AN ABSTRACT OF THE THESIS OF

Jessica Lee Haavisto for the degree of Master of Science in Crop Science presented on November 15, 2011.
Title: Hare Barley (*Hordeum murinum* ssp. *leporinum*) Biology and Management in Cool Season Perennial Grass Pastures of Western Oregon.

Abstract approved:

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Hare barley (*Hordeum murinum* ssp. *leporinum*) is a cool season annual grass that invades pastures and range areas around the world. A documented weed management issue in several Oregon counties, hare barley may infest several thousand acres in western Oregon. This study was conducted to investigate the biology and develop management options for hare barley in cool season, established perennial grass pastures. Field and laboratory studies were initiated in the fall of 2008 to generate this information for hare barley management. Experiments were conducted to evaluate herbicide treatments applied before and after hare barley emergence in perennial grass pastures. Multi-year applications of a labeled pasture herbicide, aminopyralid, and non pasture labeled herbicides, imazamox and imazamox + MCPA ester, were the only treatments that consistently resulted in a high level of hare barley control with acceptable crop safety. A laboratory experiment was initiated to develop a growing degree day model to understand when viable seed is produced in hare barley. We determined that viable seed set depends on cumulative growing degree days (GDD) regardless of the location from which the seeds were collected. The majority of

hare barley seed becomes viable after accumulating approximately 2300 GDD. This result indicates that individual pasture owners and hay producers can monitor growing degree days in their respective farming locations and base their management strategies for controlling hare barley and for preventing the spread of hare barley to other locations prior to viable seed production. A survey conducted to understand the distribution of hare barley across Oregon indicated that hare barley distribution is limited to western Oregon while two other species in the *Hordeum murinum* complex, ssp. *glaucum* and ssp. *murinum*, can also be found in the state of Oregon.

Hare Barley (*Hordeum murinum* ssp. *leporinum*) Biology and Management in Cool Season Perennial Grass Pastures of Western Oregon

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Jessica Lee Haavisto, Author

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CONTRIBUTION OF AUTHORS

Dr. Andrew G. Hulting provided guidance of this research project and editorial assistance for this thesis. Gene Pirelli was involved with selection of sites for these experiments.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF APPENDIX TABLES

DEDICATION

For Grandma

1939-2010

Hare Barley (*Hordeum murinum* ssp. *leporinum*) Biology and Management in Cool Season Perennial Grass Pastures of Western Oregon

1. INTRODUCTION

1.1 General Introduction

Hare barley, *Hordeum murinum* ssp. *leporinum*, is a vigorous, cool season annual in the Poaceae family. Native to Eurasia, hare barley has become globally distributed and can be found in unmanaged areas, intensely grazed pastures and range areas and was probably first introduced to California in the 1700's with the arrival of Spanish missionaries (DiTomaso and Healy 2007.) Hare barley can also be found from Maine to British Columbia, Alaska to Mexico but is absent in most Midwestern states (Gould 1951). Hare barley has now become widely distributed throughout many western states including Oregon. In Oregon, hare barley is documented as a weed management issue in perennial pastures in several counties including Benton, Clackamas, Coos, Douglas, Lane, Lincoln, Linn, Marion, Polk, Yamhill and Washington counties. Hare barley may infest up to 10,000 pasture acres in western Oregon (Pirelli 2011).

1.2 Taxonomy

Hordeum murinum ssp. *leporinum* is one of three subspecies in the *Hordeum murinum* complex and is often confused with the other two. The other two subspecies are smooth barley (*Hordeum murinum* ssp. *glaucum*) and wall barley (*Hordeum murinum* ssp. *murinum*). All three subspecies are similar in appearance, but hare barley and wall barley are both cool season annuals and smooth barley is a warm-season annual (DiTomaso and Healy 2007). The spikelets and florets of the three subspecies are useful for distinguishing between the three subspecies (Cocks 1976). Common names for hare barley include, but are not limited to: barley grass, common foxtail, farmer’s foxtail, foxtail, leporinum barley, mouse barley and wild barley. Hare barley is neither a foxtail, nor the native foxtail barley *H. jubatum,* which is a cool season perennial and also invades managed pastures. Prior to flowering, hare barley can be distinguished from foxtail barley by the auricles present on hare barely.

1.3 Biology and Ecology

The genus *Hordeum* is thought to have originated in western Asia, often referred to as the Fertile Crescent, and is indigenous to the Mediterranean region. The native range of hare barley extends from central Europe, to northern Africa and to western Asia and the Caucasus (USDA ARS 2005). Dispersal to other continents is believed to have occurred in the early nineteenth century. The exact location from which the species was introduced is unclear. Livestock, primarily sheep and cattle, and forage were exported from the Mediterranean and shipped through many ports in Europe and Africa before reaching North and South America, Australia and New Zealand where hare barley is now naturalized (Smith 1972; Cocks et al. 1976; and Halloran and Pennell 1981). Though not native, hare barley is a valuable forage grass in the Central Asian countries, Argentina and in portions of Australia.

Hare barley is a many-branched, spreading or nearly prostrate annual grass that grows 15 to 60 cm tall. Leaf blades are broad and flat, 4 to 10 cm long and 3 to 8 mm wide, with slender, claw-like auricles. The foliage is sparsely hairy with long stiff hairs. Hare barley has a thick, erect spike that is pale green to purplish and 4 to 8 cm long and 1cm wide. Generally, the spike is partially enclosed by the uppermost expanded leaf sheath with 3 to 5 spikelets present per cm of length. The pollen grain of hare barley is about 6mm long and hairy at the top. Hare barley is tetraploid (2n=28) (Parker 1972; Crampton 1974; Cocks et al. 1976). Root growth, especially in a clay loam soil, is fibrous and roots can penetrate the soil profile vertically to about 75cm, but spread laterally no more than 8-10cm with the greatest root biomass mass concentrated at a depth of 15cm (Biddiscombe et al. 1954).

Hare barley can be distinguished from the other species in the *murinum* complex by the size of the anthers in the central floret, the exertion of the anthers at flowering and a looser spike (Figure 1.1) (Cocks et al. 1976). Based on plant material collected and analyzed in Australia, the inflorescence of each member of the *murinum* complex consists of three single-flowered spikelets at each node of the articulate rachis of which there may be 20-30 such triads of spikelets. The spikelets fall from the mature plant during late spring and summer as triads. Central spikelets of each of the triads are bisexual and the later outer spikelets are male or sterile. Glumes and lemmas of each spikelet have long, bristly awns with the lemma awns being much longer than the glume awns (Cocks et al. 1976). Hare barley has a sessile central spikelet and the lemma awns of the lateral spikelets are shorter than those of the central spikelet. *H. murinum* ssp. *glaucum* and *leporinum* have pedicellate central spikelets and lemma awns on the lateral spikelets longer than those of the central spikelet (Covas 1949; Bor

1968, 1970). To distinguish between H. *murinum* ssp. l*eporinum* and *glaucum*, the anthers in the central floret need to be observed. *Leporinum* has larger anthers that are light-colored and occasionally brown. *H. glaucum* has anthers that are black, sometimes pale and never exerted at anthesis. Awns are 1.5 to 2cm long, stiffly erect and spreading. In the spikelet, anthers are 0.8 to 1.5mm long with a strongly bilobed base.

1.4 Impacts

Characteristics of hare barley that allow it to become so widely dispersed include its long awns which are rough and bristly and develop on the spikelets. These awns attach to the wool of sheep, or the hair or fur of other animals, and to the clothing of humans transporting seeds to another site. Hare barley also grows in grass hay or alfalfa fields and is often cut with the early harvests and can be spread with hay (USDA ARS 2005).

The ability for seed to remain dormant at high temperatures, the protective barbed awns, and adaptations to germinate on the soil surface in a wide range of conditions are reasons why hare barley is so adaptable to numerous environments, especially those with Mediterranean type climates (Halloran and Pennell 1981). Seasonal fluctuations in environmental conditions are easily overcome by the high germination rate and early maturation rate of hare barley when compared to other cool season grasses.

After flowering, hare barley matures quickly, producing a large number of viable seeds. The number of seeds per head varies from 19 to 29 and approximately 92% of these seeds are viable (Halloran and Pennell 1981). The production of a large number of viable seeds along with a quick maturation rate allows the species to quickly dominate other vegetation in invaded areas. Seed heads remain intact on the plant long after senescence. However, when the seed head is brushed by the fur of a passing animal, the long awns attach to the fur and the seed is easily dislodged from the seed head, an example of its dispersal ability. Once the seed reaches the soil, it remains dormant through the heat of the summer but is initiated to germinate by lower autumn temperatures and moisture (Smith 1968, 1972).

Hare barley will produce viable seed in a variety of environmental conditions including drought and high summer temperatures. Moderately cold temperatures in the winter will delay flowering until warming spring temperatures occur. Hare barley does have a short primary dormancy period that diminishes gradually after a few weeks (Davison 1971). It is possible for plants to flower in the fall as a result of mid-summer precipitation (Smith 1972). Parker (1973) documented hare barley in Arizona usually flowers in March and April at lower elevations and through October at higher elevations. Flowering occurs in one month, usually between mid-August and mid-September in Australia (Biddiscombe et al. 1954). However, the exact time of flowering in Oregon is not known and may even vary within the state due to climatic and elevation differences. It is also likely that a small proportion of the seeds produced during the year remain dormant but viable through multiple first growing seasons which will insure a seed source during the following years. McGowan (1970) found seeds that exhibited delayed germination were smaller and usually found on the upper and lower ends of the seed head where development is usually later. This may also result in delayed germination of some fraction of the viable seed bank.

Hare barley seedlings can germinate on the soil surface or in mulch on the soil surface and are relatively drought resistant once established. Seeds that germinate on the soil surface tend to have larger shoots than seeds that are buried (Smith 1968). In California, the Nature Conservancy found that hare barley will grow in up to 20cm of residual dry matter and according to Dean (1990), this grass grows well in any depth of these natural mulches up to a maximum depth of 20 cm.

Germination in Australia occurs after late summer rains and when soil temperatures are between 18 and 24 C with 30 C being the upper limit (Biddiscombe et al. 1954). An experiment by Cocks and Donald (1973a) demonstrated the wide range of temperatures under which hare barley could germinate under. They observed that germination occurred in 12 days at constant air temperatures ranging from 8 to 30 C. Furthermore, when seeds were exposed to high temperatures (38 C) in a moist environment, seed mortality did not occur until after 7 days. A hard seed coat and dry conditions insure seed viability. In one extreme case, seeds that were extracted from adobe buildings in southern California and northern Mexico were tested for viability and hare barley was among one of the species that germinated in this test (Mabberley 1997; Spira and Wagner 1983).

Early germination and growth of hare barley make it a host for insects that vector disease in crops and pastures. In Israel, small grain crops are subject to infections of powdery mildew where fruiting bodies of the fungi were repeatedly recorded on many native and non native wild grasses including hare barley (Eshed and Wahl 1975). In Australia, where hare barley infests cereal grain crops, *Hednota* ssp. webworms increased with the presence of hare barley (Wallace 1970). In the United States in western Colorado, hare barley is a host for the wheat curl mite (*Aceria tosciella),* which is a vector for High Plains Disease in sweet corn, wheat and other grasses (Hammon 1999).

Although hare barley is an annual, it can and does invade perennial grass pastures and legume pastures because of its ability to germinate early and establish above ground biomass earlier in the season to compete for light resources. Studies in Australia by Cocks (1974) suggest that when barley grass is grown in pastures with ryegrass species, hare barley competes strongly. McGowan (1969) hypothesized that hare barley can establish in a perennial ryegrass pasture because it germinates faster than perennial ryegrass, germinates on the surface, germinates with shorter periods of wetting than perennial ryegrass, and the larger, heavier, awned seeds are prohibitive of removal by ants when compared to perennial ryegrass seeds. Hare barley leaves also are broader than perennial ryegrass leaves creating a shading effect and when it occurs at high densities, hare barley can quickly out-compete perennial ryegrass. Hare barley also utilizes nutrients to its advantage and when levels of soil nitrogen and calcium are high, hare barley has been found to be more competitive than ryegrass species (Moore 1970).

1.5 Management

Soil nutrient management studies have been conducted to understand the development of hare barley. Although the species prefers a fertile soil, it will grow in sites that are low in phosphorus. Hare barley growth rate is not positively correlated with soil fertility, but rather seed size is the most important determinant of early plant size (Chapin et al. 1989). Nevertheless, hare barley does respond to the addition of nutrients as illustrated by a 12 year experiment conducted by Rossiter (1964) who showed that hare barley had become the dominant annual grass in clover pastures that had additions of varying rates of phosphate.

Due to its robust early growth, hare barley is often important forage in pasture cropping systems. Many studies have been conducted to determine whether grazing is an effective management tool for controlling hare barley. Results of these studies vary with conditions and pasture forage type, but almost always result in an increase in the density of hare barley.

Hare barley can be grazed in late autumn through winter and into the spring until flowering occurs. In Australia, it comprises most of the winter diet of sheep but if consumed after flowering, causes production loss and in extreme cases, sheep death as a result of the seed heads penetrating the mouth, eyes, skin, feet and wool (Smith 1972; Warr 1981). This winter grazing can have an adverse effect if the goal of management is to reduce the density of hare barley in pastures. Intense grazing actually increases the population of hare barley. The plant is stimulated by the grazing of animals when the flowering shoots are removed and increased new growth from basal buds produces more tillers. Smith (1968; 1972) and Mclvor and Smith (1973) conducted grazing experiments with varying results in ryegrass and clover pastures. Lightly, moderately (moderate grazed plots were grazed to a length of 2.5 to 5cm) and heavily grazed plots were analyzed and an increase of hare barley biomass and increased seed germination were documented. The moderately grazed plots produced the greatest number of viable hare barley seeds and the largest seeds. The heavily grazed plots, when evaluated after two years of treatments, showed almost a complete dominance of hare barley. Heavy grazing also increased tillering and the number of heads produced even though the total biomass (stem height) and seeds produced were reduced significantly (Smith 1968d). No studies have been conducted in Oregon to determine the effect of grazing intensity, but most grazed pastures contain perennial grasses that exhibit later season growth than hare barley, suggesting that heavy winter grazing of hare barley plants may likely produce the same results that were documented in Australia.

Management of hare barley through grazing in subterranean clover pastures can also be difficult. Ewe stocking rates of 8 and 12 ewes/ha were examined in clover and ryegrass seeded pastures in Australia. Higher ewe stocking rates favored hare barley invasion. The only time the higher stocking rate did not produce this result, most likely due to an increase in competition, was when the clover pastures were seeded with oats and/or alfalfa (Fitzgerald 1976). Results similar to these were documented in a study conducted in northern California (Rosiere 1987). These results are most likely due to grasslands in northern California becoming highly infested with invasive annual grasses. Grasslands and grass woodlands were tested over a five year period with three grazing treatments. Results of this trial indicated an increase in the density of hare barley of up to 150% at a moderate stocking rate, but showed the lowest increase at a high stocking rate. Means of the stocking rates were from 0.8 to 8.0 and 1.8 to 10.0 ewes/ha in woodlands and grasslands, respectively (Rosiere 1987).

Anecdotal evidence from farmers and ranchers in the northern Willamette Valley, OR, suggests that cultural control practices such as mowing, intense grazing, propane flaming and other efforts to limit seed production and the spread of established hare barley populations are of little value. Chemical control of hare barley is the most effective management practice. However, chemical control is problematic for several reasons. These reasons include questions regarding herbicide application timing for maximum control, a lack of active ingredients labeled for pasture use, maintenance of usable forage while controlling hare barley and the need for repeated annual herbicide applications.

Labeled herbicide options to selectively control grass weeds in established grass or mixed grass-clover pastures and forage fields are limited. During the 1970’s, the Oregon State University (OSU) Weed Program conducted research documenting that pronamide (Kerb^{TM}) effectively controlled hare barley in pastures. However, a lack of established tolerances for pronamide in livestock forage ruled out pursuing pasture labels for this product. Newer herbicide chemistries have reached the market place since that time that may prove effective for hare barley control in cool season perennial grass pastures. Two products with current pasture labels, aminopyralid (Milestone™) and imazapic (Plateau™) have the potential to suppress or control hare barley. To our knowledge, limited testing using these products on hare barley has been completed under western OR conditions. Several other candidate herbicides identified through the OSU Weed Group which are either under development or established products may also be good candidates for pasture labels.

Two experiments were initiated in the fall of 2008 to address questions related to the biology and management of hare barley in western OR. We hypothesized that the use of both pasture labeled and experimental herbicides could be used to effectively control hare barley in cool season perennial grass pastures. A multi-year field study quantified the efficacy of these herbicides on the control of hare barley and the injury of desirable species in established pastures belonging to farmers in the northern Willamette Valley near Molalla, OR. The two sites used for the herbicide evaluation studies differed in climate and elevation. In addition to those studies, we hypothesized that viable seed production and maturity of hare barley varied throughout the Valley and would occur sooner in lower elevation sites when compared to higher elevation sites. Lab studies were conducted to determine when viable seed was produced in relation to growing degree days accumulated which was quantified through the use of permanent weather stations installed at each site. Data from this study were quantified and used as a tool to aid in management practices for controlling hare barley based on the location of the pastures and the climatic conditions they are associated with.

Information generated on the effective use of currently registered pasture herbicides, including herbicide application timings, use rates and potential pasture injury are the immediate benefits to OR farmers and ranchers as a result of these experiments. In the future, data collected as part of this research will improve our understanding of the seed biology of hare barley. Additionally, this data may help support future pasture herbicide registrations to manage hare barley infestations, decrease overall weed management costs and increase regional forage production. Although conducted in western OR, the results this research are applicable to other areas of the state where hare barley has become established.

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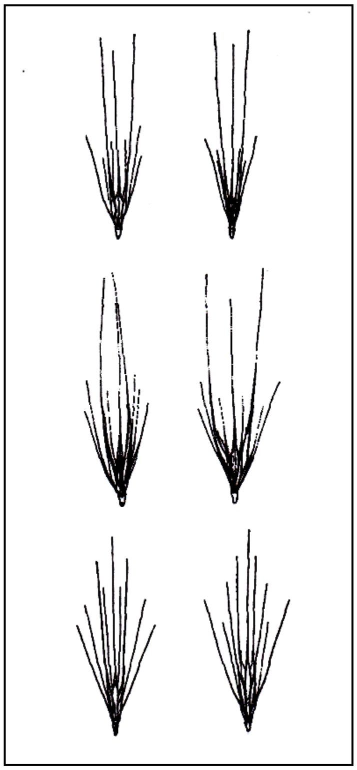
Figure 1.1. Drawing of the dispersal units of the three sub-species in the *Hordeum murinum* complex (Cocks 1976)



Dispersal units of H. *glaucum* (top), H. *leporinum* (centre), and H. *murinum* (bottom). Note the shorter awns on the lateral spikelets compared with the central spikelet and the short pedicel of the central spikelet in *H. murinum*.

2. HARE BARLEY (*HORDEUM MURINUM* SSP. *LEPORINUM*) CONTROL IN COOL SEASON PERENNIAL GRASS PASTURES

2.1 Abstract

Hare barley (*Hordeum murinum* ssp. *leporinum)* is a vigorous, cool season winter annual in the Poaceae family. It is an extremely successful invader of disturbed sites and can be found in waste areas, intensely grazed locations and rangeland environments. Robust early growth makes hare barley an important forage grass in pasture systems, but the awns that develop as the plant matures cause injury to livestock. In Oregon, hare barley is a weed management concern in perennial cool-season grass pastures. Field experiments were conducted in two locations in established perennial grass pastures during 2008-2011 near Molalla, OR, to evaluate potential control of hare barley using labeled and non-labeled pasture herbicides. Although several herbicides were evaluated in these experiments, three treatments were useful for controlling hare barley. Aminopyralid, a currently labeled herbicide for use in pastures in several western states, was applied in the fall at 0.122 kg ai/ha and 0.244 kg ai/ha. Imazamox, a herbicide not labeled for use in pastures, was applied postemergence in the spring at 0.052 kg ai/ha and imazamox + MCPA ester was applied postemergence in the spring at 0.052 kg ai/ha and 0.389 kg ai/ha, respectively. All treatments included a non-ionic surfactant (NIS) at 0.25% v/v for aminopyralid treatments and at 0.50% v/v for imazamox treatments. Imazamox + MCPA treatments included urea ammonium nitrate (UAN) at 2.5% v/v. Visual evaluations of percent hare barley control and percent pasture injury were made at monthly intervals following application. Aminopyralid applications resulted in 82-87% control of hare barley and minimal pasture injury. The experimental treatments of imazamox and imazamox +MCPA ester applied as a spring post-emergent treatment resulted in 78-93% control of hare barley. Pasture injury was acceptable, ranging from 30-37% with injury consisting of stunted growth and delayed maturity of the perennial grasses. Fall applications of aminopyralid provided acceptable levels of hare barley suppression and imazamox + MCPA treatments were also effective. These results indicate treatments of aminopyralid and imazamox or imazamox + MCPA ester can be used successfully to manage and suppress hare barley.

2.2 Introduction

Hare barley is an invasive winter annual grass that is widely distributed across western Oregon and other western states. This species has several common names including wild barley, foxtail or foxtail barley, though it is neither a foxtail species nor the common native, perennial foxtail barley (*Hordeum jubatum*), which can also be a weed in wet pastures. Misidentification or a lack of field observation may prevent pasture owners from recognizing infestations of hare barley until flowering occurs anywhere from late spring to early summer in western OR. Control options for hare barley after flowering are limited.

The characteristic “wild barley” seed head may remain intact on plants long after hare barley has completed its life cycle. Immature plants are palatable to livestock and often is an important forage component for fall grazing. However, as spiklets develop, the awns can injure the mouth, eyes, ears and skin of livestock so mature plants are avoided by grazing animals leading to abundant seed production. This abundant seed production and dispersal by grazing livestock leads to the expansion of hare barley populations in orchardgrass, tall fescue, perennial ryegrass pastures or mixed grass pastures managed by livestock owners in western OR. Anecdotal evidence from several pasture owners in western OR suggests that cultural and mechanical control methods such as tillage, intensive grazing early in the season, addition of nutrient amendments, soil pH amendments, propane flaming or mowing are of limited value for stopping the spread of established hare barley populations.

Labeled herbicide options to selectively control hare barley in established grass or mixed grass-clover pastures and forage fields are limited. Two herbicide products, aminopyralid (Milestone^{TM}) and imazapic (Plateau^{TM}), currently have pasture labels and the potential to suppress or control hare barley, but to our knowledge, limited testing on the control of hare barley has been completed under western OR conditions. There are several other candidate herbicides, which are either under development or established products that may be good candidates for pasture labels. These products may have activity on hare barley and limited potential for crop injury and include pyroxasulfone (a product being developed by Kumiai Chemical Company), flufenacet (Define^{TM}), metsulfuron (Escort^{TM}), mesotrione (Callisto^{TM}) and glufosinate (Rely^{TM}).

Other products such as sulfosulfuron (Maverick^{TM}) and imazamox + MCPA (Clearmax^{TM}) are labeled for *Hordeum* spp. control in various crops around the world, but little research has been done locally in pasture cropping systems. Patent literature suggests that Clearmax is effective for reducing hare barley biomass and that postemergence applications can suppress seed head formation (Jones 2004). Spring imazamox (Raptor^{TM}) applications are effective at controlling hare barley in established alfalfa fields in Siskiyou County, CA (Wilson and Orloff 2003). In Australia, hare barley has become resistant to three herbicides, paraquat, diquat and fluazifop-P (Tucker and Powles 1991; and Matthews et al. 2000). However, this resistance is not surprising since these non-selective herbicides have been used for nearly two decades to control hare barley in alfalfa crops in Australia (Hidayat 2006).

Herbicide evaluation studies are needed to identify chemical management strategies for hare barley control in pastures and to begin to develop the data profiles that may eventually support local herbicide product registrations for pasture weed management in the future. Therefore, we evaluated several preemergence (PRE) and postemergence (POST) herbicide treatments for control of hare barley and potential crop injury in perennial grass pastures systems in western OR.

2.3 Materials and Methods

Studies were conducted in two established perennial grass pastures in Clackamas County, OR in 2008, 2009 and 2010. One site, owned by Dale and Julie

Bystrom of Molalla, OR is a perennial pasture composed of perennial ryegrass, tall fescue and colonial bentgrass. A second site, owned by Gordon Wanner of Grassland Farms, located near Canby, OR, is a pasture primarily composed of perennial ryegrass. Both pasture owners raise cattle and horses and agreed to exclude a 0.10 hectare area from their pastures within established hare barley populations using electric fencing for these experiments. Plots were maintained for the duration of this experiment. Plots in the multiple year experiment received the same treatments over time to quantify the effects of multiple season herbicide applications.

A total of 32 PRE and POST emergence herbicide treatments were applied to small research plots ($14m^2$) in a randomized complete block design. Treatments were replicated three times and compared to an untreated check. Herbicide treatments were applied with a bicycle wheel sprayer which was calibrated to deliver an application volume of 75.7 L/ha. Fall herbicide treatments, which included both PRE and POST herbicides, were made in October 2008, November 2009 and September 2010. POST herbicide treatments were applied in April 2009, March 2010 and April 2011. Herbicide application dates and weather conditions during these application timings can be found in Appendix B. Fall and spring environmental conditions in western OR vary considerably and are often rainy. Variance in application timings from year to year was a result of these environmental conditions both to ensure adequate drying time required by each herbicide and to prevent damage to pastures during wet soil conditions. Rates and timings of herbicide treatment applications are presented in Tables 2.1 - 2.12.

Data collection included visual ratings of hare barley control and pasture injury at 60 days after treatment (DAT) in the fall of 2008 and spring of 2009 and at 30 and 60 days after each herbicide treatment from fall 2009 through spring 2011. Treatments were compared to an untreated check and ranked on a scale from 0 to 100%. A 0% pasture injury rating is equivalent to no damage to the pasture including stunting, reduced yield or death of desirable pasture grasses. Stunting of desirable pasture grasses, foliage discoloration and reduced yield were given higher percent injury ratings and unacceptable pasture, injury including death of desirable grasses, were rated at 70% or greater. A 0% control rating was equal to no control of hare barley, more than 50% control was considered suppression of hare barley and a rating greater than or equal to 80% was considered control of hare barley.

Single season treatments were analyzed using ANOVA (R. v.2.10.2 2009) to detect differences ($P \leq 0.05$) among treatment means 60 DAT. Mean separations of significant effects were evaluated with Fisher’s Protected LSD test ($P \leq 0.05$). Two and three season applications were analyzed using ANOVA (R. v.2.10.1 2009) to detect differences ($P \leq 0.05$) among treatment means 60 DAT during the last year of application. Mean separations of significant effects were evaluated with Tukey’s HSD test ($P \leq 0.05$). Each site was analyzed separately.

During the summer of 2009, 2010 and 2011, above ground biomass was removed from the research sites and burned. The livestock at both sites were excluded from the experiments for the duration of the project.

2.4 Results and Discussion

Hare barley control was highly variable ($P < 0.001$) among treatments, ranging from 0 to 100% (odd numbered Tables 2.1 - 2.11). Pasture injury also was different ($P < 0.001$) among treatments, ranging between 0 and 100% as well (even numbered Tables 2.2 - 2.12). The high variability in differences of control and injury are most likely due to the difference in population densities of the pasture grasses at each site. Some treatments provided unacceptable levels of control and pasture injury than others and therefore only were applied for a single season.

Single Season Treatments

Fall 2008 PRE treatments provided hare barley control between 0 and 90% and 0 and 53% at Bystrom and Grassland Farms, respectively (Tables 2.1 and 2.3). Pasture injury was also variable, between 0 and 13% and 0 and 80% at Bystrom and Grassland Farms, respectively (Tables 2.2 and 2.4). Spring 2009 treatments of imazapic at rates of 0.0625, 0.09375 and 0.125 lbs ai/ha provided 90, 100 and 100% and 47, 63 and 67% control of hare barley at Bystrom and Grassland Farms respectively. However, pasture injury was unacceptable following imazapic treatments, ranging from 77-87% and 37-67% at Bystrom and Grassland Farms respectively, which allowed hare barley to reestablish and out-compete the pasture grasses in these plots. Due to this injury, imazapic treatments were not applied for the remainder of the experiment. In an effort to increase the efficacy of the fall PRE treatments, imazamox was added to each PRE treatment in the fall of 2009. Control of hare barley increased to 100% for each of these treatments at each site 60 DAT. However, pasture injury also increased ranging from 80 to 93% at Bystrom Farms and 77 to 100% at Grassland Farms. The combination of residual herbicide chemistries with imazamox and prolonged cold temperatures in the late fall of 2009 resulted in these treatments being too injurious to the pasture grasses (Tables 2.2 and 2.4). As a result, PRE treatments with the addition imazamox were not applied for the remainder of the experiment.

Two Season Treatments

Fall 2009 and 2010 treatments at both Bystrom Farms and Grassland Farms (Tables 2.5 - 2.8) included sulfosulfuron, aminopyralid + metsulfuron, mesotrione followed by a spring application of glufosinate, glufosinate followed by a spring application of mesotrione, mesotrione + glufosinate, and at Grassland Farms an additional treatment of mesotrione + glufosinate + flufenacet. Again, control of hare barley was variable among treatments ($P < 0.001$). Treatments of sulfosulfuron and aminopyralid + metsulfuron resulted in little pasture injury, $\leq$ 5%, however, hare barley reestablished and out-competed the pasture grasses in these plots. The treatments including mesotrione and glufosinate at Grassland Farms, resulted in 63 to 78% and 57 to 67% control at Bystrom and Grassland Farms respectively. The alternating treatments of glufosinate and mesotrione in the fall followed by the other chemical in the spring were not significantly different ($P \geq 0.05$) (Tables 2.5 and 2.7). While the addition of flufanacet to the mesotrione + glufosinate treatment at Grassland Farms provided 63% control of hare barley, it also resulted in 57% pasture injury and allowed hare barley to reestablish in these plots. Spring 2010 and 2011 treatments of imazamox + MCPA ester provided 88 and 93% control of hare barley and 36 to 32% pasture injury.

Three Season Treatments

Treatments of aminopyralid and mesotrione were applied in the fall of 2008, 2009, and 2010 at Bystrom and Grassland Farms (Tables 2.9 - 2.12). Control of hare barley using aminopyralid at 0.122 kg ai/ha increased from 57 to 83% at Bystrom Farms between the first year application and the second year application. At Grassland Farms, control increased from 37 to 85% between the first year application and the second year application. Three years of treatment resulted in 83 and 87% control and at 0.244 kg ai/ha 82 and 83% control at Bystrom and Grassland Farms, respectively. Mesotrione at 0.209 kg ai/ha resulted in 63% control at both sites after three years of treatments. No difference was found in the percent control between rates of aminopyralid ($P \geq 0.05$).

Treatments of imazamox at 0.052 kg ai/ha and imazamox + MCPA ester at 0.052 and 0.389 kg ai/ha in the spring of 2009, 2010 and 2011 (Tables 2.9 - 2.12) resulted in 72 to 77% control of hare barley after a single treatment at Bystrom Farms and 48% control at Grassland Farms. After the second year treatment, control of hare barley was not a successful at Bystrom Farms at 33 to 50%, but increased at Grassland Farms to 90 and 95% after the second year treatment. Three years of treatment resulted in 78 and 85% control and 92 and 93% control of hare barley at Bystrom and Grassland Farms, respectively.

These results indicate that fall applications using PRE herbicides result in unacceptable pasture injury due to unpredictable fall weather conditions in the Willamette Valley. Spring treatments of imazamox and imazamox + MCPA ester are successful at controlling hare barley with multiple year treatments, however, further research is needed to develop at database that can eventually support local herbicide product registrations for hare barley control in perennial grass pastures in the future.

Results of these experiments indicate the best method for control of hare barley in perennial grass pastures are fall applications of aminopyralid at 0.122 kg ai/ha, but applications must be made on a multiple year basis. Timing of fall applications of aminopyralid should be made during September or October before fall rains start. This timing allows for injury of germinating or newly emerged hare barley to the point that established pasture grasses may out-compete hare barley through the winter and into the spring growing season.

2.5 Literature Cited

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Table 2.1. Visual estimate of hare barley control after herbicide application at Bystrom Farms. Single season applications.

Treatment[a]	Rate (kg ai/ha)	Application	Year 1 30 DAT[c]	 60DAT
			%	
untreated check	N/A[d]	N/A	0	0 a[b]
pyroxasulfone	0.074	Fall 2008	NA	0 a
pyroxasulfone	0.099	Fall 2008	NA	7 a
flufenacet	0.378	Fall 2008	NA	13 b
pendimethalin	3.33	Fall 2008	NA	3 a
s-metolachlor	1.06	Fall 2008	NA	10 b
dimethenamid-p	1.09	Fall 2008	NA	13 b
nicosulfuron	0.051	Fall 2008	NA	87 c
nicosulfuron	0.078	Fall 2008	NA	90 c
imazapic	0.069	Spring 2009	NA	90 c
imazapic	0.104	Spring 2009	NA	100 d
imazapic	0.139	Spring 2009	NA	100 d
pyroxasulfone + imazamox	0.074 + 0.052	Fall 2009	30	100 d
pyroxasulfone + imazamox	0.099 + 0.052	Fall 2009	30	100 d
flufenacet + imazamox	0.378 + 0.052	Fall 2009	33	100 d
pendimethalin + imazamox	3.330 + 0.052	Fall 2009	40	100 d
s-metolachlor + imazamox	1.06 + 0.052	Fall 2009	40	100 d
dimethenamid-p + imazamox	1.09 + 0.052	Fall 2009	37	100 d
nicosulfuron + imazamox	0.051 + 0.052	Fall 2009	53	100 d
nicosulfuron + imazamox	0.078 + 0.052	Fall 2009	53	100 d
LSD (0.05)				10.92

[a] All treatments were applied with nonionic surfactant at 0.25% (v/v) except imazapic treatments which were applied with metholated seed oil at 0.3 L/ha.

[b] Means within the same column with the same letter are not significantly different (P= 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.2. Visual estimate of pasture injury after herbicide application at Bystrom Farms. Single season applications.

Treatment[a]	Rate (kg ai/ha)	Application	Year 1	
			30 DAT[c]	60 DAT
			%	
untreated check	N/A[d]	N/A	0	0 a[b]
pyroxasulfone	0.074	Fall 2008	NA	0 a
pyroxasulfone	0.099	Fall 2008	NA	0 a
flufenacet	0.378	Fall 2008	NA	0 a
pendimethalin	3.33	Fall 2008	NA	0 a
s-metolachlor	1.06	Fall 2008	NA	0 a
dimethenamid-p	1.09	Fall 2008	NA	0 a
nicosulfuron	0.051	Fall 2008	NA	63 b
nicosulfuron	0.078	Fall 2008	NA	80 c
imazapic	0.069	Spring 2009	NA	77 c
imazapic	0.104	Spring 2009	NA	77 c
imazapic	0.139	Spring 2009	NA	87 d
pyroxasulfone + imazamox	0.074 + 0.052	Fall 2009	23	87 d
pyroxasulfone + imazamox	0.099 + 0.052	Fall 2009	23	80 c
flufenacet + imazamox	0.378 + 0.052	Fall 2009	27	87 d
pendimethalin + imazamox	3.330 + 0.052	Fall 2009	27	80 c
s-metolachlor + imazamox	1.06 + 0.052	Fall 2009	27	80 c
dimethenamid-p + imazamox	1.09 + 0.052	Fall 2009	27	87 d
nicosulfuron + imazamox	0.051 + 0.052	Fall 2009	87	93 e
nicosulfuron + imazamox	0.078 + 0.052	Fall 2009	90	93 e
LSD (0.05)				5.75

[a] All treatments were applied with nonionic surfactant at 0.25% (v/v) except imazapic treatments which were applied with metholated seed oil at 0.3 L/ha.

[b] Means within the same column with the same letter are not significantly different (P= 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.3. Visual estimate of hare barley control after herbicide application at Grassland Farms. Single season applications.

Treatment[a]	Rate (kg ai/ha)	Application	Year 1 30 DAT[c]	 60DAT
			%	
untreated check	N/A[d]	N/A	0	0 a[b]
pyroxasulfone	0.074	Fall 2008	NA	7 ab
pyroxasulfone	0.099	Fall 2008	NA	13 b
flufenacet	0.378	Fall 2008	NA	20 b
pendimethalin	3.33	Fall 2008	NA	3 a
s-metolachlor	1.06	Fall 2008	NA	30 c
dimethenamid-p	1.09	Fall 2008	NA	33 c
nicosulfuron	0.051	Fall 2008	NA	43 d
nicosulfuron	0.078	Fall 2008	NA	53 e
imazapic	0.069	Spring 2009	NA	47 de
imazapic	0.104	Spring 2009	NA	63 f
imazapic	0.139	Spring 2009	NA	67 f
pyroxasulfone + imazamox	0.074 + 0.052	Fall 2009	40	100 g
pyroxasulfone + imazamox	0.099 + 0.052	Fall 2009	40	100 g
flufenacet + imazamox	0.378 + 0.052	Fall 2009	27	100 g
pendimethalin + imazamox	3.330 + 0.052	Fall 2009	30	100 g
s-metolachlor + imazamox	1.06 + 0.052	Fall 2009	43	100 g
dimethenamid-p + imazamox	1.09 + 0.052	Fall 2009	23	100 g
nicosulfuron + imazamox	0.051 + 0.052	Fall 2009	80	100 g
nicosulfuron + imazamox	0.078 + 0.052	Fall 2009	60	100 g
paraquat + flufanacet	0.556 + 0.378	Fall 2009	90	100 g
LSD (0.05)				9

[a] All treatments except imazapic and paraquat were applied with nonionic surfactant at 0.25% (v/v). Imazapic treatments which were applied with metholated seed oil at 0.3 L/ha. Paraquat treatments were applied with crop oil concentrate at 0.50% (v/v).

[b] Means within the same column with the same letter are not significantly different (P= 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.4. Visual estimate of pasture injury after herbicide application at Grassland Farms. Single season application.

Treatment[a]	Rate (kg ai/ha)	Application	Year 1	
			30 DAT[c]	60DAT
			%	
untreated check	N/A[d]	N/A	0	0 a[b]
pyroxasulfone	0.074	Fall 2008	NA	0 a
pyroxasulfone	0.099	Fall 2008	NA	0 a
flufenacet	0.378	Fall 2008	NA	3 a
pendimethalin	3.33	Fall 2008	NA	0 a
s-metolachlor	1.06	Fall 2008	NA	0 a
dimethenamid-p	1.09	Fall 2008	NA	3 a
nicosulfuron	0.051	Fall 2008	NA	10 a
nicosulfuron	0.078	Fall 2008	NA	13 b
imazapic	0.069	Spring 2009	NA	37 c
imazapic	0.104	Spring 2009	NA	57 d
imazapic	0.139	Spring 2009	NA	67 de
pyroxasulfone + imazamox	0.074 + 0.052	Fall 2009	30	77 e
pyroxasulfone + imazamox	0.099 + 0.052	Fall 2009	30	85 e
flufenacet + imazamox	0.378 + 0.052	Fall 2009	30	77 e
pendimethalin + imazamox	3.330 + 0.052	Fall 2009	30	87 e
s-metolachlor + imazamox	1.06 + 0.052	Fall 2009	30	88 e
dimethenamid-p + imazamox	1.09 + 0.052	Fall 2009	30	80 e
nicosulfuron + imazamox	0.051 + 0.052	Fall 2009	30	85 e
nicosulfuron + imazamox	0.078 + 0.052	Fall 2009	33	85 e
paraquat + flufanacet	0.556 + 0.378	Fall 2009	90	100 f
LSD (0.05)				13

[a] All treatments except imazapic and paraquat were applied with nonionic surfactant at 0.25% (v/v). Imazapic treatments which were applied with metholated seed oil at 0.3 L/ha. Paraquat treatments were applied with crop oil concentrate at 0.50% (v/v).

[b] Means within the same column with the same letter are not significantly different (P= 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.5. Visual estimate of hare barley control after herbicide application at Bystrom Farms. Two season applications.

Treatment[a]	Rate (kg ai/ha)	Application	Year 1 30 DAT[c]	Year 1 60 DAT	Year 2 30 DAT	Year 2 60 DAT
			%		%	
untreated check	N/A[d]	N/A	0	0	0	0 a[b]
sulfosulfuron	0.034	Fall[e]	NA	52	12	45 b
aminopyralid + metsulfuron	0.164	Fall[e]	NA	55	0	0 a
mesotrione + glufosinate	0.104 + 0.417	Fall[f] Spring[g]	18	47	50	63 c
glufosinate + mesotrione	0.417 + 0.104	Fall[f] Spring[g]	12	43	63	65 c
mesotrione + glufosinate	0.104 + 0.417	Fall[f]	43	60	63	78 d
imazamox + MCPA ester	0.052 + 0.389	Spring[g]	46	77	25	88 e

[a] Sulfosulfuron treatments were applied with nonionic surfactant at 0.50% (v/v). Aminopyralid + metsulfuron treatments were applied with nonionic surfactant at 0.25% (v/v). Mesotrione + glufosinate treatments were applied with crop oil concentrate at 0.50% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v).

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

[e] Applications were made in the fall of 2008 and 2009.

[f] Applications were made in the fall of 2009 and 2010.

[g] Applications were made in the spring of 2010 and 2011.

Table 2.6. Visual estimate of pasture injury after herbicide application at Bystrom Farms. Two season applications.

	Rate		Year 1		Year 2	
Treatment[a]	(kg ai/ha)	Application	30 DAT[c]	60 DAT	30 DAT	60 DAT
			%		%	
untreated check	N/A[d]	N/A	0	0	0	0 a[b]
sulfosulfuron	0.034	Fall[e]	NA	13	3	5 b
aminopyralid + metsulfuron	0.164	Fall[e]	NA	12	0	2 a
mesotrione + glufosinate	0.104 + 0.417	Fall[f] Spring[g]	12	0	12	0 a
glufosinate + mesotrione	0.417 + 0.104	Fall[f] Spring[g]	7	0	7	0 a
mesotrione + glufosinate	0.104 + 0.417	Fall[f]	18	0	12	0 a
imazamox + MCPA ester	0.052 + 0.389	Spring[g]	26	32	12	36 c

[a] Sulfosulfuron treatments were applied with nonionic surfactant at 0.50% (v/v). Aminopyralid + metsulfuron treatments were applied with nonionic surfactant at 0.25% (v/v). Mesotrione + glufosinate treatments were applied with crop oil concentrate at 0.50% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v).

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

[e] Applications were made in the fall of 2008 and 2009.

[f] Applications were made in the fall of 2009 and 2010.

[g] Applications were made in the spring of 2010 and 2011.

Table 2.7. Visual estimate of hare barley control after herbicide application at Grassland farms. Two season applications.

	Rate		Year 1		Year 2	
Treatment[a]	(kg ai/ha)	Application	30 DAT[c]	60 DAT	30 DAT	60 DAT
			%		%	
untreated check	N/A[d]	N/A	0	0	0	0 a[b]
sulfosulfuron	0.034	Fall[e]	NA	28	13	67 b
aminopryalid + metsulfuron	0.164	Fall[e]	NA	17	0	23 c
mesotrione + glufosinate	0.104 + 0.417	Fall[f] Spring[g]	27	42	27	67 b
glufosinate + mesotrione	0.417 + 0.104	Fall[f] Spring[g]	40	30	27	57 b
mesotrione + glufosinate	0.104 + 0.417	Fall[f]	50	67	50	67 b
mesotrione + glufosinate + flufenacet	0.104 + 0.417 + 0.378	Fall[f]	50	80	93	63 b
imazamox + MCPA ester	0.052 + 0.389	Spring[g]	41	76	25	93 d

[a] Sulfosulfuron treatments were applied with nonionic surfactant at 0.50% (v/v). Aminopyralid + metsulfuron treatments were applied with nonionic surfactant at 0.25% (v/v). Mesotrione + glufosinate treatments were applied with crop oil concentrate at 0.50% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v).

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

[e] Applications were made in the fall of 2008 and 2009.

[f] Applications were made in the fall of 2009 and 2010.

[g] Applications were made in the spring of 2010 and 2011.

Table 2.8. Visual estimate of pasture injury after herbicide application at Grassland Farms. Two season applications.

	Rate		Year 1		Year 2	
Treatment[a]	(kg ai/ha)	Application	30 DAT[c]	60 DAT	30 DAT	60 DAT
			%		%	
untreated check	N/A[d]	N/A	0	0	0	0 a[b]
sulfosulfuron	0.034	Fall[e]	NA	22	32	2 a
aminopryalid + metsulfuron	0.164	Fall[e]	NA	22	0	3 a
mesotrione + glufosinate	0.104 + 0.417	Fall[f] Spring[g]	30	0	17	0 a
glufosinate + mesotrione	0.417 + 0.104	Fall[f] Spring[g]	7	0	7	0 a
mesotrione + glufosinate	0.104 + 0.417	Fall[f]	47	23	40	0 a
mesotrione + glufosinate + flufenacet	0.104 + 0.417 + 0.378	Fall[f]	50	27	57	57 b
imazamox + MCPA ester	0.052 + 0.389	Spring[g]	32	35	14	32 c

[a] Sulfosulfuron treatments were applied with nonionic surfactant at 0.50% (v/v). Aminopyralid + metsulfuron treatments were applied with nonionic surfactant at 0.25% (v/v). Mesotrione + glufosinate treatments were applied with crop oil concentrate at 0.50% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v).

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

[e] Applications were made in the fall of 2008 and 2009.

[f] Applications were made in the fall of 2009 and 2010.

[g] Applications were made in the spring of 2010 and 2011.

Table 2.9. Visual estimate of hare barley control after herbicide application at Bystrom Farms. Three season applications.

	Rate		2008-2009		2009-2010		2010-2011	
Treatment[a]	(kg ai/ha)	Application	30 DAT[c]	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
			%		%		%	
untreated check	N/A[d]	N/A	0	0	0	0	0	0 a[b]
aminopyralid	0.122	Fall	NA	57	70	83	77	83 b
aminopyralid	0.244	Fall	NA	60	77	82	73	82 b
imazamox	0.052	Spring	NA	72	30	33	23	78 bc
imazamox + MCPA ester	0.052 + 0.389	Spring	NA	77	47	50	30	85 b
mesotrione	0.209	Fall	NA	43	17	20	13	63 c

a Aminopyralid treatments were applied with nonionic surfactant at 0.25% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v). Mesotrione treatments were applied with nonionic surfactant at 0.50% (v/v) and AMS at 3.86 kg/378.5 L.

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.10. Visual estimate of pasture injury after herbicide application at Bystrom Farms. Three season applications.

Treatment[a]	Rate (kg ai/ha)	Application	2008-2009		2009-2010		2010-2011	
			30 DAT[c]	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
			%		%		%	
untreated check	N/A[d]	N/A	0	0	0	0	0	0 a[b]
aminopyralid	0.122	Fall	NA	23	2	2	2	0 a
aminopyralid	0.244	Fall	NA	27	3	3	2	0 a
imazamox	0.052	Spring	NA	25	33	17	12	30 b
imazamox + MCPA ester	0.052 + 0.389	Spring	NA	23	33	20	12	37 b
mesotrione	0.209	Fall	NA	0	0	3	0	0 a

a Aminopyralid treatments were applied with nonionic surfactant at 0.25% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v). Mesotrione treatments were applied with nonionic surfactant at 0.50% (v/v) and AMS at 3.86 kg/378.5 L.

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.11. Visual estimate of hare barley control after herbicide application at Grassland Farms. Three season applications.

	Rate		2008-2009		2009-2010		2010-2011	
Treatment[a]	(kg ai/ha)	Application	30 DAT[c]	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
			%		%		%	
untreated check	N/A[d]	N/A	0	0	0	0	0	0 a[b]
aminopyralid	0.122	Fall	NA	37	85	90	82	87 b
aminopyralid	0.244	Fall	NA	40	85	90	82	83 b
imazamox	0.052	Spring	NA	48	13	90	23	92 b
imazamox + MCPA ester	0.052 + 0.389	Spring	NA	48	17	95	30	93 b
mesotrione	0.209	Fall	NA	28	50	50	50	63 c

a Aminopyralid treatments were applied with nonionic surfactant at 0.25% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v). Mesotrione treatments were applied with nonionic surfactant at 0.50% (v/v) and AMS at 3.86 kg/378.5 L.

[b] Means within the same column with the same letter are not significantly different (P = 0.05).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

Table 2.12. Visual estimate of pasture injury after herbicide application at Grassland Farms. Three season applications.

Treatment[a]	Rate (kg ai/ha)	Application	2008-2009		2009-2010		2010-2011	
			30 DAT[c]	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
			%		%		%	
untreated check	N/A[d]	N/A	0	0	0	0	0	0 a[b]
aminopyralid	0.122	Fall	NA	0	2	0	0	0 a
aminopyralid	0.244	Fall	NA	0	2	0	0	0 a
imazamox	0.052	Spring	NA	18	3	33	8	33 b
imazamox + MCPA ester	0.052 + 0.389	Spring	NA	20	3	33	13	33 b
mesotrione	0.209	Fall	NA	0	0	0	0	0 a

a Aminopyralid treatments were applied with nonionic surfactant at 0.25% (v/v). Imazamox treatments were applied with nonionic surfactant at 0.50% (v/v) and UAN at 2.5% (v/v). Mesotrione treatments were applied with nonionic surfactant at 0.50% (v/v) and AMS at 3.86 kg/378.5 L.

[b] Means within the same column with the same letter are not significantly different ($P = 0.05$).

[c] Abbreviation: DAT, days after treatment.

[d] Abbreviation: N/A, not applicable.

3. VIABLE SEED PRODUCTION OF HARE BARLEY (*HORDEUM MURINUM* SPP. *LEPORIUNM*) BASED ON GROWING DEGREE DAYS

3.1 Abstract

Hare barley is a weed management issue for livestock and hay producers in cool season perennial grass pastures in western OR. Transportation or movement of livestock, hay harvest techniques and cultural weed management practices during the spring have the potential to distribute viable hare barley seeds to new locations creating new populations. Germination experiments were conducted in the laboratory using seeds collected from two locations differing in climate and elevation in western OR throughout the growing seasons of 2010 and 2011. Cumulative growing degree days (GDD) were determined at the two field locations using daily maximum and minimum air temperature data that were recorded with permanent weather stations installed at each seed collection site. ANOVA was used to determine differences between sites for when peak viable hare barley seed production occurs. Estimation of the GDD value for peak viable seed production was approximately 2300 GDD. The cumulative GDD value occurred at different calendar dates for each site. Cumulative GDD differences may be attributed to differing climate and elevation conditions at each respective site.

3.2 Introduction

Hare barley *(Hordeum murinum* ssp. *leporinum*) is a vigorous winter annual grass species that matures quickly after flowering and produces abundant viable seed in numerous environmental conditions. The three subspecies in the *H.murinum* complex have been reported to be distributed along climate variation gradients in their native European habitats as well as on continents where they have been introduced. For example, in Europe, hare barley is reported to be restricted to the Mediterranean margin and western Asia while *H. murinum* ssp. *glaucum* grows in the dry, eastern parts of the region and H. *murinum* ssp. *murinum* grows throughout the region (Bor 1970).

Similar studies in Australia found that *H. murinum* ssp. *murinum* grew throughout their sampling region. Hare barley was restricted to wetter, more Mediterranean regions and *H. murinum* ssp. *glaucum* was found in drier regions (Cocks et al. 1976). More specifically, the distribution of hare barley was found to be above a 425 mm per year rainfall gradient. Hare barley could be found on the drier side of this rainfall gradient and ssp. *glaucum* could be found on the wetter side of this rainfall gradient though occurrences were rare. Although several factors may be attributed to differences in seed biology and rates of seed maturation, Cocks et al. (1976) also found ecotypic variation in both hare barley and ssp. *glaucum* that varied with days to flowering and length of the growing season associated with these two species. There are no reports of climate being a factor on hare barley distribution in North America.

European populations of *H. murinum* had obligate requirements for vernalization and plants that were sown earlier in the fall both flowered and produced viable seed earlier, and produced more spikes than plants sown later in the fall or winter seasons (Davison 1971).

All three subspecies in the *Hordeum murinum* complex have been identified in OR but hare barley is the only subspecies found in the Willamette Valley. Infestations of hare barley in perennial pastures cause a reduction in available forage for livestock and hay production resulting in economic losses for local farmers and ranchers. An understanding of the development of hare barley, especially when viable seed is produced, could enhance the control of hare barley through more timely management practices. Many ranchers in the Willamette Valley harvest hay at least once a season from pastures that they also graze. In pastures infested with hare barley, knowing approximately when viable hare barley seed is produced could limit dispersing seed in hay or livestock transport and would aid in preventing the establishment of new hare barley populations.

The Willamette Valley is located in the northwest section of the state of Oregon. Starting at the Columbia River near Portland, OR, it stretches approximately 177 kilometers south to Eugene, OR, and is approximately 96 kilometers wide, bordered on the west by the Coast range and the east by the Cascade mountain range. The climate of the Willamette Valley in western OR can be characterized as a Mediterranean-like climate with cool, wet winters and warm, dry summers. This climate is similar to areas in Europe and Australia where hare barley can be found.

Approximately 50% of the rainfall received in the Willamette Valley occurs during the winter months and the amount of rainfall is highly variable and dependent on elevation (Taylor 1993). Therefore, the objective of this research was to quantify viable seed production of hare barley, in terms of cumulative GDD’s, for two hare barley populations whose locations differ in environmental conditions and elevation in western OR.

3.3 Materials and Methods

Two sites in the Willamette Valley, OR, were used to conduct hare barley seed viability studies. One site was located in the foothills of the Cascades near Molalla, OR, and the second site was located on the valley floor near Canby, OR. Both sites are established perennial grass pastures consisting of orchardgrass, tall fescue, perennial ryegrass and colonial bentgrass and are used primarily for cattle grazing and hay production. Both pastures have well established populations of hare barley.

An initial study was conducted during the growing season in 2010. Hare barley spikelets were randomly selected from the naturally occurring populations in a total of 9 research plots at each site which had received no herbicide treatments and had not been exposed to grazing from October 2008 through August 2011 (Table 3.1). Collection of spikelets occurred bi-weekly beginning in May, when flowering occurred, through August when individual seeds began disarticulating from the spikelets .This sampling regime resulted in a total of five sampling dates. A $0.5m^2$

quadrat was randomly placed in each plot and all seed heads within the quadrat were collected. The samples were then bulked by sampling date and site and stored under ambient laboratory conditions in paper bags at room temperature for a period five months to afterripen.

Permanent weather stations were installed within the research plots at each experimental site using Adcon Telemetry units. Each unit was solar powered and allowed for wireless data transmission on a daily basis. Each unit collected and transmitted daily high and low temperatures and daily precipitation data and cumulative growing degree day (GDD) values in degrees C. Data were logged and visible over the internet using Adcon Software managed by Precision Agri Lab. GDD were calculated following a model developed by Klepper (1988) where GDD =(daily maximum temperature + daily minimum temperature)/2. Similar to methods described by Ball (2004), cumulative GGD were calculated from January 1 of each year with a base value of 0 C and any negative GGD values were reset to zero.

Following collection of the seeds in the field, a growth chamber experiment following after ripening was established to determine if the seeds collected from each sample date were germinable. A total of forty randomly selected seeds from each sample date and site were placed in Petri-dishes on moistened filter paper. Only the central floret of hare barley is fertile (Davison 1971), therefore a study similar to that of Popay (1981) was designed in that the lateral florets and glumes were removed and the awn on the central floret was trimmed with scissors prior to placing the seeds in Petri-dishes. The Petri-dishes were placed in the growth chamber where the temperature was set to 18 degrees C for 12 hours of daylight and 6 degrees C for 12 hours of dark. Temperature and day length were determined using October averages for the Willamette Valley, OR (Taylor 1993). Each sample date was replicated four times and the experiment was repeated.

After placing seeds in the growth chamber, germinated seeds (those with radicals emerged) were counted and removed from the Petri-dishes every three days. Germination tests were continued for 21 days. At the end of the experiment, percent germination of the seeds tested and cumulative GDD were recorded for each population with respect to site and sample date. To detect differences between sites of cumulative GDD values at which the peak germination of viable seed occurred, estimated viable seed values were evaluated with ANOVA ($\alpha = 0.05$).

A second, more detailed study was conducted in 2011 to estimate the number of GDD required for the production of germinable hare barley seed. At each site, twice weekly, from May 31 through July 14, 2011, three randomly selected, replicate samples of 30 hare barley spikelets were collected from the 9 non-treated, non-grazed plots used in the previous study. The spikelets were placed in paper bags and stored in lab conditions at room temperature for two months to afterripen. Daily maximum and minimum temperatures were recorded to calculate the cumulative GDD using the weather stations that had remained on the sites for the duration of the experiment (Table 3.2).

Again, a growth chamber experiment was conducted using 12 hours day and 12 hour night settings with temperatures of 18 degrees C during the day and 6 degrees C during the night. Thirty randomly selected, trimmed, central florets from each sample date and site were placed in Petri-dishes on moistened filter paper. Seed from each date was replicated three times and the experiment was repeated.

Following the same procedure as the first study, after placing seeds in the growth chamber, germinated seeds (those with radicals emerged) were counted and removed from the Petri-dishes every three days. Germination tests were continued for 21 days. At the end of the experiment, percent germination of the seeds tested and cumulative GDD were recorded for each population with respect to site and sample date. To detect differences between sites of cumulative GDD values at which the peak germination of viable seed occurred, estimated viable seed values were evaluated with ANOVA ($\alpha = 0.05$).

Results and Discussion

In the initial study, seed collection began on May 15, 2010, when hare barley flowering began (Table 3.1). At Bystrom Farms, cumulative GDD were 1866 and at Grassland Farms, cumulative GDD were 2018. At the next seed collection date, June 1, 2010, seeds began to germinate (12%) with cumulative GDD of 2164 at Bystrom

Farms. Germination was 69% and cumulative GDD were 2483 at Grassland Farms for the seeds tested. Germination neared 100% after approximately 2700 GDD were accumulated. The calendar date at which this occurred was different between sites. Germination reached 97% for the seeds sampled on July 1, 2010, from Bystrom Farms and germination reached 98% for the seeds sampled on June 15, 2010, from Grassland Farms. However, the results of the ANOVA suggest that there was no difference between sites ($P = 0.15$) perhaps due to the small number of seed collection dates and variability in germinations rates of collected seed.

In the second study, seed collection began on May 31, 2011, when hare barley flowering began (Table 3.2). At Bystrom Farms, cumulative GDD were 1730 and at Grassland Farms, cumulative GDD were 1991. Seeds began to germinate after approximately 2000 cumulative GDD at Bystrom Farms and approximately 2200 cumulative GDD at Grassland Farms. Germination at both sites reached approximately 90% after approximately 2300 cumulative GDD. Again, the calendar date at which this occurs was different between sites and was earlier at Grassland Farms, which is the Valley floor site, when compared to Bystrom Farms which is located in the Cascade foothills site ($P < 0.001$). The average daily temperature by the time each site reached 2300 GDD was 7.8 C at Grassland Farms and was 7 C at Bystrom Farms. Germination of viable seed also increased at a faster rate, approximately a week sooner, at the lower elevation site most likely due to a greater accumulation of GDD earlier in the growing season. These results are similar to those found by Davison

(1977) and Parker (1973) where flowering, growth and development of hare barley were reduced or delayed at upland or high elevation sites.

These results support the hypothesis that hare barley seed germination can be related to cumulative GDD at a given location and can be estimated to begin to occur around 2000 GDD with nearly 100% of hare barley seed germinating by a cumulative 2300 GDD with a starting date of January 1 each year. Farmers and ranchers could use this information and track changes in accumulation of GDD's to plan their hay harvest prior to viable hare barley seed production to prevent establishing new populations of hare barley. Limiting livestock movement through pastures with established populations of hare barley after viable seed is produced also will prevent the spread of viable seed to other locations within the pasture or on other ground used for grazing. The best possible method to reduce the dispersal of viable hare barley seed is to time spring pasture management operations prior to the accumulation of 2000 GDD.

Further research is needed to predict when the start of viable seed set occurs in other locations throughout OR. The response of hare barley to cumulative GDD should be evaluated in other locations before suggesting a model for use by pasture owners and hay producers outside the Willamette Valley, OR.

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Table 3.1. Spikelet sampling dates and mean hare barley seed % germination in 2010 at Bystrom Farms and Grassland Farms.

Bystrom Farms			Grassland Farms		
	Cumulative	Germination		Cumulative	Germination
Date	GDD[a]	%	Date	GDD	%
May 15	1866	0	May 15	2018	0
June 1	2164	12	June 1	2384	69
June 15	2502	87	June 15	2734	98
July 1	2893	97	July 1	3209	93
July 15	3367	97	July 15	3685	98
August 1	3952	94	August 1	4210	95
LSD (0.05)		5.2			5.2

[a] Abbreviation: GDD, growing degree days.

Table 3.2. Spikelet sampling dates and mean hare barley seed % germination in 2011 at Bystrom Farms and Grassland Farms.

Bystrom Farms			Grassland Farms		
	Cumulative	Germination		Cumulative	Germination
Date	GDD[a]	%	Date	GDD	%
May 31	1730	0	May 31	1991	0
June 3	1805	0	June 3	2076	0
June 6	1903	0	June 6	2177	0
June 9	1968	0	June 9	2253	12
June 13	2061	25	June 13	2359	90
June 16	2127	44	June 16	2440	94
June 20	2227	92	June 20	2567	94
June 23	2311	100	June 23	2657	99
June 27	2423	99	June 27	2794	100
June 30	2502	99	June 30	2894	100
July 5	2656	100	July 5	3110	99
July 8	2746	100	July 8	3264	100
July 11	2832	100	July 11	3377	100
July 14	2912	100	July 14	3472	100
LSD (0.05)		4.9			4.7

[a] Abbreviation: GDD, growing degree days.

CONCLUSION

4. GENERAL CONCLUSION

The experiments discussed in this thesis were conducted to better understand the biology and management of hare barley in cool season perennial grass pastures in western OR. Results of these experiments revealed chemical control options that are effective for suppressing or controlling hare barley. The results also provide land managers with information related to when viable seed production in hare barely occurs.

Use of the herbicide aminopyralid applied in the fall was effective for suppressing hare barley with minimal pasture injury, but successful control will likely depend on multiple applications over several years. The spring applications with the experimental pasture herbicide imazamox were also effective for controlling hare barley. Even though the risk of pasture injury was higher using these treatments, the injury was acceptable, according to the stakeholders involved in these efficacy trials and indicates the continued need for development of registered pasture herbicides that control grass weed species. Further research using non-pasture labeled herbicides in multiple application studies in both the spring and fall are needed to determine the best timing of herbicide applications to maximize control of hare barley and minimize pasture injury. Future experiments could also incorporate cultural methods of control such as grazing, mowing or tillage with the use of herbicides to determine the most effective method of control for hare barley.

Viable seed production of hare barley can be related to cumulative GDD for a given location in the Willamette Valley of OR. Results indicated that nearly 100% of hare barley seed will germinate after approximately 2300 cumulative GDD. A better target for timing spring management operations is prior to 2000 cumulative GDD as indicated by when seeds tested in the laboratory began to germinate. This GDD accumulation occurs at lower elevation sites sooner than higher elevation sites. In order to create a predictive model regarding viable hare barley seed production, further studies utilizing more populations across a greater geographic area within and outside the Willamette Valley would be needed. More studies to characterize the vernalization requirements and other seed biology factors of hare barley would be needed to create a complete predictive model for when viable seed set occurs in hare barley. This model would then allow pasture owners and hay producers to improve the timeliness of spring control options of hare barley and hay harvest to reduce the amount of hare barley seed distribution to other locations that may create new infestations.

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APPENDICES

APPENDIX A. SURVEY OF HARE BARLEY DISTRIBUTION IN THE STATE OF OREGON

A survey was completed in 2010 to characterize the distribution of hare barley in the state of Oregon. Little research has been done in the United States to understand the distribution of hare barley and no work has been conducted to understand its distribution in Oregon. The information collected will be useful in justifying Special Local Need herbicide labels for the control of hare barley and for understanding the degree to which hare barley poses a weed management issue in Oregon. Letters and e-mail announcements were sent to Agriculture and Natural Resource Extension faculty and staff across the state of Oregon asking for participation in the survey.

Individuals were asked to submit plants and/or images of plants in their respective areas that resemble hare barley. They also were asked to provide information regarding the location and management scenario from the location where each sample was taken. A website was established for photo submission and other inquiries. Information regarding this survey and instructions for submitting samples can be found on the web at http://cropandsoil.oregonstate.edu/weeds/harebarley. After submission, samples were identified by Dr. Richard Halse in the Department of Botany and Plant Pathology, Oregon State University.

Limited participation from individuals across the state provided minimal information about hare barley distribution. However, all three subspecies in the *H. murinum* complex have been identified in Oregon as a result of survey participation. A list of samples submitted and the county from which they were collected from are presented in table A.1.

Table A.1 Identification of Samples Submitted for the Hare Barley Distribution Survey

Species	**Common Name**	**County**
Hordeum jubatum	Foxtail barley	Sherman
Hordeum jubatum	Foxtail barley	Klamath
Hordeum marinum Huds. ssp. *gussoneanum*	Mediterranean Barley	Benton
Hordeum murinum ssp. *glaucum*	Smooth barley	Union
Hordeum murinum ssp. *glaucum*	Smooth barley	Klamath
Hordeum murinum ssp. *leporinum*	Hare barley	Clackamas
Hordeum murinum ssp. *leporinum*	Hare barley	Marion
Hordeum murinum ssp. *murinum*	Wall barley	Gilliam/Wheeler
Taeniatherum caput-medusae (L.)	Medusahead	Benton

APPENDIX B. DATES AND WEATHER CONDITIONS OF HERBICIDE APPLICATIONS

The herbicide efficacy studies explained in chapter two of this thesis were carried out over three years with varying fall and spring application timings. The application dates and weather conditions for when these herbicide applications took place are presented in Table A.2.

Table A.2. Dates and Weather Conditions of Herbicide Applications

Application Timing	Date	Bystrom Farms Temperature °C	Bystrom Farms Humidity %	Grassland Farms Temperature °C	Grassland Farms Humidity %
Fall 2008	October 3	6.7	70	16	100
Spring 2009	April 10	8.3	80	13.3	60
Fall 2009	November 3	12.2	82	13.9	68
Spring 2010	March 19	12.8	52	14.4	49
Fall 2010	September 28	27.8	63	27.8	45
Spring 2011	April 1	14.4	79	18.3	72