]Dichlobenil 4G was applied preemergence one month prior to other treatments. One MAT is two months after Dichlobenil 4G application.

Table 4.5: Percent contol of field horsetail from various herbicides at the Holt site (Site 4) in 2005 and 2006.

Treatment	2005 Site 4		2006 Site 4		
	1 MAT[a]	2 MAT	1 MAT	2 MAT	3 MAT
2,4-D	NP	NP	78	50	50
2,4-D + Prodiamine	NP	NP	91	75	75
2,4-D + Triclopyr	NP	NP	99	67	58
Clopyralid + MCPA	65	65	88	77	70
Clopyralid + Triclopyr	NP	NP	98	89	92
Dichlobenil CS	94	48	NP	NP	NP
Fluroxypyr	NP	NP	97	82	87
MCPA	77	60	85	63	45
Triclopyr	83	80	98	82	75
Quinclorac	NP	NP	100	85	75
Untreated	0	0	0	0	0
LSD (0.05)	**16**	**31**	**11**	**28**	**32**
CV	**13**	**32**	**8**	**24**	**30**
p-value	**<0.0001**	**0.0028**	**<0.0001**	**<0.0001**	**<0.0001**

[a]Abbreviations: MAT=Months after treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

Table 4.6: Percent control and dry weights of potted field horsetail plants six weeks after various herbicide treatments (WAT) and plant dry weights six and 10 WAT in four greenhouse studies.

	Study 1		Studies 2 and 3[a]			Study 4	
	% Control	DW[b] (g)	% Control	DW (g)	RG (g)	% Control	DW (g)
Treatment	6 WAT	6 WAT	6 WAT	6 WAT	10 WAT	6 WAT	10 WAT
2,4-D	NP	NP	98	0.66	0.05	NP	NP
2,4-D + Triclopyr	NP	NP	100	0.62	0.04	100	0.10
Clopyralid	20	2.44	38	1.86	0.22	18	1.13
Clopyralid + Halosulfuron	63	3.26	NP	NP	NP	0	2.25
Clopyralid + MCPA	95	2.57	95	0.98	0.05	NP	NP
Clopyralid + Triclopyr	NP	NP	100	0.87	0.08	NP	NP
Flumioxazin	83	1.9	NP	NP	NP	95	0.33
Flumioxazin + Glufosinate	97	2.4	NP	NP	NP	97	0.25
Flumioxazin + Glufosinate + Oryzalin	98	1.76	NP	NP	NP	98	0.02
Flumioxazin + Halosulfuron	81	1.62	NP	NP	NP	83	0.73
Fluroxypyr	NP	NP	99	0.82	0.18	98	0.28
Glufosinate	96	1.71	NP	NP	NP	87	0.25
Glyphosate	89	1.17	NP	NP	NP	62	1.07
Halosulfuron	51	2.33	NP	NP	NP	20	1.23
MCPA (0.56 kg ai/ha)	NP	NP	100	1.12	0.05	NP	NP
MCPA (1.12 kg ai/ha)	NP	NP	99	1.17	0.08	NP	NP
Mesotrione	16	2.23	NP	NP	NP	23	1.18
Triclopyr	NP	NP	100	0.75	0.00	NP	NP
Untreated Control	0	3.57	0	1.88	0.71	0	2.41
LSD (0.05)	14	1.2	8	0.6	0.15	30	0.76
CV	15	37	9	55	107	30	52
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] Study by treatment interaction was not significant, so data were combined in studies 2 and 3.

[b] Abbreviations: DW=Dry weight. RG=Regrowth dry weight. WAT=Weeks after treatments. NP=Treatment not present. LSD=Least significant difference. CV=Coefficient of variance.

References

Burrill, L.C. and R. Parker. 1994. _"Field Horsetail and Related Species." A Pacific Northwest Extension Publication 105. Oregon, Idaho, Washington.

Curran, W. et al. 2002. Weed Control Manual 2002. Meister Pub. Co. Willoughby, OH

Doll, J. 2002. "Biology and Control of Field Horsetail (*Equisetum arvensis* L., Horsetail Family." Available http://ipcm.wisc.edu/uw_weeds/extension/articles/conhorsetail.htm

Duphar, B.V. 1985. "Dichlobenil (Casoron) Herbicide Profile 2/85." PMEP Cornell University Cooperative Extension. Available http://pmep.cce.cornell.edu/profiles/herb-growthreg/dalapon-ethephon/dichlobenil/herb-prof-dichlobenil.html

Hauke, R.L. 1978. "*Equisetum arvense* L., Sp. Pl. 1061. 1753. A taxonomic monograph of the genus *Equisetum* subgenus *Equisetum*" Nova Hedwigia Volume 30:p.385. E. Schweizerbart Science Publishers. Available http://members.eunet.at/m.matus/Equisetum_arvense.html

Mitich, L.W. 1992. "Horsetail." Weed Technology. Volume 6:p.779-781. Weed Science Society of America. Lawrence, KS.

Rook, Earl J.S. 2002. "*Equisetum arvense* Field Horsetail." Available http://www.rook.org/earl/bwca/nature/ferns/equisetumarv.html

Sullivan, J. 1993. "*Equisetum arvense*" In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available http://www.fs.fed.us/database/fies/plants/fern/equarv.html

Torstensson, L. 2001. "Use of Herbicides on Railway Tracks in Sweden." The Royal Society of Chemistry 2001. p.16-21.

Uva, R.H., J.C. Neal, and J.M. DiTomaso. 1997. Weeds of the Northeast. Cornell University Press. Ithaca, New York 14850