POISON HEMLOCK (*Conium maculatum* L.): BIOLOGY, IMPLICATIONS FOR PASTURES AND RESPONSE TO HERBICIDES

A Thesis

presented to

the Faculty of the Graduate School

at the University of Missouri

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

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MAY 2008

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To my wife **LESLIE**

and parents **ERIC** ***and*** **ROCHELLE**

ACKNOWLEDGEMENTS

I would first like to thank my advisor Dr. Reid Smeda for allowing me to complete a master's degree under his supervision. I appreciate the opportunity and knowledge gained from your expertise. Your influence has helped guide me throughout and beyond my undergraduate and graduate studies. I would also like to thank Drs. Kevin Bradley, Kelly Nelson, Robert Kremer and Robert Kallenbach for their assistance and input to my research projects and thesis. For statistical support, I would like to extend my appreciation to Dr. Mark Ellersieck, who I visited with on many occasions, as well as fellow graduate student Diego Bentivegna. For technical support I would like to thank fellow graduate students Johnathan (Johan) Dierking and Diego Bentivegna, as well as research specialist David Kleinsorge and all undergraduate workers who spent time assisting me with this research. I would also like to thank the cooperators of this research for allowing me to conduct this work at various sites; Mr. Rand Swanigan, Missouri Department of Transportation; Mr. Danny Hartwig, Missouri Conservation Department; and Mr. John Samek, Samek Dairy Farms.

Special thanks go out to everybody affiliated with Weed Control Research at the University of Missouri. This includes Dr. Smeda, Dr. Bradley, Jim Wait, Eric Riley, David Kleinsorge, Johnathan Dierking, Travis (T-bone) Legleiter, Kristin Payne, Dan Earlywine, Diego Bentivegna, Justin Pollard and Nick Monnig. Thanks for your support, guidance and friendship the past couple of years.

I must also thank my loving family and friends for their support while pursuing this degree. To my parents, Eric and Rochelle, thank you for instilling in me the work

ethic, determination and fortitude to reach my goals, while helping me remember the more important things in life. To my wife Leslie, thank you for your love, patience and support, while completing this degree. Without your presence in my life, I would not be where I am today and am truly grateful and fortunate.

Most importantly, I must thank God for all his blessings and for the ability to pursue and complete this degree.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ………………………………………………………….. **ii**
TABLE OF CONTENTS ………………………………………………………….. **iv**
LIST OF TABLES ………………………………………………………………….. **v**
LIST OF FIGURES ………………………………………………………………….. **vii**

CHAPTER I Literature Review ……………………………………………………. **1**
INTRODUCTION …………………………………………………………….. 1
BIOLOGY ……………………………………………………………………... 3
MANAGEMENT …………………………………………….................... 9
PURPOSE OF STUDY …………………………………........................ 11
LITERATURE CITED ………………………………………………………….. 13
CHAPTER II Seed Production, Seed Germination and Seed Viability of Poison Hemlock (*Conium maculatum* L.) ….…………………………...……………… **18**
Abstract: ………………………………………………………………………… 18
INTRODUCTION …………………………………………………………... 20
MATERIALS AND METHODS ……………………………………………... 22
RESULTS AND DISCUSSION ……………………………………………... 25
LITERATURE CITED ……………………………………………………..... 28
CHAPTER III Biomass Production of Poison Hemlock (*Conium maculatum* L.) and Potential Risk to Cattle (*Bos Taurus* L.) ....…………………………………... **35**
Abstract: ………………………………………………………………………… 35
INTRODUCTION …………………………………………………………….. 37
MATERIALS AND METHODS ……………………………………………... 39
RESULTS AND DISCUSSION ……………………………………………... 41
LITERATURE CITED ………………………………………………………….. 45
CHAPTER IV Chemical Management of Poison Hemlock (*Conium maculatum* L.) ....……….. **53**
Abstract: ………………………………………………………………………… 53
INTRODUCTION …………………………………………………………….. 55
MATERIALS AND METHODS ……………………………………………... 57
RESULTS AND DISCUSSION ……………………………………………... 60
LITERATURE CITED ………………………………………………………….. 63

LIST OF TABLES

Table 2.1. Properties of soils from three locations in central Missouri used to determine seed production of poison hemlock.…………………………………..…...….30

Table 2.2. Plant height ranges for each population of poison hemlock from three Missouri locations in 2006 and 2007……………………………………………………31

Table 3.1. Properties of soils from two locations in central Missouri used to determine growth of poison hemlock……………………………………………………49

Table 4.1. Herbicides, mode of actions and application rates for poison hemlock (*Conium maculatum* L.) trials in central Missouri.………..……………………………..66

Table 4.2. Dates of chemical application, size of poison hemlock plants at application and environmental conditions during application at Higginsville, Columbia and Bolivar, MO for 2006 and 2007……………….…………………………………67

Table 4.3. Visual poison hemlock injury two weeks after herbicide treatment (WAT) at Higginsville and Columbia, Missouri in 2006, and Higginsville and Bolivar, Missouri in 2007……………………………………………………………68

Table 4.4. Visual poison hemlock injury four weeks after herbicide treatment (WAT) at Higginsville and Columbia, Missouri in 2006, and Higginsville and Bolivar, Missouri in 2007……………………………………………………………69

Table 4.5. Visual poison hemlock injury eight weeks after herbicide treatment (WAT) at Higginsville and Columbia, Missouri in 2006, and Higginsville and Bolivar, Missouri in 2007.…………………………………………………………...70

Table 4.6. Mean poison hemlock emergence at 2, 4, 8, 12 and 24 weeks after treatment (WAT). Values represent means pooled over locations and years in Missouri in 2006 and 2007……………………………..………………………………..71

LIST OF FIGURES

Figure 2.1. Mean daily air temperature (A) and cumulative rain fall (B) for central Missouri during the trial period in 2006 and 2007…………………..………….32

Figure 2.2. Poison hemlock seed production per plant in Missouri in 2006 (A) and 2007 (B) by location and plant height ranges (between 1.2 to 3.4 m; see Table 2.1)….33

Figure 2.3. Mean viability and germination of seed (combined over locations) collected different times after maturity from poison hemlock populations in central Missouri in 2007………………..………………………………………………...34

Figure 3.1. Cumulative rainfall (A) and mean daily air temperature (B) for Columbia and Houstonia, Missouri in 2007.……………..……………..………………….50

Figure 3.2. Mean dry weight of poison hemlock above ground biomass for 1, 3, 9, and 27 plants/m^2 from Columbia, Missouri. Dashed (2.4 kg) and dotted (1 kg) lines represent the daily lethal amount of poison hemlock needed for a 500 kg cow at stocking rates of 2.5 and 6 cows/ha, respectively……………………...……...51

Figure 3.3. Mean dry weight of poison hemlock above ground biomass for 1, 3, 9, and 27 plants/m^2 from Houstonia, Missouri. Dashed (2.4 kg) and dotted (1 kg) lines represent the daily lethal amount of poison hemlock needed for a 500 kg cow at stocking rates of 2.5 and 6 cows/ha, respectively…………………..………….52

CHAPTER I

Literature Review

Introduction

Poison hemlock (*Conium maculatum* L.) is an invasive biennial plant that is native to Europe, northern Africa and western Asia (Holm et al. 1997). It was introduced to the United States in the 1800's as an ornamental plant, and has since been established in nearly every state across the country (DiTomaso 1999; Kingsbury 1964).

Poison hemlock is also known as deadly hemlock, snake-weed, poison parsley, wode whistle and poison stinkweed (Uva et al. 1997). Poison hemlock is a member of the carrot or parsley family *Apiaceae*, formerly known as *Umbelliferae* (Mitich 1998). This family includes between 2,500 and 3,000 species and notable characteristics consist of a flattened umbrella-like inflorescence, toxicity and strong mousy odors (Heywood 1993; Mitich 1998). Six species of *Conium* are found throughout the world and poison hemlock is the only one of these species that is established in North America (DiTomaso 1999).

The name *Conium* is Greek meaning to spin or whirl, as a result of the disastrous effects of poison hemlock on the body (Mitich 1998). The species name *maculatum* is Latin for spotted or bearing spots, referring to the purple spots or mottling of the stem (Mitich 1998). Hemlock, the English name, comes from the Anglo-Saxon words hemlic or hymelic (Vetter 2004).

Poison hemlock can be mistaken for other members of the *Apiaceae* family, such as wild carrot (*Daucus carota L.*) and waterhemlock (*Cicuta spp.*) (Pokorny and Sheley 2001). Waterhemlock has a fleshy root system and broader leaves than poison hemlock (Frankton and Mulligan 1970). Wild carrot leaves are noticeably hairy, whereas poison hemlock leaves appear “lacy or fernlike” (Kingsbury 1964; Mitich 1998).

The primary habitat of poison hemlock consists of roadsides, riverbanks, waste areas, pastures and many other non-crop areas (Mitich 1998). Poison hemlock is frequently found in wet habitats, but it can also thrive in dry climates (Tucker et al. 1964). Poison hemlock is readily established on disturbed sites and can out-compete thin forage stands (Holm et al. 1997).

Currently in the U. S., poison hemlock is considered a noxious weed in CO, ID, IA, NV, NM, OH, OR and WA (USDA 2008). In these states, control is required in heavily populated areas (Castells and Berenbaum 2006). Poison hemlock is commonly identified as a problem pasture weed in the U. S. However, it has also been reported a problem weed in as many as nine crops, including cereal crops, vegetable crops and orchards in 34 different countries (Holm et al. 1997). Poison hemlock can be a problem in grain fields contaminating harvested seed (Panter and Keeler 1990). In late spring or early summer, poison hemlock can invade perennial crops such as alfalfa, but is only a real threat for the first cutting of hay (Jeffery and Robison 1990). Re-growth of poison hemlock is suppressed by subsequent re-growth of alfalfa (DiTomaso 1999). Poison hemlock may also harbor plant diseases that can spread to agricultural systems (Raju et al. 1980). Castells and Berenbaum (2006) reported that poison hemlock can harbor high levels of *Xylella fastidiosa* along the Napa Valley vineyards in California, causing

Pierce's disease in European and bunch grape cultivars. Poison hemlock can also harbor plant viruses such as the celery mosaic virus (Castells and Berenbaum 2006). This virus can be transferred to other plants by aphids feeding on the vegetation (Gracia and Feldman 1977; Sutabutra and Campbell 1971). An important step in the management of poison hemlock is to prevent establishment in new areas (Pokorny and Sheley 2001).

Biology

Life Cycle and Description. Poison hemlock is a biennial weed that typically grows 1 to 2.5 m tall and in fertile soils can grow up to 3 m (Tucker et al. 1964). It usually germinates in the early spring and/or fall, and grows as a rosette during the first growing season; the second season the plant bolts and extends a single shoot bearing seed (Pokorny and Sheley 2001). In Kentucky, plants bolt in mid-April. Flowering starts mid-May and is complete by mid-to late-June; seeds are ripe usually by late July (Baskin and Baskin 1990). Wild parsnip (*Pastinaca sativa* L.) is a similar plant in the *Apiaceae* family that lives as a biennial, but also as a monocarpic perennial (Doll 2001). Monocarpic perennials grow as a rosette until the second, third or fourth season before flowering begins (Baskin and Baskin 1979). Like wild parsnip, some authors indicate poison hemlock will not only grow as a biennial, but may grow as a short-lived monocarpic perennial (Holm et al. 1997). In some cases, the plant can behave as a winter annual, germinating in the fall or winter and flowering the next summer (Holm et al. 1997).

The root system of poison hemlock is a long, white taproot (Holm et al. 1997). The taproot can grow 20 to 25 cm long and has a well developed secondary fibrous root system (Uva et al. 1997). The stems of poison hemlock are light green with purple mottling and are hollow throughout except at the nodes (Holm et al. 1997). The leaves possess many deeply dissected narrow segments and are very large, placed alternately on the stem or crown of the rosette (Holm et al. 1997). The inflorescences of poison hemlock are arranged in large compound umbels measuring 4 to 6 cm across (Mitich 1998). The flowers are small, white and grouped in large loose clusters (Mitich 1998). The fruit of poison hemlock is a schizocarp and are circular shaped containing two maricarps or seeds which are gray or brown in color, 2.5 to 3.0 mm in length and 1.4 to 1.9 mm in width (Davis 1993; Holm et al. 1997). The two seeds usually separate but may stay attached (Davis 1993). Each seed possesses five prominent, wavy, longitudinal ridges (Holm et al. 1997).

Seed Ecology. Despite prolific seed production, up to 38,000 seed per plant, poison hemlock seed usually fall directly to the ground and is not well developed for long distance travel (Panter and Keeler 1988; Pokorny and Sheley 2001; Whittet 1968). Seed of poison hemlock are typically ripe by late July and the dispersal period may last from mid-September to February of the next year (Baskin and Baskin 1990). This long dispersal period allows plants to become established at various times of the year and increases the potential for long-term survival (Pokorny and Sheley 2001). It was reported by Baskin and Baskin (1990) that 50% of seed were dispersed by mid-October, 75 to 90% by mid-December, and only 1 to 2% remains on the plant in January and February. Seed distribution occurs by water, rodents and birds (Holm et al. 1997).

A majority of the seed that is dispersed early to mid-September will germinate at that time. Seed dispersed in October or November may germinate that fall, late winter or the following fall (Baskin and Baskin 1990). The last portion of seed remaining on the stalk is eventually dispersed during late winter and will give rise to groups of seedlings in the spring or the following fall. In Kentucky, the seed of poison hemlock germinates all year, except in April, May, June and July depending upon environmental conditions (Baskin and Baskin 1990). The optimum mean daily minimum and maximum air temperatures for poison hemlock germination are between 17.1 and 28.5 C, respectively (Baskin and Baskin 1990). Poison hemlock germination will cease whenever the daily minimum and maximum air temperatures are above 22.3 and 33.8 C and below 0.2 and 9.3 C, respectively (Baskin and Baskin 1990). Seed from poison hemlock can remain viable in the soil at least 2 years and is capable of germinating in complete darkness (Baskin and Baskin 1990). However, seed stored in dry conditions at room temperature remained viable for up to 5 years (Holm et al. 1997). In England, it was reported that from the time the seed matures, 26% germinates within the first year, 7.5% germinates the following year, 2.8% the third year and less than 1% each year thereafter (Holm et al. 1997).

Mature poison hemlock seed possess underdeveloped embryos and exhibit both morphological (MD) and morphophysiological dormancy (MPD) (Baskin and Baskin 1990). Once the embryo is fully developed and elongated within the seed, the dormancy period ends (Baskin and Baskin 1990). Morphological dormancy occurs in approximately 85% of poison hemlock seeds, which require suitable temperature, moisture and light to germinate. However, this percentage can change from year to year

(Baskin and Baskin 1990). For poison hemlock seeds with MD, approximately 15 days are required for growth of the embryo and germination to occur (Baskin and Baskin 1990). The other 15% of seed produced have MPD, requiring conditions such as high summer or low winter temperatures, to break dormancy before and during embryo growth (Baskin and Baskin 1990). MPD can be broken in seed that have not been dispersed and remain on the upright shoots throughout the summer (Baskin and Baskin 1990). However, seeds that remain attached to upright shoots through the end of August may enter or re-enter MPD (Baskin and Baskin 1990). A small percentage of seeds will remain in MD when entering the winter months, allowing them to germinate (Baskin and Baskin 1990).

Toxicity. Toxicity of poison hemlock is a major concern that dates back to BC 399, when it was used to execute the Greek philosopher Socrates as well as political prisoners in ancient Greece (Everist 1974; Holm et al. 1997). Native Americans used the toxins from poison hemlock in the tips of their arrows (Smith et al. 1982). Humans have been poisoned by eating poison hemlock leaves, roots, and seeds, mistaking them for other species like parsley (*Petroselinum crispum* L.), parsnips (*Pastinaca sativa* L.), and anise (*Pimpinella anisum* L.) (Everist 1974). Children have suffered the effects of poisoning by blowing on flutes or pea shooters constructed from the hollow stems (Everist 1974). Poison hemlock has some medicinal capability, but the closeness between therapeutic and toxic levels limits its use (Case 1969; Holm et al. 1997).

Eight poisonous alkaloids are found in poison hemlock; coniine (2-propylpiperidine), γ-coniceine (2n-propyl-Δ^1-piperidine), N-methyl coniceine (1-methyl-2-propylpiperidine), conhydrine [2-(1-hydroxypropyl) piperidine}, pseudoconhydrine

[(5-hydroxypropyl) piperidine], conhydrinone [2-(2-ketopropyl) piperidine], N-methyl pseudoconhydrine (1-methyl-5-hydroxy-2-propylpiperidine) and 2-methyl piperidine (Panter et al. 1988b). Of these eight, the principle toxins are the piperidine alkaloids coniine and γ-coniceine, which are the most abundant and deadly (Panter et al. 1988b). Concentrations of these alkaloids will vary, depending upon environmental conditions, time of year and location (Panter et al. 1988b). Fairbairn and Challen (1959) reported γ-coniceine was highest in concentration during very wet seasons, but coniine was highest in concentrations during dry conditions. During fruit ripening, the concentration of coniine greatly increased while γ-coniceine concentrations dropped considerably (Fairbairn and Challen 1959). It was reported that the alkaloid concentration in the plant is lowest when plants are in the seedling stage (Fairbairn and Challen 1959). Lopez, et al. (1999) reported that the total alkaloid content (γ-coniceine plus coniine) in different parts of the poison hemlock plant, expressed as a percentage in dry matter, was 0 to 0.5% in roots, 0.01% in dry stems, 0.02 to 0.8% in shoots, 0.3 to 1.5% in leaves, 1.0% in flowers, 1 to 3% in unripe fruits, 0.2 to 1% in ripe fruits and 0.02 to 0.9% in seeds.

Domesticated livestock and wild animals are susceptible to poisoning from poison hemlock (Holm et al. 1997). In 1951, it was reported that 244 hogs (*Sus scrofa* L.) were poisoned by consuming barley (*Hordeum vulgare* L.) grain contaminated with poison hemlock seed which resulted in 45 deaths (Panter et al. 1988b). In another case, 24 dairy cows (*Bos Taurus* L.) and 26 heifers died from ingesting green-chopped hay contaminated with poison hemlock (Kubik et al. 1980; Panter et al. 1988b). The most recent case of reported poisoning occurred in Missouri during the spring of 2005, when five heifer calves weighing approximately 230 kg ingested fatal amounts of poison hemlock, as was evident upon a post-mortem examination (Burton 2005). Poisoning from poison hemlock can result in lower meat and milk production, a reduction in the quality of milk, and congenital effects such as deformed offspring or even abortions (Holm et al. 1997). Losses from poisonous plants, such as poison hemlock, have been classified as either direct or indirect (James et al. 1992). Examples of direct losses include livestock deaths, decreased performance, and reproductive losses (James et al. 1992). Indirect losses consist of preventative costs or management costs a livestock owner deals with when poisonous plants invade the habitat (James et al. 1992).

When ingested, poison hemlock acts on the central nervous system, causing symptoms such as nervousness and trembling, along with difficulty in the movement of limbs (Kingsbury 1964). Other symptoms include a weakened heartbeat initially and later becoming very rapid, frequent urination, nausea, convulsions, heavy salivation and respiration, and lowering of body temperature (Forsyth 1968; Kingsbury 1964). Symptoms of poisoning will appear 2 to 4 hours after the plant has been ingested (Tucker et al. 1964). If enough of the plant was ingested, the animal will die from respiratory failure (Kingsbury 1964). Death can occur 5 to 10 hours after symptoms have been witnessed and an autopsy of the animal will reveal nothing significant (Tucker et al. 1964). Depending upon the amount ingested, an animal that has been suffering symptoms from poisoning can recover (Tucker et al. 1964). Animals can develop a tolerance to coniine, much the same as humans do to the alkaloid nicotine (Holm et al. 1997).

Cattle are the most sensitive to poisoning, pigs are the least sensitive and goats (*Capra aegagrus hircus* L.) and sheep (*Ovis aries* L.) are intermediate (Holm et al. 1997).

Fresh plants administered to cows at a dose of 5.3 g/kg of body weight (BW) were lethal (Keeler and Balls 1978; Panter et al. 1988a). Pure coniine, administered by stomach tube resulted in severe clinical signs of toxicity to cows with doses as little as 3.3 mg/kg BW and was lethal at 16 mg/kg BW (Keeler et al. 1980). Doses of fresh plants were lethal to sheep and pigs at 10 and 13.7 g/kg BW, respectively (Panter et al. 1988a, b). Mares (*Equus caballus* L.) and ewes responded with signs of toxicity when administered coniine by stomach tube at 15.5 and 44.0 mg/kg BW, respectively (Keeler et al. 1980). Poison hemlock is a plant that will remain green in pastures during the late winter and early spring and may be eaten by hungry livestock (Panter and Keeler 1988). If desirable vegetation is available, animals will avoid eating poison hemlock unless forced. However, when it is harvested with alfalfa for hay, animals cannot discriminate (Jeffery and Robison 1990).

Management

Since poison hemlock is a concern to livestock producers, current control techniques are needed to reduce the occurrence of poisoning. Early detection, prevention, containment and small-scale eradication are the keys to management. Control strategies such as biological, herbicidal and cultural methods are typically used (DiTomaso 1999).

The only researched biological method for control of poison hemlock involves the use of the Palearctic moth, also known as the hemlock moth (*Agonopterix alstroemeriana*) (Pokorny and Sheley 2001). In Tompkins County, New York the hemlock moth caterpillar was found on flowers and foliage for the first time in the United States (Berenbaum and Passoa 1983). In the mid-to late-1980's, the moth was found in the northwestern part of the country, and was first found in the Midwest near Columbus, OH in 1990 (Powell and Passoa 1991). Poison hemlock is the only known host plant for the moth in Europe and the U. S. (Pokorny and Sheley 2001). If high enough populations of the hemlock moth caterpillar infest a plant, it can completely defoliate and limit seed production (Pokorny and Sheley 2001).

Chemical control is an effective method to manage poison hemlock infestations. Glyphosate, glyphosate plus S-metolachlor, rimsulfuron plus thifensulfuron, metsulfuron, sulfometuron plus metsulfuron, chlorsulfuron, 2,4-D, 2,4-D plus picloram and dicamba are herbicides currently labeled for control (CPCR 2006). Dicamba, 2,4-D, 2,4-D plus triclopyr, and glyphosate have resulted in good control of poison hemlock when applied early in the lifecycle (Nice et al. 2005). When applied in the rosette stage, glyphosate at 1.12 kg ae/ha resulted in excellent control (Jeffery and Robison 1990). Chlorsulfuron and metsulfuron alone or in combination has resulted in excellent preemergence control of seedlings or postemergence control of rosettes (DiTomaso 1999). Effective preemergence herbicides for the control of poison hemlock are hexazinone at 1.68 kg ai/ha, metribuzin at 1.12 kg ai/ha and terbacil at 1.12 kg ai/ha (Jeffery and Robison 1990). Repeated applications may be required for several years to manage and deplete poison hemlock from the seedbank (Panter and Keeler 1988).

Management techniques such as cultivation and mowing can provide an alternate method for control of poison hemlock (DiTomaso 1999). Poison hemlock is not a problem weed in croplands where soil is frequently tilled. Repeated mowing will deplete the carbohydrate energy reserves of the plant and decrease its competitive ability (Smith et al. 1982). Tillage and mowing will prevent new plants from establishing and can reduce competitiveness (Pokorny and Sheley 2001). Burning has been considered as a cultural control for poison hemlock; however there is usually not enough dry vegetation for fuel in areas where the plant is dominant (DiTomaso 1999).

Purpose of Study

Since its introduction as an ornamental plant in the 1800's, poison hemlock has readily established in many states across the U. S. Poison hemlock has been identified as an invasive weed and declared noxious in several states. Poison hemlock has the ability to emerge many months throughout the year and can invade habitats such as roadsides or pastures. Poison hemlock plants may reach 3 m in height and can reduce driver visibility along roadways or intersections. Perhaps the greatest concern with poison hemlock is its toxicity to livestock. It is highly toxic when ingested and may cause detrimental effects to humans and animals. Control methods for poison hemlock are implemented to prevent potential of livestock poisoning, or to improve visibility along roadsides.

Currently there is little information regarding the biology and control of poison hemlock. A better understanding of the biology of this plant, such as seed dormancy characteristics and seed production may elucidate better management techniques to maintain and prevent new populations from forming. Research is also needed to identify herbicides that optimally control emerged plants as well as provide residual control for preventing establishment of new populations. Also, there is no information in the literature regarding the total above ground biomass produced within a given area. The literature focuses on the poisonous alkaloid concentrations within the plant and the total amount of poison hemlock plant material needed to be ingested by livestock for poisoning to occur. This research will attempt to fill the gap in the literature regarding seed ecology and investigate chemical management of poison hemlock with new herbicides. It will also explore the amount of above ground biomass on a per area basis that can be produced by poison hemlock plants and compare with the literature to determine a threshold for when poisoning may occur in a pasture setting.

The thesis research is divided into three parts.

A) Seed Ecology

The seed ecology research includes two objectives: a) to determine poison hemlock seed production per plant; and b) determine the viability and germination of the seed produced upon maturity.

B) Biomass Production

Biomass production includes two objectives: a) determine the amount of above ground biomass produced by poison hemlock through early spring; and b) incorporate data from previous research regarding animal toxicity.

C) Herbicide Control

Herbicide control includes two objectives: a) identify the response of poison hemlock to selected herbicides when applied in early spring; and b) monitor the amount of seedling suppression provided by selected herbicides through spring, summer, and early fall.

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CHAPTER II

Seed Production, Seed Germination and Seed Viability of Poison Hemlock (*Conium maculatum* L.)

Carl A. Woodard *

Abstract. Poison hemlock is an invasive, biennial plant found commonly along roadsides, riverbanks, waste areas and pastures throughout the United States. Research to determine seed production of poison hemlock plants in relationship to plant height as well as the extent of seed dormancy following plant maturation were conducted in 2006 and 2007 at three locations in central Missouri. Using natural populations, plants ranging in size from 1.2 to 3.4 m were harvested approximately 56 days after flower initiation. Seed production ranged from 1,700 to 39,000 seed per plant with taller plants producing the largest amount of seed. Germination and viability of mature seed collected from two locations in central Missouri were measured in 2007. Mean germination of freshly harvested seed was 11%. As seed aged under natural field conditions, germination increased to 34% when collected in mid-September. Seed viability remained constant between 83 and 87% throughout the study. Results indicate poison hemlock is a prolific, viable seed producer and that the seed have no dormancy restriction. This enables seedlings to readily establish in new areas with favorable conditions. Management

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techniques should focus on eliminating seed production and suppressing emerging seedlings.

Nomenclature: poison hemlock, *Conium maculatum* (L.) COIMA.

Key Words: invasive, pasture, roadside, seed germination, seed production, seed viability.

Introduction

Poison hemlock (*Conium maculatum* L.) is a plant in the *Apiaceae* family that was introduced into the United States in the 1800's as an ornamental (Mitich 1998). Plants originated in Europe, northern Africa and western Asia (Holm et al. 1997). In the U. S., poison hemlock can be found growing in relatively un-disturbed areas in nearly every state (DiTomaso 1999; Kingsbury 1964).

Poison hemlock is a biennial plant; seedling germination occurs in the spring and fall. Once seedlings are established, plants grow as a rosette through the fall and winter into early spring (Pokorny and Sheley 2001; Tucker et al. 1964). In the Midwest, plants bolt in mid-April, extending a single shoot up to 3 m in height (Baskin and Baskin 1990; Tucker et al. 1964). Flowering begins in mid-May with white inflorescences arranged in large compound umbels (Mitich 1998). The fruit is a schizocarp composed of two seeds, gray or brown in color, 2.5 to 3.0 mm in length and 1.4 to 1.9 mm in width (Davis 1993; Holm et al. 1997). Seed production per plant may reach 38,000 and seeds are usually ripe by late July followed by seed dispersal in September (Baskin and Baskin 1990; Whittet 1968).

Poison hemlock is a competitive plant that can displace thin forage stands and readily invades disturbed sites (Holm et al. 1997). Perhaps the main concern regarding poison hemlock is its toxicity when ingested (Panter et al. 1988). It is a producer of eight poisonous alkaloids, which exist in all parts of the plant including mature seed (Lopez et al. 1999; Panter et al. 1988). Poison hemlock seed are poorly developed for long distant travel and will fall directly from the plant to the ground resulting in plants that grow in groups or communities (Pokorny and Sheley 2001). Roadsides, riverbanks, waste areas, and pastures are typical sites invaded by poison hemlock (Mitich 1998).

Baskin and Baskin (1990) reported that seed germination of poison hemlock occurs over a wide range of temperatures. Optimum minimum and maximum air temperatures for poison hemlock germination were 17 and 29 C respectively (Baskin and Baskin 1990). Germination ceased whenever the daily minimum and maximum air temperatures were above 22 and 34 C and below 0.3 and 9 C, respectively (Baskin and Baskin 1990). Poison hemlock seed may exhibit both morphological dormancy (MD) and morphophysiological dormancy (MPD) (Baskin and Baskin 1990). This enables seedlings to become established at different times throughout the year. MD occurs in approximately 85% of the seed produced, which requires roughly 15 days of suitable conditions for germination (Baskin and Baskin 1990). The remaining 15% of seed produced have MPD, requiring a vernalization period of cold winter or hot summer temperatures to break dormancy before germination and emergence (Baskin and Baskin 1990). It was reported in England that from the time seed maturity is reached, 26% germinated within the first year, 7.5% the following year, 2.8% the third year and less than 1% each year thereafter (Holm et al. 1997). Seed of poison hemlock will remain viable in the soil for at least two years (Baskin and Baskin 1990). However, viability of recently matured seed has not been recorded.

Research regarding the amount of seed produced per plant, as well as germination and viability of poison hemlock seed after maturity is limited. A better understanding of the seed ecology of poison hemlock may identify growth factors that favor encroachment and lead to management practices that reduce establishment in new areas. The objectives of this research were to quantify seed production from natural populations of poison hemlock in relationship to plant height, and to identify the viability and germination of seed produced.

Materials and Methods

Seed Production. Quantification of seed production was determined from established stands of poison hemlock at three locations in central Missouri (Higginsville, Houstonia and Columbia) in the summer of 2006 and 2007. Soil properties from each location are displayed in Table 2.1. The Higginsville location consisted of a pasture or rangeland habitat, while Houstonia and Columbia locations represented a roadside habitat. All habitats consisted of natural populations of poison hemlock mixed with weak stands of tall fescue (*Lolium arundinaceum* S.). The Higginsville location consisted of a Winfield silt loam (fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs) with soil pH of 6.6, and an organic matter content of 4.1%. Houstonia consisted of an Arispe silt loam (fine, smectitic, mesic Aquertic Argiudolls) with a pH of 6.5 and 5.6% organic matter. The soil at Columbia was an Armstrong loam (fine, smectitic, mesic Aquertic Hapludalfs) with a pH of 7.2 and 4.2% organic matter. At each location, 16 plants were randomly selected from natural populations and categorized into four different height ranges between 1.2 and 3.4 m. Height ranges were representative of plant height distribution from each population and varied by location and year (Table 2.2).

Selected plants were harvested on July 6 in 2006 and 2007, approximately 56 days after flowering began and roughly 1 to 2 weeks prior to plant senescence. This harvest time was selected to reduce loss from seed shattering. In addition, 16 plants were randomly selected 2 weeks prior to harvest at the Columbia location, and covered with light mosquito netting to eliminate seed loss. Seed production from these plants was compared to the original harvest method to determine if shattering was an issue. All plants were harvested by cutting near ground level and placed in paper bags. Plants were allowed to dry naturally for 1 to 2 weeks in a greenhouse environment. Seed was gathered from each plant by hand threshing and cleaned using sifting screens. Seed from each plant was quantified by establishing the mean weight of 100 seed for each plant, and dividing that into the total mass of seed produced per plant.

Seed counts were subjected to ANOVA using PROC GLM procedure in SAS (SAS 2003). The Shapiro-Wilk's test for normality and Bartlett's test for equal variance were performed using PROC UNIVARIATE and PROC GLM procedure in SAS at a $P \leq 0.05$. (SAS 2003). A log transformation was needed to ensure homogeneity of variance (Little and Hills 1978). Seed production means were separated using Fisher's Protected LSD at a $P \leq 0.05$.

Seed Germination and Viability. Additional seed from plants at Columbia and Houstonia locations were collected July 6, 2007 from randomly selected plants within the same populations explained above. Seed used for the germination and viability tests were separate from seed collected for determining seed production. The seed was bulked and placed in five mesh Shandon Tissue Specimen Bags[1] with mesh size of approximately 0.07 mm^2 to allow for gas and moisture exchange under natural field conditions. Bags were immediately tied to colored flags staked in the ground, laying on the soil surface with no cover at the respective locations in areas of mature poison hemlock. At 0, 18, 36,

[1] Thermo Electron Corporation, 81 Wyman Street, Walthom, MA 02454.

54 and 72 days after initial harvest, one specimen bag was collected from each location: Percent germination and viability of the seed was then measured. Germination tests for each group of seed collected consisted of 100 seed placed in Fisher Brand Petri[2] dishes with filter paper added, and replicated 4 times. Seeds were placed in a growth chamber at 24 C with a 14 hour photoperiod for approximately 90 days to evaluate seed germination. These environmental conditions correspond to the optimal temperatures for poison hemlock germination (Baskin and Baskin 1990). A seed was classified as germinated when the radical reached 2 mm in length. Germinated seedlings were counted 2 to 3 times per week, and dishes were kept moist by adding sufficient amounts of de-ionized water. To prevent fungi and bacteria growth on the seed, a 1% v/v solution of azoxystrobin-methyl was prepared and applied to each dish at 3 week intervals.

Viability of remaining seed was measured by location and collection date. Viability tests were performed by incubating dissected seed in a 0.02% tetrazolium solution at 36 C for two hours (Bradbeer 1992). Tetrazolium tests consisted of 50 random seeds from each location and collection date, replicated 3 times. Seeds were considered viable if the embryo possessed a pink to red tint following the tetrazolium test (Bradbeer 1992).

Cumulative germination and viability data were subjected to ANOVA using PROC GLM procedure of SAS (SAS 2003). The Shapiro-Wilk's test for normality was performed using PROC UNIVARIATE procedure in SAS at a $P \leq 0.05$ (SAS 2003). The Bartlett's test for equal variance was performed using PROC GLM procedure in SAS at a

[2] Fisher Scientific, 2000 Park Lane Drive, Pittsburg, PA 15275-9952.

$P \leq 0.05$ (SAS 2003). Germination and viability means were separated using Fisher's Protected LSD at a $P \leq 0.05$.

Results and Discussion

Seed Production. Seed shattering from plants prior to harvest and during harvest was an initial concern when developing this study. However, no significant interactions or main effect involving seed production from bagged or un-bagged plants were observed (data not shown). Therefore, it was concluded that little to no seed loss occurred during the time period between plant maturity and harvest, and during the harvest itself.

A significant two-way interaction between location and year occurred for seed production data. Therefore, data from all locations and years were analyzed separately. Central Missouri experienced unusually low nightly air temperatures ranging from -8 to -4 C between April 4 and 9, 2007 (Figure 2.1). Poison hemlock plants sustained frost injury, but plants recovered and resumed growth by mid-April. Across a range of plant heights (1.2 to 3.4 m), seed production per plant varied from 2,000 to 39,000 in 2006, and from 1,700 to 17,000 in 2007 (Figure 2.2). These data are consistent with reports that poison hemlock is capable of producing approximately 38,000 seed per plant (Whittet 1968). Overall, seed production was between 17 to 80% greater in 2006 than 2007, likely the result of the cold injury that plants sustained in April 2007. Taller plants (within range 4, 1.9 to 3.4 m) produced up to 91% more seed than plants within range 1 (1.2 to 2.4 m) in 2006 and 2007. Significant location main effects and overall differences in plant height were likely due to the different habitats and soils. Overall, Higginsville soils contained greater amounts of organic material (Table 2.1) and that location in 2006 produced greater amounts of seed (between 47 and 89% greater) than the Houstonia and Columbia locations. In 2007, Higginsville and Houstonia locations, consisting of silt loams and much greater levels of Phosphorous and Potassium (Table 2.1), overall produced between 49 and 61% greater amounts of seed than the Columbia location.

Seed Germination and Viability. There was no significant location interaction; therefore seed germination and viability data were pooled over location, and collection date means were separated using Fisher's Protected LSD at a $P \leq 0.05$ (Figure 2.3). Freshly harvested seed began germinating approximately 13 days after onset of incubating in Petri plate assays. Seed collected from the field at 18 days after harvest required approximately 18 days for germination (data not Shown). This is consistent with reports that poison hemlock seed requires approximately 15 days of suitable conditions following maturity to allow maturation of the embryo, ending MD and allowing germination to occur (Baskin and Baskin 1990). Seed collected at 36, 54 and 72 days after initial harvest resulted in emerged seedlings at 5, 6, and 3 days, respectively after onset of incubating in Petri plate assays. For seed collected at 0, 18 and 36 days after initial harvest, germination rates reached 85% at 39, 14, and 21 days, respectively. Seed collected at 54 and 72 days after initial harvest, germination rates reached 85% at 11 days (data not shown). Freshly harvested seed resulted in cumulative germination of 11% 90 days after onset of incubating in Petri plate assays (Figure 2.3). As the period in which seed lay dormant under field conditions lengthened, cumulative germination increased to a maximum of 34%.

Viability of seed across all collection dates ranged from 83 to 87%. Viable seed that did not germinate may require a vernalizing period to break MPD (Baskin and Baskin 1990). The remaining non-viable seed observed were shrunken or easily collapsed and were considered dead.

In summary poison hemlock is a very prolific and viable seed producer, depositing large amounts of seed into the soil seed bank. Seed production and overall plant height within poison hemlock populations may vary depending upon environmental conditions and soil properties. Natural stands of mature plants may reach densities of 27 plants/m^2 (Woodard and Smeda 2007); if each plant averages 20,000 seed, up to 540,000 seed may be deposited per m^2. This enables plants to establish in non-crop areas leading to invasion of pastures and rangelands (Panter et al. 1992). Large groups of seedlings emerging from seeds germinating under favorable conditions, and a variable germination rate over extended periods are factors which make poison hemlock difficult to control. Management methods should focus not only on eliminating growing rosettes, but also reducing seed production and seedling germination.

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Table 2.1. Properties of soils from three locations in central Missouri used to determine seed production of poison hemlock.

Location	Soil series	Bray 1 - P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	pH	Organic matter	Sand	Silt	Clay	Texture
							---------------%---------------				
Higginsville	Winfield	478	4399	795	1714	6.6	4.1	17.5	57.5	25	Silt loam
Houstonia	Arispe	216	5243	444	1103	6.5	5.6	22.5	65	12.5	Silt loam
Columbia	Armstrong	34	5897	386	450	7.2	4.2	27.5	47.5	25	Loam

Table 2.2. Plant height ranges for each population of poison hemlock from three Missouri locations in 2006 and 2007.

	Plant height at harvest (m)					
	Higginsville		Houstonia		Columbia	
Range	2006	2007	2006	2007	2006	2007
1	2.1 to 2.3	1.2 to 1.4	1.5 to 1.7	1.2 to 1.4	1.5 to 1.7	1.2 to 1.4
2	2.4 to 2.6	1.5 to 1.7	1.8 to 2.0	1.5 to 1.6	1.8 to 2.0	1.5 to 1.6
3	2.7 to 2.9	1.8 to 2.0	2.1 to 2.3	1.7 to 1.8	2.1 to 2.3	1.7 to 1.8
4	3.0 to 3.4	2.1 to 2.4	2.4 to 2.7	1.9 to 2.1	2.4 to 2.7	1.9 to 2.1

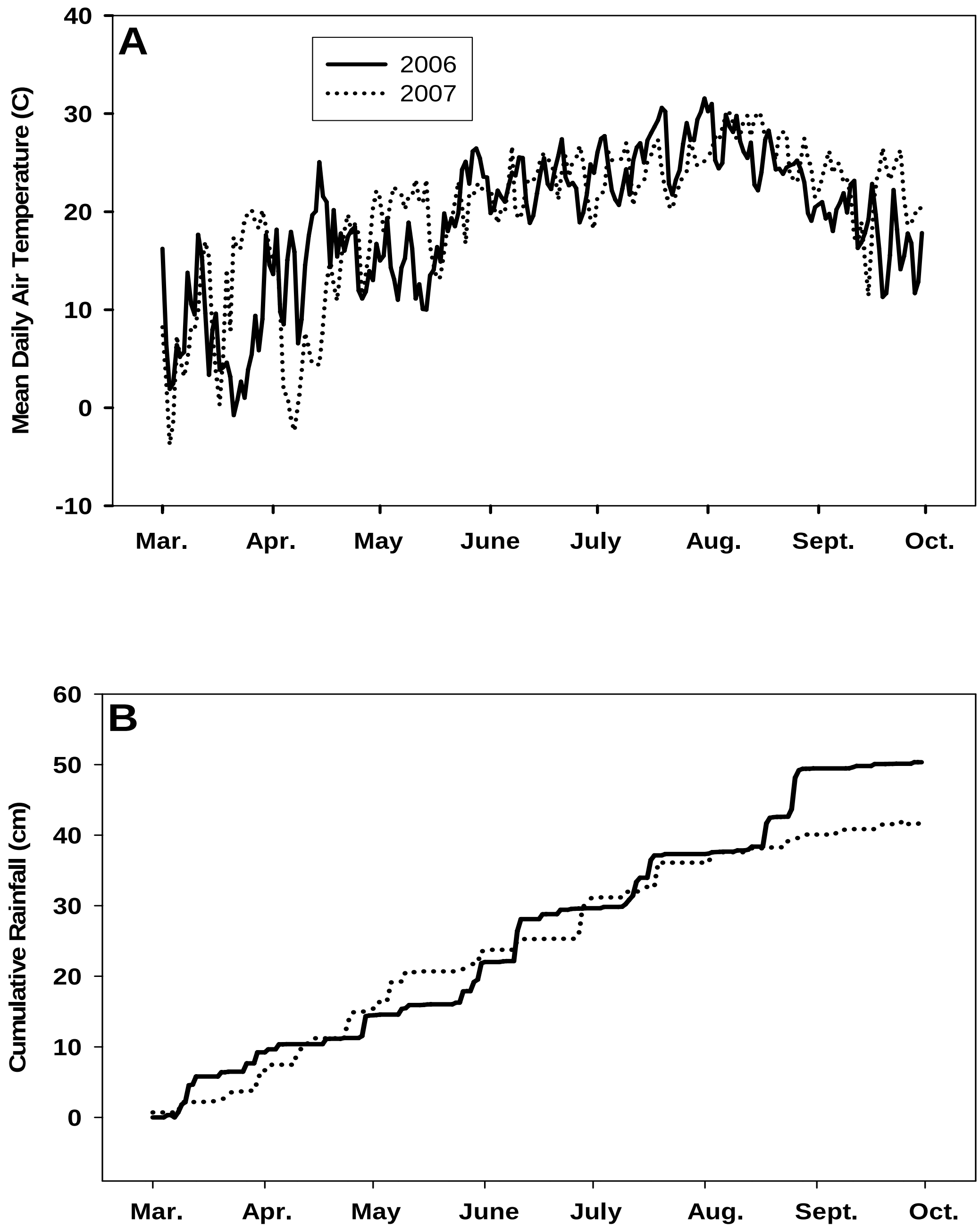
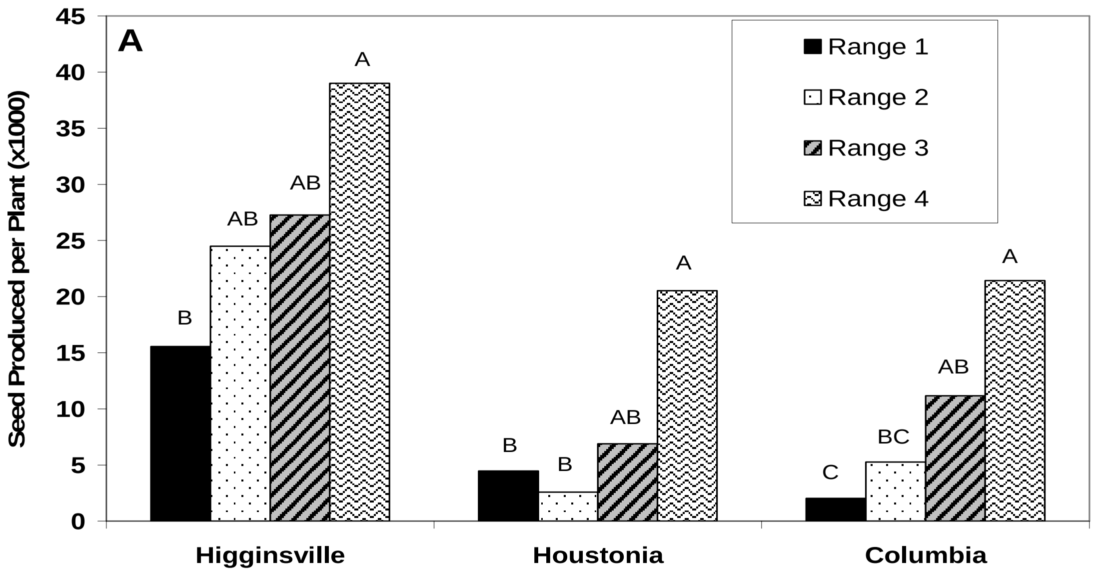


Figure 2.1. Mean daily air temperature (A) and cumulative rain fall (B) for central Missouri during the trial period in 2006 and 2007. Data obtained from a weather station at the University of Missouri Bradford Research and Extension Center near Columbia, Missouri.



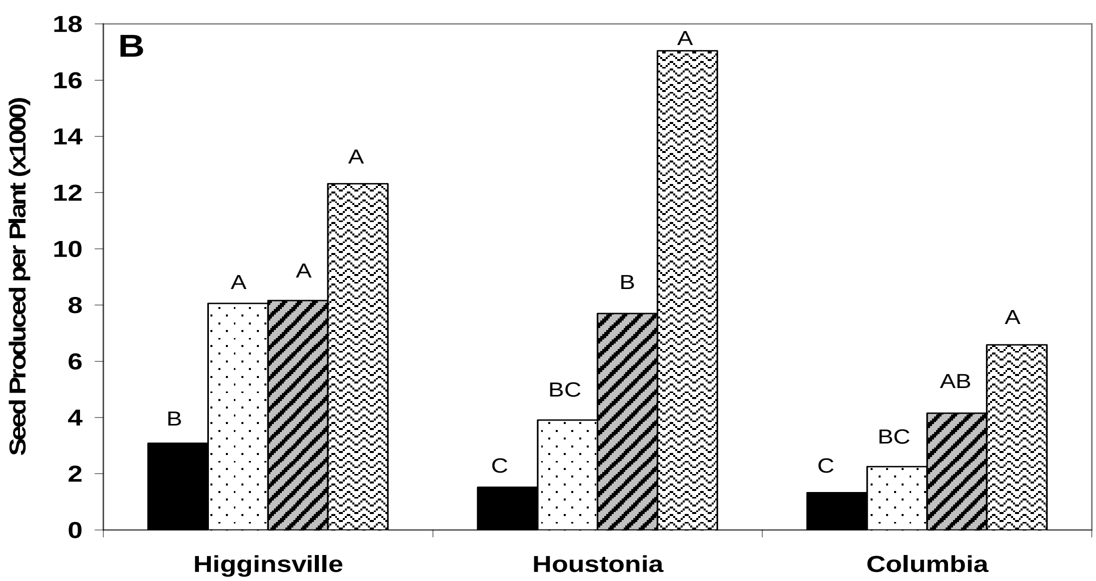


Figure 2.2. Poison hemlock seed production per plant in Missouri in 2006 (A) and 2007 (B) by location and plant height ranges (between 1.2 to 3.4 m; see Table 2.1). Bars with similar letters within a location are not significantly different according to Fisher's Protected LSD at a $P \leq 0.05$.

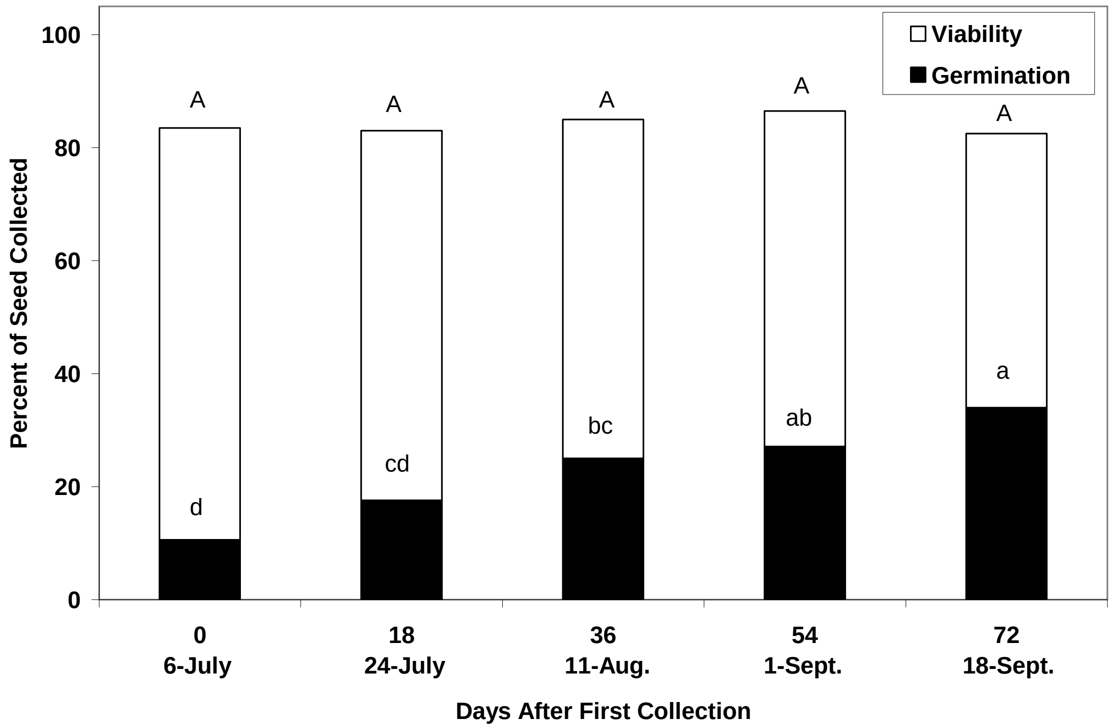


Figure 2.3. Mean viability and germination of seed (combined over locations) collected different times after maturity from poison hemlock populations in central Missouri in 2007. Letters above bars represent significant differences in either viability or germination means according to Fisher's Protected LSD at $P \leq 0.05$.

CHAPTER III

Biomass Production of Poison Hemlock (*Conium maculatum* L.) and Potential Risk to Cattle (*Bos Taurus* L.)

Carl A. Woodard [*]

Abstract. Poison hemlock is a biennial plant commonly found along roadsides and pastures throughout the United States. Of great concern is its toxicity to livestock when ingested, particularly pregnant cattle. A field study was conducted at two sites in central Missouri in spring 2007 to determine the impact of poison hemlock density on biomass production over time. Plant densities included 1, 3, 9, and 27 plants/m^2, and above ground tissue were harvested March 15, April 1, April 15, May 1 and May 15. On a per hectare basis, dry biomass production for both locations at densities of 1, 3, 9 and 27 plants/m^2 ranged from 13 to 946 kg, 17 to 2,644 kg, 60 to 3,656 kg, and 115 to 3,464 kg, respectively, between mid-March and mid-May. Dry biomass production was strongly correlated ($R^2 \geq 0.98$) with days after initial harvest and increased exponentially over time. Considering typical daily dry matter intake for cows weighing approximately 500 kg, and typical short term stocking rates in Missouri (2.5 to 6 cows/ha), only 1 and 2.4 kg/ha/d of poison hemlock (dry weight basis) would be necessary for a lethal dose,

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respectively. The minimum thresholds for toxic levels of poison hemlock in early spring were exceeded for all plant densities studied.

Nomenclature: poison hemlock, *Conium maculatum* (L.) COIMA.

Key Words: biennial, invasive, livestock poisoning, pasture, plant density, roadside.

Introduction

Poison hemlock is a member of the *Apiaceae* family and was introduced into the United States from Europe in the 1800's (Holm et al. 1997; Mitich 1998). Poison hemlock grows in relatively undisturbed areas with adequate moisture and nutrients; including roadsides, pastures and other non-crop areas (Mitich 1998; Tucker et al. 1964).

Poison hemlock is a biennial that grows 1 to 3 m in height and possesses a deep taproot. Notable characteristics for identification include: fine, pinnatified leaves; an umbrella-like inflorescence; and the stems of bolting plants are mottled with purple blotches (Holm et al. 1997; Tucker et al. 1964; Uva et al. 1997). Germination of seedlings occurs in the fall and early spring (Pokorny and Sheley 2001). Plants will grow as a rosette until an extended cold period triggers bolting the following spring. Flowering initiates in mid-May and plants mature by mid- to late-June (Baskin and Baskin 1990).

In the U. S., poison hemlock is considered a noxious weed in: CO, ID, IA, NV, NM, OH, OR and WA (USDA 2008). Poison hemlock is reportedly a problem in as many as nine crops in 34 different countries, but it is most commonly identified as a problem weed in pastures in the U.S. (Holm et al. 1997).

The most notable aspect of poison hemlock concerns its toxicity when ingested by animals. Eight poisonous alkaloids are produced and found in all plant parts. Of these, the piperidine alkaloids coniine and γ-coniceine are the most abundant and lethal (Panter et al. 1988b). Alkaloid concentrations vary within the plant depending upon environmental conditions, time of year and geographical location (Panter et al. 1988b).

Fairbairn and Challen (1959) reported that the alkaloid concentration in poison hemlock is lowest following emergence through formation of small rosettes.

There have been numerous reports of domesticated livestock poisoning following ingestion of poison hemlock (Holm et al. 1997). Poisoning will not always result in death but rather milk production and quality may be reduced, weight gain slowed and congenital affects in offspring induced (Holm et al. 1997). Symptoms of poisoning include nervousness, trembling, difficulty moving limbs, irregular heartbeat, frequent urination, nausea, convulsions, heavy salivation and respiration, and lower body temperature (Forsyth 1968; Kingsbury 1964). Sensitivity to poisoning varies among animals, with cattle the most sensitive, followed by goats (*Capra aegagrus hircus* L.) and sheep (*Ovis aries* L.), and pigs (*Sus scrofa* L.) the least sensitive (Holm et al. 1997). Consumption of fresh plant material by pregnant cows at a daily dose of 5.3 g/kg of body weight (BW) over 25 days resulted in death (Keeler and Balls 1978; Panter et al. 1988a).

Poison hemlock plants remain green in pastures into the late fall and resume growth again in late winter (Panter and Keeler 1988). During this time, poison hemlock may be the only green forage available and large amounts may be ingested by cattle (Case 1969). If desirable vegetation is available, animals avoid eating poison hemlock unless forced. However, when plant tissue is harvested with alfalfa for hay, animals lack the ability to discriminate (Jeffery and Robison 1990). Recently in Missouri a case of livestock poisoning from ingestion of poison hemlock occurred during spring of 2005. Five heifer calves, each weighing approximately 230 kg ingested fatal amounts of poison hemlock, as was evident upon a post-mortem examination (Burton 2005).

Although research data regarding the toxic concentration of poison hemlock on a tissue weight basis are available, information linking the biomass produced under field conditions is lacking. These data may establish poison hemlock plant thresholds in areas used for cattle grazing. The objective of this research was to determine poison hemlock above ground biomass production for a given area at various plant densities during the spring growing season. In addition, previous research regarding animal toxicity was incorporated into this study to determine lethal poison hemlock plant thresholds.

Materials and Methods

Two locations in central Missouri were selected for this study; Columbia and Houstonia. Each location was along a roadside with established stands of poison hemlock. Soil properties from each location are displayed in Table 3.1. The soil at Columbia was an Armstrong loam (fine, smectitic, mesic Aquertic Hapludalfs) with a pH of 7.2 and 4.2% organic matter; Houstonia was an Arispe silt loam (fine, smectitic, mesic Aquertic Argiudolls) with a pH of 6.5 and 5.6% organic matter. At each location, plant densities of 1, 3, 9 and 27 plants in 1 m^2 plots were established by hand thinning natural stands. Five plots were maintained for each density, so that biomass could be measured at five different intervals throughout the spring. Selected plant densities were based upon counts taken from natural populations of poison hemlock from both locations the previous spring. Plant densities were established initially in mid-February 2007 and maintained weekly throughout the study. Other plant species within the plots were manually removed weekly to prevent competition. The study was designed as a randomized complete block with 5 replications. Plants were harvested March 15, April 1, April 15, May 1 and May 15. March 15 was chosen as the initial harvest because this corresponds with the time period in Missouri when livestock owners typically reduce or stop feeding hay in the early spring, persuading cattle to begin grazing pastures. Harvest intervals extended to mid-May to represent the time when initial baling of hay occurs. At the designated harvest dates, plants in each plot were harvested by cutting all tissue at ground level. Fresh weight of tissue was recorded and samples were placed in a drying oven for 4 days at 60 C at which time dry weights (DW) were then recorded.

All data were combined and subjected to ANOVA using PROC GLM procedure of SAS (SAS 2003) to determine if data could be pooled over location. Normality and residual tests were performed using PROC UNIVARIATE procedure of SAS (SAS 2003) with a $P \leq 0.05$. Biomass means, by harvest date, were separated using a Fisher's Protected LSD with a $P \leq 0.05$. A logarithmic transformation of plant DW data was used to ensure homogeneity of variances (Little and Hills 1978). Means of DW data were converted into kg/ha and subjected to a regression analysis, by plant density, using a two parameter single exponential growth curve (SigmaPlot 2004):

$$y = a\left(e^{(bx)}\right) \qquad [1]$$

where *y* equals plant biomass produced and *x* equals the time in days after the initial harvest on March 15. The parameters are represented by *a* and *b*; *a* is related to the biomass produced and *b* represents an intrinsic rate of biomass increase per day. The constant *e* represents the exponential function which is the inverse of a natural log (Hunt 1990). Paired t-tests ($t_{0.025}$) (Kaps and Lamberson 2004) were performed to determine if mean biomass at all harvest dates and plant densities were different than lethal poison hemlock plant thresholds.

Results and Discussion

At the initial harvest date (March 15), poison hemlock plants were in the rosette stage, approximately 6 cm in height. By May 15, plant heights ranged from 0.75 to 1.2 m and were in pre-flower stage (data not shown). There was a significant location by plant density by harvest date interaction for biomass production; therefore, data were analyzed separately for each location and harvest date.

Central Missouri experienced unusually low nightly air temperatures ranging from -8 to -4 C between April 4 and 9, 2007. The plants sustained partial vegetative tissue loss, but re-growth occurred shortly after temperatures increased. Mean daily air temperature and cumulative precipitation for Columbia and Houstonia over the course of the study are shown in Figure 3.2.

The biomass of poison hemlock correlated with days after harvest ($R^2 \geq 0.98$ for all plant densities) and increased exponentially from March through May (Figures 3.2 and 3.3). Overall, biomass production from plants at Houstonia was approximately 47% greater than Columbia; likely the effect of different soil properties. Houstonia soils had greater levels of Phosphorous and Potassium and more organic material than the Columbia soils (Table 3.1). Poison hemlock growth at all densities was somewhat slow through March and early April, ranging from 13 to 490 kg DW/ha at Columbia and 14 to

867 kg DW/ha at Houstonia. However, growth increased greatly after April 15, resulting in up to 1,657 kg DW/ha at Columbia and 3,464 kg DW/ha at Houstonia in mid-May.

The toxicity of poison hemlock depends upon the amount of tissue ingested. Keeler and Balls (1978) reported that for a 425 kg pregnant cow that 2.3 kg of fresh poison hemlock ingested per day (5.3 g/kg of BW/d), over a 25 day period, was lethal. Since this research was conducted, the mature size of beef cows in the U. S. has increased to approximately 500 kg (R. L. Kallenbach, personal communication[3]). Thus, the lethal dose for a typical cow today is likely 2.7 kg of fresh poison hemlock per day for 25 days. Poison hemlock plants in this study averaged 85% moisture; therefore, a mature cow would need to consume a daily minimum of 0.4 kg of poison hemlock on a dry matter basis for a lethal dose. Dry matter intake for an early lactation beef cow is approximately 2.5% of BW, or for a 500 kg cow, 12.5 kg/d (NRC 2000). Typical stocking rates in the Midwest, or number of cows per given area, are between 2.5 to 6 cows/ha/d (Gerrish and Roberts 1999). Thus, using the lowest short term stocking rate, (2.5 cows/ha/d) and a dry matter intake of 12.5 kg/cow/d, there is a potential dry matter intake of 31.3 kg/ha/d. If 0.4 kg/cow is the daily lethal dose and there are 2.5 cows/ha, a minimum of 1 kg/ha of poison hemlock (DW) available each day would be enough to provide a lethal dose (Figures 3.2 and 3.3). Using the highest short term stocking rate (6 cows/ha/d) and the same daily dry matter intake per cow, the potential dry matter intake from the pasture is 75 kg/ha/d. At this higher stocking rate, about 2.4 kg/ha of poison hemlock (DW) would be needed daily to provide a lethal dose to a mature cow. In short, the lethal amount of

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poison hemlock ingested by cattle is slightly more than 3% of the animal's daily dry matter intake.

When comparing minimum lethal doses of poison hemlock to actual biomass production from both locations, all biomass means exceeded the minimum threshold for both stocking rates. Biomass production from both locations after April 1 significantly exceeded the minimum thresholds. Plant biomass at Columbia at densities of 1 and 3 plants/m^2 in early April showed no statistical difference compared to the minimum threshold at the high stocking rate, but was significant compared to the low stocking rate. During mid-March, biomass from Columbia at 1 and 3 plants/m^2 and Houstonia at 1 plant/m^2 showed no statistical difference compared to the minimum lethal threshold for both stocking rates. However biomass means (March 15) from Columbia at densities of 9 and 27 plants/m^2, and from Houstonia at 3, 9 and 27 plants/m^2 were statistically greater than the minimum thresholds at both stocking rates. In Missouri, cattle typically begin grazing pastures in mid-April (Wen et al. 2002), when most cool season grasses and legumes are initiating new growth (Strieker et al. 1979). Poison hemlock is actively growing in mid-March, which is approximately 2 to 4 weeks earlier than available biomass from cool season grasses and legumes (Strieker et al. 1979).

Contamination of hay is an issue considering the toxicity of poison hemlock (Jeffery and Robison 1990), as well as the biomass produced in early- to -mid-May, a time period when the first cutting of hay is made in Missouri (Henning and Nelson 1993; Henning 2000). With potentially large amounts of poison hemlock biomass produced during the cutting and harvesting of hay, contamination of hay is likely. It is known that alkaloid amounts decrease in poison hemlock as the plants dry, however substantial concentrations of piperidine alkaloids may still be present (Keeler and Balls 1978).

In summary, DW production of poison hemlock exceeded the minimum lethal threshold for cattle at all plant densities beginning in mid-March, and increased exponentially through mid-May. Currently there is no minimum threshold level for poison hemlock in pastures. Management practices that eliminate poison hemlock infestations in pastures, or isolation of these pastures from grazing cattle or hay production should be implemented by cattle owners to ensure the safety of their herds.

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Table 3.1. Properties of soils from two locations in central Missouri used to determine growth of poison hemlock.

Location	Soil series	Bray 1 - P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	pH	Organic matter	Sand	Silt	Clay	Texture
							--------------------%--------------------				
Houstonia	Arispe	216	5243	444	1103	6.5	5.6	22.5	65	12.5	Silt loam
Columbia	Armstrong	34	5897	386	450	7.2	4.2	27.5	47.5	25	Loam

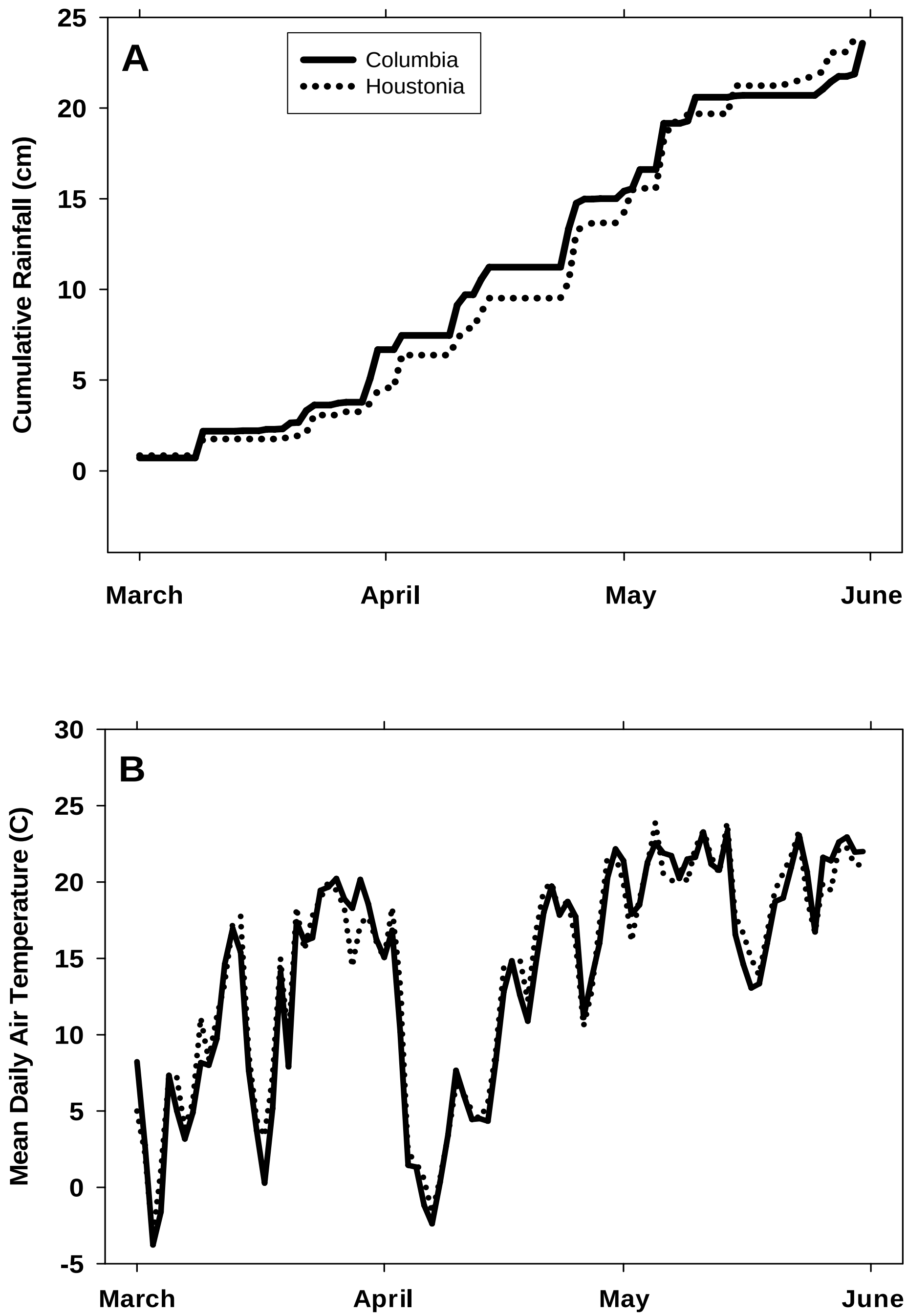

Figure 3.1. Cumulative rainfall (A) and mean daily air temperature (B) for Columbia and Houstonia, Missouri in 2007. Rainfall and temperature data collected from weather stations at the Bradford Research and Extension Center, Columbia and Shores of Tabo Creek, Higginsville.

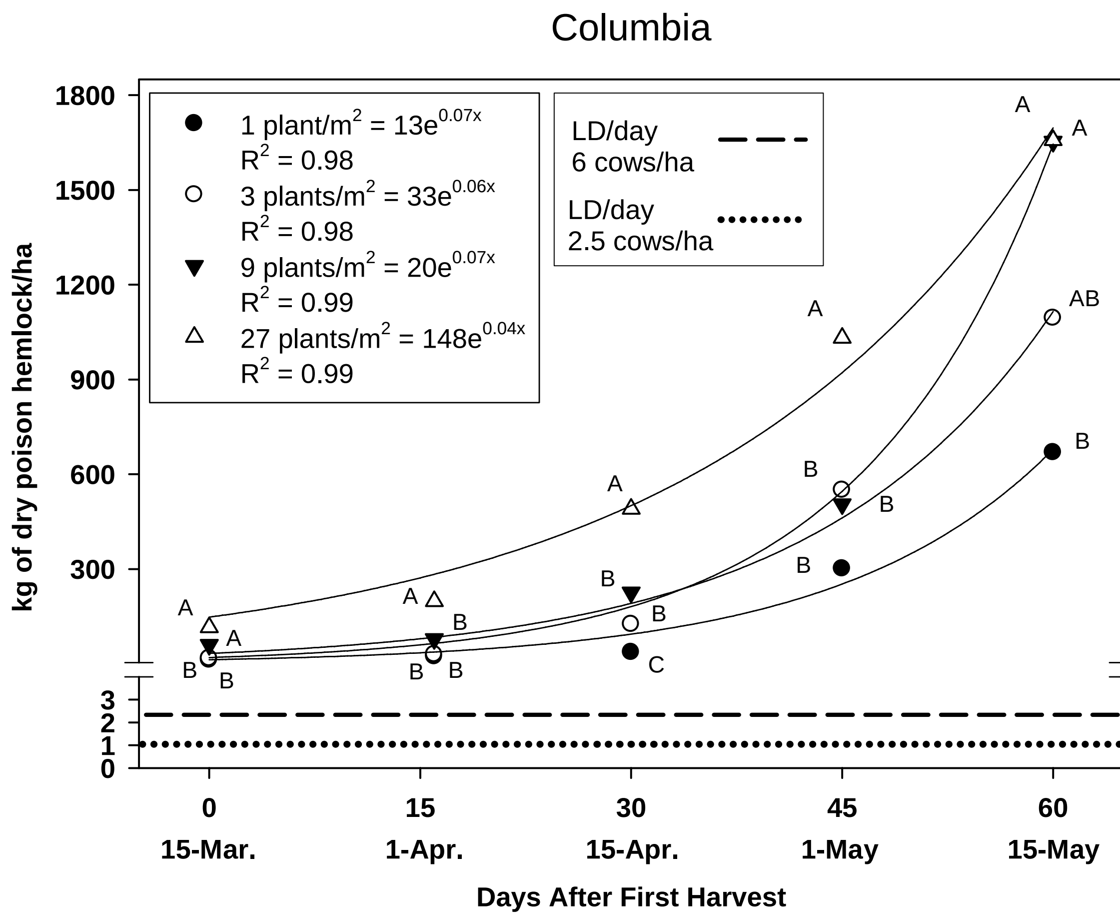

Figure 3.2. Mean dry weight of poison hemlock above ground biomass for 1, 3, 9, and 27 plants/m^2 from Columbia, Missouri. Dashed (2.4 kg) and dotted (1 kg) lines represent the daily lethal amount of poison hemlock needed for a 500 kg cow at stocking rates of 2.5 and 6 cows/ha, respectively. Different letters within each harvest interval represent significant differences according to Fisher's Protected LSD, P $\leq$ 0.05.

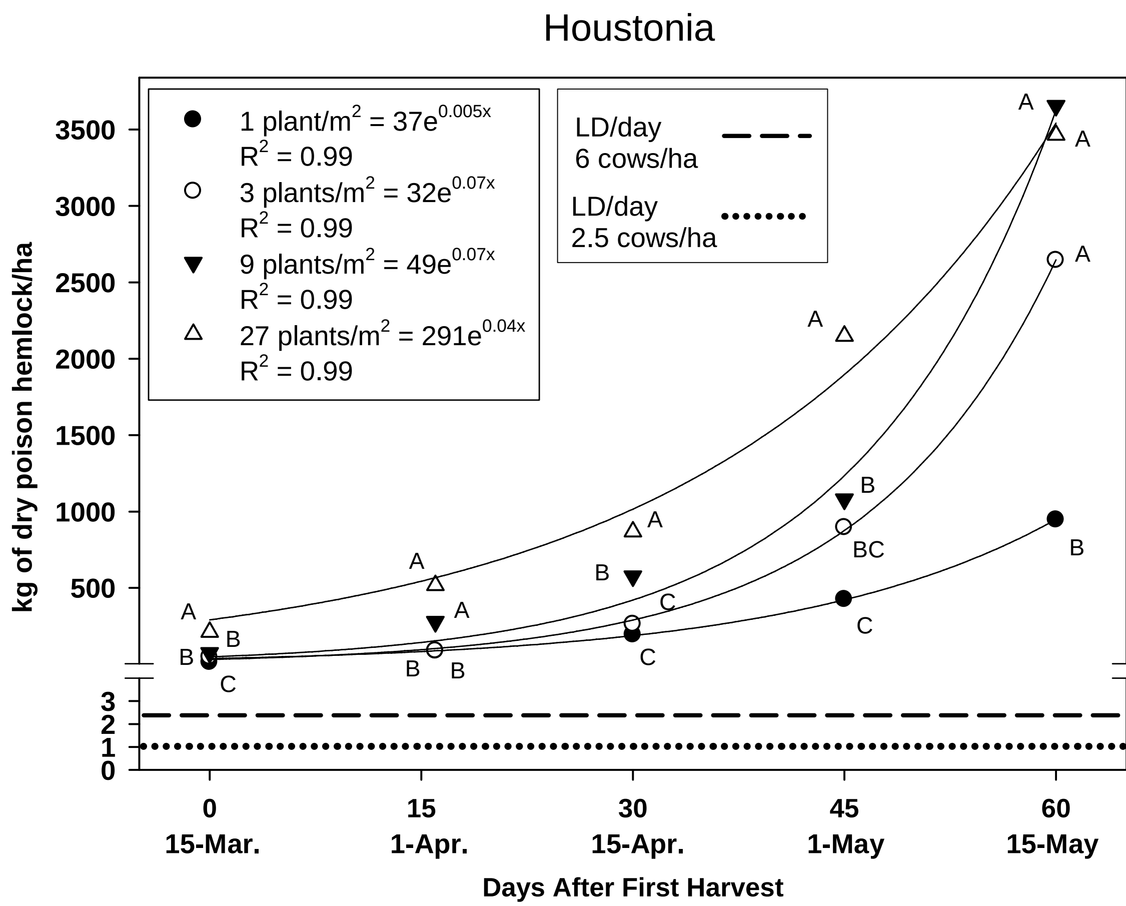

Figure 3.3. Mean dry weight of poison hemlock above ground biomass for 1, 3, 9, and 27 plants/m^2 from Houstonia, Missouri. Dashed (2.4 kg) and dotted (1 kg) lines represent the daily lethal amount of poison hemlock needed for a 500 kg cow at stocking rates of 2.5 and 6 cows/ha, respectively. Different letters within each harvest interval represent significant differences according to Fisher's Protected LSD, P $\leq$ 0.05

CHAPTER IV

Chemical Management of Poison Hemlock (*Conium maculatum* L.)

Carl A. Woodard [*]

Abstract. Poison hemlock is an invasive, biennial weed commonly found in pastures and along roadsides in Missouri. In the United States, poison hemlock is considered noxious in eight states, yet little information is available regarding the control of this species with herbicides. Field trials were established at two locations in Missouri in 2006 and 2007 to evaluate spring applied herbicides for the control of emerged rosettes as well as soil residual activity. Poison hemlock injury was assessed visually 2, 4 and 8 weeks after treatment (WAT). Seedling emergence was monitored in selected treatments at 2, 4, 8, 12 and 24 WAT. Chlorsulfuron, imazapic, imazapic plus glyphosate, metsulfuron and metsulfuron plus 2,4-D plus dicamba resulted in 84 to 100% control of poison hemlock rosettes 8 WAT. Control of poison hemlock with the growth regulator herbicides was erratic (triclopyr, picloram plus 2,4-D, and 2,4-D alone) at 26 to 98% control or ineffective (dicamba plus diflufenzopyr, and aminopyralid) at 0 to 51% control. Herbicides with residual soil activity (imazapic, chlorsulfuron, metsulfuron, triclopyr plus clopyralid, aminopyralid and picloram plus 2,4-D) reduced seedling emergence up to 71% compared to herbicides with no residual activity through 12 WAT. However,

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residual herbicide activity declined thereafter, with fall emergence of seedlings 26 to 82% greater at 24 WAT compared to 12 WAT. Several herbicides adequately controlled poison hemlock when applied in the spring, but continued emergence through the fall requires sequential herbicide applications to minimize re-infestations.

Nomenclature: Aminopyralid, 4-amino-3, 6-dichloropyridine-2-carboxylic acid; chlorsulfuron; clopyralid; dicamba; diflufenzopyr, 2-(1-[([3,5-difluorophenylamino] carbonyl)-hydrazono]ethyl-3-pyridinecarboxylic acid; imazapic; metsulfuron; picloram; triclopyr; 2,4-D; poison hemlock, *Conium maculatum* (L.) COIMA.

Key Words: Herbicide, invasive, pasture, roadside.

Introduction

Poison hemlock (*Conium maculatum* L.) is an invasive, biennial weed introduced into the United States from Europe as an ornamental plant (DiTomaso 1999; Holm et al. 1997; Kingsbury 1964). Poison hemlock invades roadsides, riverbanks, waste areas, pastures and other non-crop environments (Mitich 1998), often out-competing thin stands of established species (Holm et al. 1997). Poison hemlock is found in many states and plants are considered noxious in CO, ID, IA, NV, NM, OH, OR and WA (USDA 2008).

Poison hemlock is a biennial, with mature plants reaching 1 to 3 m in height, and anchored by a deep taproot (Holm et al. 1997; Tucker et al. 1964; Uva et al. 1997). This growth habit enables plants to dominate surrounding vegetation. Optimum air temperatures for poison hemlock germination are between 17 and 29 C (Baskin and Baskin 1990), allowing early spring and late fall emergence. Germination of seedlings may occur all year depending upon moisture and temperature conditions (Baskin and Baskin 1990; Pokorny and Sheley 2001). In Missouri, peak emergence of seedlings typically occurs in April through early June as well as September through November, with little to no emergence during the summer and winter months (Woodard and Smeda 2006). Plants grow as rosettes after emergence until a vernalization period induces bolting and flowering (Baskin and Baskin 1990). Poison hemlock produces up to 38,000 seeds per plant (Whittet 1968), and seeds may remain viable in the soil for up to two years (Baskin and Baskin 1990).

Poison hemlock is extremely toxic to livestock if ingested, thus justifying control in pasture environments (Holm et al. 1997; Panter and Keeler 1988). Poison hemlock plants are photosynthetically active during the late winter and early spring when air temperatures may be rather low, making plants difficult to control (Panter and Keeler 1988). In the late spring or early fall, poison hemlock can invade perennial forage crops such as alfalfa (*Medicago sativia* L.), and contaminate hay (Jeffery and Robison 1990). Poison hemlock has also been reported as a problem in as many as nine crops, including vegetable crops and orchards, in 34 different countries (Holm et al. 1997). In addition, the presence of poison hemlock along highway right-of-ways and intersections may reduce driver visibility due to the tall growing stalks (Rand Swanigan, personal communication[4]).

Management strategies for poison hemlock are necessary to reduce or eliminate the potential for livestock poisoning (DiTomaso 1999). Current management techniques include repeated cultivation or mowing, and the use of herbicides (DiTomaso 1999). Repeated cultivation prevents establishment of poison hemlock seedlings and repeated mowing depletes carbohydrates in the taproot, thus eliminating seed production (Panter and Keeler 1988; Smith et al. 1982). Chemical control is reportedly an effective method used to manage poison hemlock infestations in habitats where mowing or cultivation are difficult (Jeffery and Robison 1990; Nice et al. 2005). Glyphosate, glyphosate plus S-metolachlor, rimsulfuron plus thifensulfuron, metsulfuron, sulfometuron plus metsulfuron, chlorsulfuron, 2,4-D, 2,4-D plus picloram and dicamba are herbicides currently labeled for control (CPCR 2006). Dicamba, 2,4-D, 2,4-D plus triclopyr, and glyphosate have resulted in adequate control of poison hemlock when applied on small rosettes (Nice et al. 2005). When applied in the rosette stage, glyphosate at 1.12 kg ae/ha resulted in excellent control ($\geq$ 90%) (Jeffery and Robison 1990). DiTomaso (1999)

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reported that acetolatate synthase inhibitors (ALS) such as chlorsulfuron and metsulfuron alone or in combination resulted in excellent preemergence (PRE) and postemergence (POST) control of rosettes. Effective PRE herbicides for poison hemlock control include hexazinone at 1.68 kg ai/ha, metribuzin at 1.12 kg ai/ha and terbacil at 1.12 kg ai/ha (Jeffery and Robison 1990).

Despite label recommendations, little research has been conducted on the effectiveness of various herbicides and application timings on poison hemlock control. The objectives of this research were to evaluate spring application of herbicides for the control of established poison hemlock rosettes and subsequent control of seedling emergence.

Materials and Methods

Field trials were established at Columbia and Higginsville, Missouri in the spring of 2006, and at Bolivar and Higginsville, Missouri in the spring of 2007. The habitat was a roadside or pasture situation with stands of established poison hemlock. Each location contained weak stands of tall fescue (*Lolium arundinaceum* S.) following years of infrequent mowing. The Higginsville location included a Winfield silt loam (fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs) with a soil pH of 6.7 and organic matter of 5.9% in 2006 and a soil pH of 6.6 and organic matter of 4.1% in 2007. The Columbia location consisted of an Armstrong loam (fine, smectitic, mesic Aquertic Hapludalfs) with a pH of 7.2 and 4.2% organic matter. The Bolivar location consisted of a Racket silt loam (fine-loamy, mixed, superactive, mesic Cumulic Hapludolls) with a pH of 5.8 and organic matter of 4.8%. Trials were arranged in a randomized complete block design with four replications, with plot sizes of 3 by 6 m at Bolivar and Higginsville, and 2.3 by 3 m at Columbia. Plot sizes were smaller at Columbia because of the limited area infested with poison hemlock at that location. Fourteen treatments were applied at each location, including an untreated control (Table 4.1). Most of the herbicides applied were labeled for poison hemlock or recommended for control of broadleaf weeds in roadside or pasture habitats. Rates applied were based upon label recommendations for poison hemlock or a similar biennial weed. Application dates and weather conditions at the time of treatment are presented in Table 4.2. Weather conditions were recorded by a Kestral® 3000[5] pocket weather station. Soil temperature was registered by a portable temperature probe. In 2007, Missouri experienced unusually low night temperatures (3 nights of < -3 C) in early April, which damaged much of the plant tissue. Application dates for 2007 were delayed to allow frost damaged plants to initiate new vegetative growth. Applications were made using a CO_2 backpack sprayer at a speed of 4.8 km/hr and TeeJet[6] 8002 nozzle tips at a total spray volume of 140 L/ha. Plants treated were in the rosette or pre-bolting stage and ranged from 13 to 46 cm in height.

Herbicide effectiveness was determined by visual evaluation of plant injury. Evaluations were recorded 2, 4, and 8 weeks after application. A percent rating scale of 0 to 100 was used for the evaluation of treated plants compared to the untreated control, where 0 represented no control and 100 represented complete control.

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[5] Kestral® 3000. Forestry Suppliers, INC. 205 West Rankin Street Jackson, Mississippi, 39201
[6] TeeJet XR Spraying Systems CO., North Ave., Wheaton, IL 60188.

For select treatments (2,4-D, aminopyralid, picloram plus 2,4-D, imazapic, metsulfuron, triclopyr plus clopyralid, glyphosate, and chlorsulfuron), poison hemlock seedling emergence was monitored. These treatments were selected based upon soil persistence and residual activity characteristics. The glyphosate treatment was utilized as a control due to the lack of residual activity and strong, rapid adsorption to soil particles when used at labeled rates (WSSA 1994; Monaco et al. 2002). Within treated plots, two 0.3 by 0.3 m quadrants were marked with colored flags for repeated estimation of emerging poison hemlock seedlings. Within the quadrants, emerged poison hemlock seedlings were counted at 2, 4, 8, 12 and 24 weeks after initial herbicide application. Once counted, paraquat at 1.17 kg ai/ha plus crop oil concentrate at 1% v/v was applied broadcast to remove existing seedlings and allow for additional emergence. All data were subjected to ANOVA using the PROC GLM (percent control data) or PROC MIXED (seedling emergence data) procedure in SAS (SAS 2003). Normality was assessed using the PROC UNIVARIATE procedure of SAS with a $P \leq 0.05$ (SAS 2003). The Bartlett's test for equal variance was performed on the percent control data using the PROC GLM procedure in SAS (SAS 2003). Equal variance was tested on the seedling emergence data by plotting the residuals using PROC UNIVARIATE procedure in SAS (SAS 2003). A logarithmic transformation of the seedling emergence data was needed to ensure homogeneity of variance (Little and Hills 1978). Treatment means were converted to seedlings/m^2 and separated using Fisher's Protected LSD at $P \leq 0.05$.

Results and Discussion

There were significant two and three-way interactions among locations, treatments, and the time of evaluation. Therefore, poison hemlock control is presented separately by times and locations.

Two weeks after treatment (WAT) in 2006 and 2007, control of poison hemlock ranged from 0 to 89% (Table 4.3). Overall control of poison hemlock at 2 WAT was greater in 2007 (mean of 59%) than 2006 (mean of 26%). This is likely the combined result of herbicide activity and frost damage to plant tissue in 2007. The metsulfuron plus 2,4-D plus dicamba and glyphosate treatments both resulted in the greatest control of poison hemlock for all 4 site years at 2 WAT (44 to 89%).

Overall control of poison hemlock 4 WAT was greater than control 2 WAT (Table 4.4). Herbicide activity in 2007 was greater than the activity in 2006, which was likely the lingering effect of frost-damaged plants. The use of ALS herbicides, such as imazapic, imazapic plus glyphosate, chlorsulfuron, metsulfuron or metsulfuron plus 2,4-D plus dicamba, resulted in $\geq$ 86% control in 2007 at 4 WAT. In 2006, control with these herbicides ranged from 39 to 74%. Control with glyphosate alone ranged from 68 to 95% in 2006 and 2007. In 2007, the growth regulators triclopyr, triclopyr plus clopyralid, and picloram plus 2,4-D ranged from 79 to 93%. In 2006, these same herbicides provided 41 to 61% poison hemlock control. The herbicides 2,4-D, aminopyralid, and dicamba plus diflufenzopyr provided less than 45% control by 4 WAT.

Herbicide activity on poison hemlock was fully evident 8 WAT (Table 4.5). In 2006 and 2007, treatments that included an ALS-inhibiting herbicide resulted in 84 to

100% control of poison hemlock (Table 4.5). By 8 WAT, glyphosate efficacy was erratic, with control ranging from 65 to 96% in 2006 and 2007. The growth regulators triclopyr, triclopyr plus clopyralid, and picloram plus 2,4-D resulted in greater than 88% control in 3 of 4 site years. Control with 2,4-D alone ranged from 26 to 68%. Elimination of viable seed production was observed when herbicides provided approximately 90% or greater control of poison hemlock plants at 8 WAT. Aminopyralid, a new pasture and roadside product, was ineffective on poison hemlock resulting in control ranging from 5 to 51%. This level of control was consistent with reports that aminopyralid is ineffective on plants within the *Apiaceae* family (Hartzler 2006). Dicamba plus diflufenzopyr resulted in control less than 26%. Many of the herbicides evaluated in this study are labeled for use in established grass pastures (CPCR 2006). However, in pastures containing legumes such as alfalfa, broadcast applications on poison hemlock should be made before desirable legumes break winter dormancy or as a spot application (Jeffery and Robison 1990).

There was no significant location by timing by treatment interaction for poison hemlock seedling emergence data; therefore, data are combined over site years (Table 4.6). For all treatments, emergence of poison hemlock seedlings was greatest 2 and 24 WAT which corresponded to cooler parts of the growing season. Periods when air temperatures are below 29 C and above 17 C (typically spring and fall) are optimum for poison hemlock emergence (Baskin and Baskin 1990; Woodard and Smeda 2006). No treatment completely eliminated poison hemlock emergence at any evaluation period. However, when comparing the herbicide treatments to glyphosate, several treatments significantly reduced seedling emergence 2, 8, and 24 WAT. The ALS-inhibiting herbicides chlorsulfuron and metsulfuron reduced poison hemlock emergence from 19 to 71% compared to glyphosate across all evaluation periods. The relative soil half-life of chlorsulfuron and metsulfuron in soil is approximately 30 to 40 days, respectively (Monaco et al. 2002; Walker and Welch 1989). The growth regulator herbicides (2,4-D, triclopyr plus clopyralid, aminopyralid and picloram plus 2,4-D) exhibited a short-term influence on seedling emergence, with a reduction of 71% at 2 WAT compared to glyphosate alone.

In summary, several herbicides provided adequate control of emerged poison hemlock when applied in the spring to actively growing rosettes. Chlorsulfuron and metsulfuron resulted in the highest and most consistent control, which further supports the effectiveness of these ALS-inhibiting herbicides for poison hemlock management (DiTomaso 1999). Activity of growth regulator herbicides was erratic or ineffective. Glyphosate activity was also inconsistent, perhaps the result of an early spring application when air temperatures were around 11 to 20 C. Herbicides with residual soil activity suppressed spring emergence of poison hemlock seedlings. However, emergence differences among treatments at 24 WAT, although statistically significant, still resulted in at least 36 plants per m^2. This indicates that repeated applications of herbicides will be necessary in the future to effectively manage poison hemlock.

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Table 4.1. Herbicides, mode of actions and application rates for poison hemlock (*Conium maculatum* L.) trials in central Missouri.

Herbicide	Mode of action[a]	Rate[b]
Untreated	--	--
Glyphosate +	AAB inhibitor	2.52 kg ae/ha
AMS	--	2 % w/v
Imazapic +	ALS inhibitor	0.14 kg ai/ha
MSO	--	2.34 L/ha
Imazapic + glyphosate +	ALS inhibitor +AAB inhibitor	0.11 + 0.21 kg ai/ha
MSO	--	2.34 L/ha
Metsulfuron +	ALS inhibitor	0.04 ai/ha
NIS	--	0.25 % v/v
Metsulfuron +	ALS inhibitor	0.04 kg ai/ha
2,4-D + dicamba +	Growth regulator	0.56 + 1.61 kg ae/ha
NIS	--	0.25 % v/v
Chlorsulfuron +	ALS inhibitor	0.11 kg ai/ha
NIS	--	0.25 % v/v
Triclopyr +	Growth regulator	1.12 kg ae/ha
NIS	--	0.25 % v/v
Triclopyr + clopyralid +	Growth regulator	0.79 + 0.26 kg ai/ha
NIS	--	0.25 % v/v
2,4-D + picloram +	Growth regulator	0.84 + 0.227 kg ae/ha
NIS	--	0.25 % v/v
2,4-D	Growth regulator	2.11 kg ae/ha
Aminopyralid +	Growth regulator	0.09 kg ae/ha
NIS	--	0.25 % v/v
Dicamba + diflufenzopyr +	Growth regulator	0.14 + 0.06 kg ai/ha
NIS	--	0.25 % v/v
Dicamba + diflufenzopyr +	Growth regulator	0.21 + 0.08 kg ai/ha
NIS	--	0.25 % v/v

[a]Abbreviations: AMS, ammonium sulfate; NIS, nonionic surfactant; UAN, urea ammonium nitrate; MSO, methylated seed oil; ALS, acetolactate synthase; AAB, amino acid biosynthesis.

[b]Abbreviations: w/v, weight per volume; v/v, volume per volume.

Table 4.2. Dates of chemical application, size of poison hemlock plants at application and environmental conditions during application at Higginsville, Columbia and Bolivar, MO for 2006 and 2007[a].

	Higginsville	Columbia	Higginsville	Bolivar
Date of Application	29 March 2006	29 March 2006	12 April 2007	27 April 2007
Plant height (cm)	39	13	32	46
Rosette width (cm)	87	25	58	71
Air temperature (C)	17	19	11	20
Soil temperature (C)	10	11	11	16
Relative humidity (%)	48	42	52	54
Mean wind speed (km/hr)	10	8	5	7

[a]Environmental conditions recorded using a Kestral® 3000 pocket weather station. Soil temperature was registered by a portable temperature probe.

Table 4.3. Visual poison hemlock injury two weeks after herbicide treatment (WAT) at Higginsville and Columbia, Missouri in 2006, and Higginsville and Bolivar, Missouri in 2007.[a]

	Poison hemlock injury 2 WAT							
	2006				2007			
Treatment	Higginsville		Columbia		Higginsville		Bolivar	
	------------------%				------------------			
Glyphosate	44	b	48	a	64	ab	89	a
Imazapic	11	de	36	abc	63	abc	79	ab
Imazapic + glyphosate	14	de	43	ab	61	bc	84	ab
Metsulfuron	14	de	44	ab	60	bc	79	ab
Metsulfuron + 2,4-D + dicamba	55	a	45	ab	70	a	88	a
Chlorsulfuron	19	d	33	bcd	61	bc	78	ab
Triclopyr	20	d	21	d	58	bc	73	bc
Triclopyr + clopyralid	33	c	44	ab	55	c	79	ab
Picloram + 2,4-D	9	ef	41	abc	55	c	73	bc
2,4-D amine	36	bc	21	d	33	d	65	c
Aminopyralid	6	ef	29	cd	58	bc	33	d
Dicamba + diflufenzopyr[b]	0	f	8	de	26	de	21	d
Dicamba + diflufenzopyr[c]	5	ef	3	e	23	e	3	e

[a]Means followed by different letters within columns are significantly different according to Fisher's Protected LSD at $P \leq 0.05$.

[b]Dicamba plus diflufenzopyr @ 0.21 + 0.08 kg ai/ha

[c]Dicamba plus diflufenzopyr @ 0.14 + 0.06 kg ai/ha

Table 4.4. Visual poison hemlock injury four weeks after herbicide treatment (WAT) at Higginsville and Columbia, Missouri in 2006, and Higginsville and Bolivar, Missouri in 2007.[a]

	Poison hemlock injury 4 WAT							
	2006				2007			
Treatment	Higginsville		Columbia		Higginsville		Bolivar	
	%							
Glyphosate	74	a	68	a	81	c	95	ab
Imazapic	39	d	54	ab	89	abc	86	bc
Imazapic + glyphosate	44	cd	68	a	92	ab	93	ab
Metsulfuron	51	bc	64	a	93	ab	93	ab
Metsulfuron + 2,4-D + dicamba	74	a	55	ab	96	ab	100	a
Chlorsulfuron	59	b	64	a	97	a	93	ab
Triclopyr	43	cd	41	b	87	bc	90	abc
Triclopyr + clopyralid	61	b	59	a	89	abc	93	ab
Picloram + 2,4-D	50	bcd	58	a	83	c	79	c
2,4-D amine	56	b	18	c	30	e	63	d
Aminopyralid	25	e	14	cd	45	d	30	e
Dicamba + diflufenzopyr[b]	1	f	1	d	30	e	15	f
Dicamba + diflufenzopyr[c]	8	f	1	d	23	e	0	g

[a]Means followed by different letters within columns are significantly different according to Fisher's Protected LSD at $P \leq 0.05$.

[b]Dicamba plus diflufenzopyr @ 0.21 + 0.08 kg ai/ha

[c]Dicamba plus diflufenzopyr @ 0.14 + 0.06 kg ai/ha

Table 4.5. Visual poison hemlock injury eight weeks after herbicide treatment (WAT) at Higginsville and Columbia, Missouri in 2006, and Higginsville and Bolivar, Missouri in 2007.[a]

	Poison hemlock injury 8 WAT							
	2006				2007			
Treatment	Higginsville		Columbia		Higginsville		Bolivar	
	---------------------------------------%---------------------------------------							
Glyphosate	65	c	92	b	70	b	96	a
Imazapic	84	b	99	a	98	a	97	a
Imazapic + glyphosate	95	a	100	a	97	a	97	a
Metsulfuron	98	a	100	a	98	a	98	a
Metsulfuron + 2,4-D + dicamba	93	ab	100	a	96	a	99	a
Chlorsulfuron	100	a	100	a	99	a	100	a
Triclopyr	64	c	88	b	98	a	98	a
Triclopyr + clopyralid	66	c	93	b	95	a	95	a
Picloram + 2,4-D	49	d	89	b	98	a	84	b
2,4-D amine	26	e	68	c	35	cd	64	c
Aminopyralid	5	f	28	d	44	c	51	d
Dicamba + diflufenzopyr[b]	0	o	0	d	26	de	18	e
Dicamba + diflufenzopyr[c]	1	f	0	d	20	e	3	f

[a]Means followed by different letters within columns are significantly different according to Fisher's Protected LSD at $P \leq 0.05$.

[b]Dicamba plus diflufenzopyr @ 0.21 + 0.08 kg ai/ha

[c]Dicamba plus diflufenzopyr @ 0.14 + 0.06 kg ai/ha

Table 4.6. Mean poison hemlock emergence at 2, 4, 8, 12 and 24 weeks after treatment (WAT). Values represent means pooled over locations and years in Missouri in 2006 and 2007[a].

	Weeks after initial herbicide application				
Treatment	2	4	8	12	24
	---------------------Emerged seedlings / m^2---------------------				
Glyphosate	103	39	52	21	87
2,4-D	84	40	48	21	100
Imazapic	82	30	33	12	66
Chlorsulfuron	73	30	15	11	36
Metsulfuron	56	30	21	17	30
Triclopyr + clopyralid	30	24	41	21	43
Aminopyralid	30	21	41	28	61
Picloram + 2, 4-D	30	21	38	28	38
Column Fisher's Protected LSD (0.05) = 21					
Row Fisher's Protected LSD (0.05) = 20					

[a]Abbreviations: LSD, least significant difference.